Multi-Agent Base Evacuation Support System Considering Altitude

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Abstract: In this paper, we propose an extension of an evacuation support system that we have previously proposed (Taga, 2018). The system suggests evacuation routes in cases of disasters. We have confirmed the usefulness of the system. When a disaster occurs, we anticipate that the current popular wireless communication based on the Internet may not be very reliable. In order to accommodate such a problem, our proposed system employs multiple mobile agents and static agents on smartphones that use a mobile ad hoc network (MANET). The proposed system collects information by mobile agents as well as diffuses information by mobile agents so that the system provides an optimal evacuation route for each user in a dynamically changing disaster environment. In simulations, our system successfully guides evacuation users to safe areas. The system, however, does not consider the altitude of the evacuation routes. Therefore, the system may not be very useful in cases of flood. When a tsunami or a flood tide occurs, low altitude location may be under water. Therefore, evacuees need to move along high altitude routes. In this paper, we also take account of the altitude information for constructing evacuation routes.

1 INTRODUCTION

In this paper, we propose an evacuation support system that provides evacuation routes in cases of disasters, and verify the usefulness of the system. In recent years, with the development of communication and portable device technologies, people can collect and spread information using the Internet regardless of time and place. Current popular wireless communication infrastructure is supported by a series of base stations and one communication equipment in such a base station handles a lot of communication. Therefore, when problems occur at equipment in such a communication base station, it may be difficult, even if possible, for the smartphones to use the Internet. In fact, in the 2011 off the Pacific coast of Tohoku Earthquake in Japan, we have observed a large-scale communication failure due to corruption of the communication equipment and traffic congestion. Paralyzed communication infrastructure made it difficult for people to collect information about the conditions of transportation and safety information about family and friends using smartphones.

Our proposed system addresses this problem of communication infrastructure by constructing mobile ad hoc network (MANET) by wireless communication between users' smartphones. Then users can share information in such a network. Since MANET is a network constructed with only portable devices, it is possible to avoid problems due to failure of communication infrastructure. However, the ever changing topology of MANET makes stable communication extremely difficult. Therefore, we propose an information sharing method using mobile software agents. A mobile agent is a program with mobility, it has a feature of perceiving environment and deciding its behaviour depending on the environment. Our proposed system constructs optimal evacuation routes by using such mobile agents to share and collect information necessary for evacuation.

In previous studies, we proposed basic configuration of the evacuation support system and verified its feasibility by simulators (Taga, 2016) (Taga, 2017). In the previous study, we have expanded the features of the system and verify its usefulness with a simulator namely NS-3 (Taga, 2018). In the study, we have introduced new mobile agents that actively collect information closely

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related to the users' potential evacuation routes. Even though the collected information includes actual and potential dangerous area, it does not collect information about altitude of the evacuation routes. Thus our support system may guide the users to low altitude area and let the users be drown in a case of flooding.

In this paper, we consider altitude information for constructing evacuation route. If a tsunami or flood tide occurs, evacuating through low altitude route could be dangerous. In order to evacuate safely, evacuees should move along high altitude route. Therefore, we propose an algorithm that constructs high altitude evacuation route, and construct simulator for verifying the feasibility of the algorithm.

The structure of the balance of this paper is as follows: the second section describes related works. The third section describes the details the proposed system. The fourth section describes the numerical experiments and discusses the results, and the fifth section discusses the future works and concludes the discussion.

2 RELATED WORKS

Komatsu et al. proposed an evacuation system that estimate impassable point automatically by comparing evacuation route presented by the system and actual evacuee's trajectories (Komatsu, 2018). Estimated impassable points are shared between evacuees by communication between their portable devices, or server through available communication infrastructure.

Wang et al. proposed a solution for fire evacuation routing problems by applying artificial bee colony optimization (BCO) algorithm (Wang, 2018). The BCO algorithm is a swarm intelligence algorithm inspired by foraging of bees. They simulated this solution at situations of evacuating from buildings with multiple exits so that they achieve to improve the total evacuation time.

Ikeda et al. proposed safety evacuation route planning using multi-objective genetic algorithm (MOGA) (Ikeda, 2016). The MOGA is a method applying genetic algorithm to the multi-objective optimization problem. An evacuee's handset records GPS data and acceleration data, and send to crowd server. The server calculates an evacuation route considering evacuation distance, evacuation time and the safety degree of evacuation route, and then provide the optimal route to the evacuees.

Kartalidis et al. proposed evacuation routing method that detects positions of evacuees by using trilateration technique using wireless access points and evacuees' smartphones, and then constructs evacuation routes based on cellular automata (Kartalidis, 2018). The states of cellular automata express the state of a specific position of the evacuation area that indicates the presence of the evacuees detected, obstacle and free area and more. For each step of the exit path exploring process, the state of each cell is refreshed. Therefore, evacuees can evacuate avoiding impassable points.

Asakura et al. proposed algorithm to calculate a simple evacuation route to reduce the burden of a particular evacuee (Asakura, 2016). If an evacuation route is complicated and meandering, the evacuees may be confused. In order to mitigate this problem, their proposed method calculates a route that has the fewest number of turns at intersections.

Avilés et al. proposed an evacuation support system using MANET and the ant colony optimization (ACO) for indoor environments (Avilés, 2014). In the study, they implemented ACO by using mobile agents so that the ACO algorithm can take the movement trajectory and speed of evacuees in consideration. Then the evacuation support system constructs an optimal evacuation route for each user.

Ohta et al. studied on evacuation support methods using ACO and MANET (Ohta, 2015). In the study, they pointed out a problem such as a conventional ACO may include dangerous locations when it constructs evacuation routes. The problem is caused by the dynamic nature of the disaster environments such as conflagration or tsunami. In order to mitigate this problem, they proposed an improved ACO-based evacuation support system that equips deodorant pheromone which erases ACO pheromone traces when dangerous locations are found. Goto et al. applied this proposed method to real data of tsunami damage (Ohta, 2016). They showed practical results by using the data of Rikuzentakata city which suffered great damage due to the 2011 off the Pacific coast of Tohoku Earthquake. They verified their method is feasible based on the real data.

Kambayashi et al. proposed and implemented a system that collects safety information of evacuees using mobile agents on MANET (Kambayashi, 2015). In the study, they proposed a method to reduce the load on transmission by combining multiple mobile agents into one. Nishiyama et al. proposed communication system using portable devices that switch between MANET and Delay

Tolerant Networking (DTN) according to communication situations (Nishiyama, 2014). DTN is a method for coping with a network environment where maintaining stable communication connection is hard to achieve. When communication is disconnected, portable devices accumulate data, and then transmitted when communication is resumed. Their proposed system apply MANET when there are many portable devices in the surroundings, and apply DTN when there are few. With such a method, they achieved to cope with various network environments.

As mentioned above, there are various works aimed at supporting disaster evacuation. In order to carry out safe and quick evacuation, it is necessary to promptly identify places that are impassable (such as the place where a fire occurs) and construct evacuation route. These can be achieved by using servers or sensors device installed in town. However, these fixed devices may be damaged when a disaster occurs and become unusable. Instead, our proposed system uses only smartphones owned by evacuees, and identifies places that are impassable and construct evacuation routes.

3 AGENT BASE EVACUATION SUPPORT SYSTEM

In this section, we describe our proposed system in detail. The proposed system aims to provide an optimal evacuation route for each user (hereafter we call the evacuation user). Since the proposed system maintains the map information of the evacuation area, it is possible to calculate the shortest route to the destination (i.e. safe place). However, at the time of a disaster, there should be many occurrences of unsuitable points for evacuation (hereafter we call dangerous point) due to fire, building collapse, or inundation. Since nobody knows these points before the occurrence of a disaster, it is necessary to collect the information during evacuation. When an evacuation user finds a dangerous point, he or she inputs the position information to the system. Then the proposed system constructs a new evacuation route avoiding this dangerous point, and provides it to the user. At the same time, the system diffuses the information about the dangerous point and new route to other users' smartphones. As a result, evacuation users other than the discoverer can know the dangerous point and avoid it in advance. In order to realize this function, we use multiple mobile agents.

A multi-agent system is a system that consists of multiple agents and achieves tasks by their cooperative operations. The agents can be categorized into two types: mobile agents and static agents. A mobile agent is generated when it is needed and executes a task through migrating among communication sites including smartphones. Every mobile agent has a unique identifier. A static agent resides on communication site including, of course, a smartphone. Unlike mobile agents, static agent has no unique identifier. We describe the details of each agent we use in the proposed system below.

3.1 Static Agents

3.1.1 Information Agent

Information Agent is a static agent residing on a smartphone that interacts with mobile agents and constructs evacuation routes. When requested from the system, it creates mobile agent.

The information agent processes the request in the following order. (i) It generates the requested mobile agent. (ii) It acquires the information necessary for the generated mobile agent from the node management agent and passes it to the mobile agent. (iii) It stores the mobile agent in a queue. It periodically checks the queue, and dispatches the mobile agents to the neighbouring smartphones. When a mobile agent comes from another smartphone, the information agent receives information held by the mobile agent. Then it passes the requested information to the arrived mobile agent and store it in the queue in the same way as the above step (iii). The information agent records the unique identifier of the mobile agent that visited the smartphone as well as it created in a list called visitor list. The information agent requests the visitor list of other smartphones when it communicates with them. It then passes the received visitor list to the mobile agent that needs it in the queue. The mobile agent decides the next destination from this visitor list.

The information agent constructs evacuation routes based on the information it initially has, and the information collected from the visited mobile agents. The evacuation route is the route to the destination avoiding dangerous points that are currently known by the information agent. The evacuation route is determined based on the Dijkstra's algorithm. The Dijkstra's algorithm is an algorithm for solving the shortest path problem between two nodes in a graph, and was proposed by Edgar Dijkstra in 1959 (Dijkstra, 1959). In the proposed system, the graph consists of intersection as the nodes, and the distances between intersections as the edge weights. In this proposed system, in order to construct high altitude evacuation route, this proposed system calculate edge weight by dividing distance by altitude of the node. Hence, high altitude route is preferentially selected as evacuation route. This evacuation route may not be the shortest route, but evacuation users can avoid a tsunami or flood tide and reach safe areas. The information agent constructs an initial evacuation route at the system start up time. After that, when a mobile agent arrives and let the information agent know a dangerous point exists on the current evacuation route, the information agent reconstructs a new evacuation route.

3.1.2 Node Management Agent

Node Management Agent is another static agent residing on a smartphone for man-aging the information on the smartphone. The node management agent stores the dangerous point information collected from the visited mobile agents in the information table. At this time, if the same information already exists in the information table, the node management agent delete older information. Also, if the information agent requests information about dangerous points, the node management agent passes the requested information.

3.2 Mobile Agents

3.2.1 Information Diffusion Agent

Information Diffusion Agent is a mobile agent that diffuses the information of the dangerous point found by the evacuation user to neighbouring smartphones.

When an evacuation user finds a dangerous point and input its information into the system, the information agent generate the information diffusion agent. The information agent passes the coordinates of the discovered point to the generated information diffusion agent. And then, the information diffusion agent waits until a link with another smartphone is established. After that the information diffusion agent act as follows: (i) When communication links with other smartphones are established, the information diffusion agent copies itself by the number of linked smartphones and moves to each smartphone. However, if the information diffusion agent finds that it has already visited the smartphone (i.e. the smartphone's visitor list has its identifier), it does not move but commit suicide. (ii) After the movement, it passes its own information to the information agent on the destination, and be into standby state until the next communication link being established. It repeats this process a constant number of hops. When the information diffusion agent copies itself, it copies not only its own information but also its own unique identifier. Therefore, it does not move to the smartphone that its own copy has visited. This mechanism prevents a smartphone from receiving the same information multiple times.

3.2.2 Information Collecting Agent

Information Collecting Agent is another mobile agent that collects information about the events on the evacuation route and returns to the original smartphone. The information diffusion agent diffuses the information discovered by the evacuation user around the discovery point, but there is no guarantee that this information can be conveyed to all evacuation users who need it. In order to solve this problem, we propose the information collecting agent that actively collects information diffused by the information diffusion agent as shown in Figure. 1.

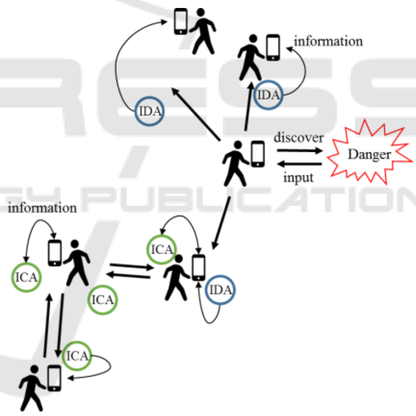

Figure 1: Information diffusing and information collecting.

The information collecting agent returns to the original smartphone after the information collecting process, but there is a problem with the return method. In the situation of the proposed system being used, it is difficult to return through the movement history of the agent in reverse order due to the disappearance of the smartphones it has visited. They may move out of wireless communication range or their batteries may be exhausted. For this reason, the proposed system predicts the current location of the original smartphone based on the evacuation route, moving speed and elapsed time of the original smartphone.

The information agent generates the information collecting agent at regular time intervals. Then, the information agent passes the current evacuation route information, the moving speed of the user, and the life time of the information collecting agent, to the generated information collecting agent. And then, this information collecting agent waits until a communication link with another smartphone is established. When it is established, the information collecting agent moves to the neighbouring smartphone. The information collecting agent has two states, the collecting state and the return state, and the behaviour changes depending on the state. Initially it is in the collecting state. The collecting state is a state of collecting information and acts as follows. (i) The information collecting agent moves to the smartphones along the current evacuation route of the user. Though, of course, it excludes the smartphone that it has already visited. (ii) It acquires information from the destination smartphone. The information collecting agent repeats this process during the collecting state. If the information collecting agent acquires information that tells there is a dangerous points on the evacuation route, or exceeded half of the its own life time, or cannot find the next migration candidate, the information collecting agent becomes in the return state. The return state is a state of returning to the original smartphone and acts as follows. (i) The information collecting agent calculates the predicted current position of the original smartphone based on the information it has; i.e. evacuation route information of the original smartphone and the moving speed of the evacuation user of the smartphone, and the elapsed time since it was generated as shown in Figure. 2. (ii) It moves to the smartphone closest to the calculated expected position.

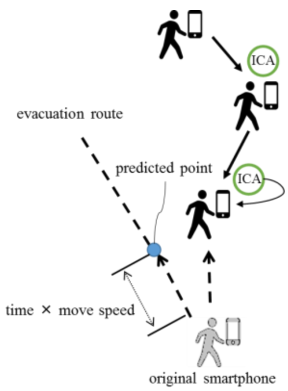

Figure 2: Predict the position of original smartphone.

Unlike the collecting state, in the return state, it may moves to the smartphone it has visited before. It repeats this process until returning to the original smartphone. When the information collecting agent return to the original smartphone, it passes the collected information to the information agent on the smartphone and disappears. If the information collecting agent cannot returns even exceed the own life time, or if it cannot find the original smartphone in the vicinity of the calculated predicted current position, it commits suicide.

One of the disadvantages of the information collecting agent is that, since it is generated from each smartphone, the network load tends to increase. In order to mitigate this problem, the proposed system controls the generation of the information collecting agents by broadcasting messages to the neighbouring smartphones that request to stop generating the information collecting agent for certain period. This message contains the address and the evacuation route of the sender, and the life time of the information collecting agent. The smartphones that receive this message stop generating information collecting agents if its own evacuation route is the same as described one in the message. If the own evacuation route is different from what described in the message, it ignores and discards the message. When the information collecting agent returns to the sender smartphone of the message, this smartphone broadcasts messages that permit generating information collecting agents and the collected information to the neighbouring smartphones. The smartphones that have stopped generating information collecting agent resume generating of the agents when they receive this message. The smartphones also resume generating information collecting agents when the stopping period in the message elapses.

4 NUMERICAL EXPERIMENT

This section describes the numerical experiment of the proposed system. We have verified by simulation in situations that people use the proposed system at the disaster area. We used NS-3 for simulation. NS-3 is a discrete-event network simulator which is open for research and educational use. The model of the communication environments and processes in a form close to the real world, and the simulator makes it possible to perform various verification experiments.

4.1 Experimental Conditions

We have created a simulation map that represents the evacuation area (Figure. 3). This simulation map shows a part of downtown Tokyo, and is modelled of the real geography. This area consists of upland, lowlands and landfill sites, so it is rough terrain. In this experiment, we need to verify the algorithm considering altitude information, therefore such a terrain is suitable as a model. We use the map images acquired and edited from Google MAP (Google, 2018). We also obtained the altitude information from the map published by the Geospatial Information Authority of Japan on the Web (Geospatial Information Authority of Japan, 2018). This simulation map consists of nodes and edges. The edge is a straight sidewalk, evacuees move along the edge. The node is an intersection point of edges. As destination of evacuees, five safe areas provided in the map. This map is about 4.5 square kilometre in the real map, and includes altitude information. The number of node is 1430, the lowest altitude of node is 5.4 metre, and the highest altitude of node is 32.0 metre. In order to express tsunami or flood tide disasters, nodes become the dangerous point in order from the lowest altitude node, i.e. along the river. The dangerous point increases every 10 seconds.

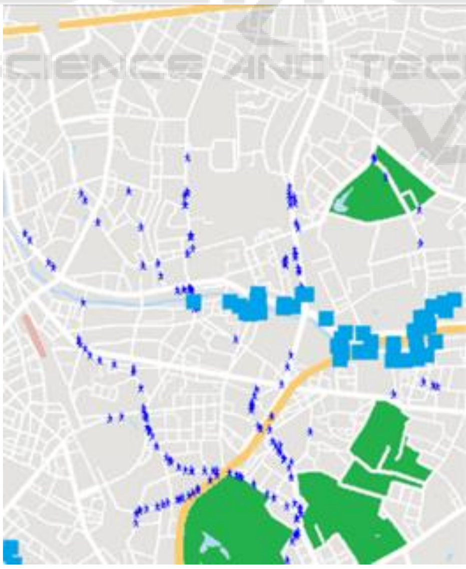

Figure 3: Simulation maps.

Evacuation users are randomly placed and move toward nearest safe area from current position. The moving speed of the evacuation user is set to 1 meters per second. The proposed system has the map information. All evacuees moves through the evacuation route constructed by the information agent in his or her smartphone. The proposed system does not have dangerous point information in advance, and they will know for the first time when evacuation user actually touches to the dangerous point or be notified from other evacuation users through mobile agents. When an evacuation user knows a new dangerous point, the information agent reconstructs the evacuation route avoiding this dangerous point. At this time, the previous nearest safe area from current position of evacuation user may change. If such a case occurs, information agent changes the destination to a new nearest safe area. The communication distance of the smartphone is 50m. The evacuation user who arrives at the destination (hereafter we call the safe evacuation user), or who it is impossible that arrive the destination due to be surrounded by dangerous points (hereafter we call the dead evacuation user) terminates the communication and stop. When all evacuation users stop, the simulation ends.

In this verification experiment, we measured (1) the number of the touches to the dangerous points of all evacuees, (2) the number of the safe evacuation users and the dead evacuation users. We have verified the effect of considering the altitude information. We measured the above numbers in the case of not considering it, and in the case of not using the proposed system (i.e. evacuation user's smartphone calculates an evacuation route to shelter, but does not share information of dangerous points, and does not consider altitude information).

The number of hops of an information diffusion agent is 1, and the life time and the generation interval of an information collecting agent is set to 120 seconds. In all the cases, we further divided the cases that the number of evacuees 50, 100, 150, 200. We have carried out all the cases 50 times each, and taken the averages as the results.

4.2 Results and Discussion

Figure. 4 shows the results of the number of the touches to the dangerous points. "no altitude" is the case of not considering altitude, and "altitude" is the case of considering altitude. "not use" is the case of not using the proposed system. In the case of the number of the evacuees is 50 to 150, there is no significant difference between the "not use" and the "no altitude", but in the case of the number of evacuees is 200, the "no altitude" is smaller than the "no use". In all the cases, the "altitude" shows good results.

Figure. 5 shows the results of the number of the safe evacuation users and the dead evacuation users. Unlike the result shown in Figure. 4, in the case of the number of the evacuees is 200, there is no significant difference between result of "no altitude" and "altitude". On the other hand, "altitude" shows

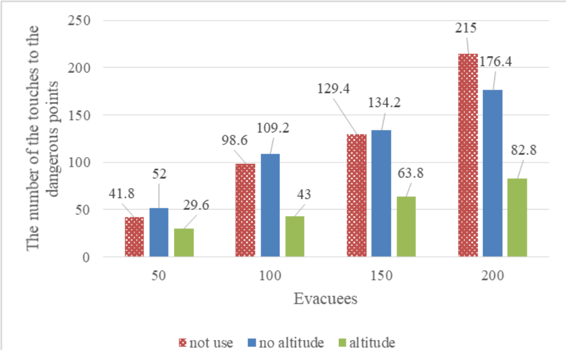

Figure 4: Results of the number of the touches to the dangerous points.

good result in all the cases. If the number of evacuation users who participate the MANET is few, evacuees can only know information in the nearby position because the network is only partially constructed. Therefore, an evacuee nearby dangerous point may be surrounded by other dangerous points before escaping, even if he or she could know the information of that point in advance. Therefore, selecting higher evacuation routes by avoiding places with low altitude in advance contribute evacuees' safe evacuations.

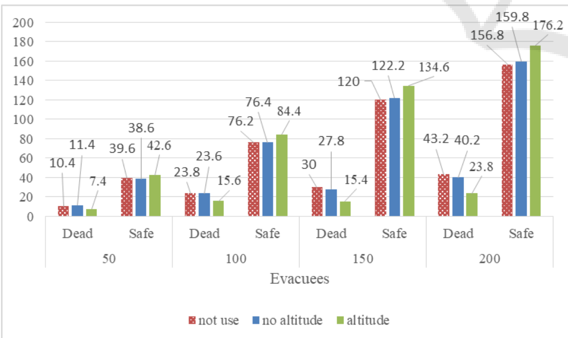

Figure 5: Results of the number of the safe evacuation users and the dead evacuation users.

5 CONCLUSION

In this paper, we proposed an evacuation support system that enables information sharing under environments where people cannot use the Internet communication due to the disaster. In the system, we also took account of the altitude information when constructing evacuation route. In the experiment, we showed that evacuees can grasp dangerous points in advance and avoid them by using the proposed system. We also showed that evacuees can safely evacuate by choosing high altitude routes as evacuation routes when they are hit by tsunamis and flood tides.

As a future work, it is necessary to address the increase of the load in the relay smartphones. Since the information collecting agent moves along the evacuation route of the evacuation user, they frequently move in a busy street such as main streets and in front of evacuation centres. As a result, the network load drastically increases in particular places. Therefore, it is necessary to develop a mechanism for controlling the flow amount of the agent in such places. In addition, we need to consider an evacuation time when choosing high altitude route. By preferentially selecting high altitude routes, evacuees can safely escape from the tsunami and flood tides. However, since this route is not the shortest route to the safe place, the evacuation time will increase. As a method to solve this problem, it is conceivable to change the priority of selecting a route with a high altitude according to the altitude of the current position of the evacuee. If the current position of the evacuee is a place with a low altitude, it is necessary to move quickly to a high place. But if an evacuee is in a sufficiently high place from the beginning, the necessity of selecting a higher place is low. In this case, it may be safer to move a route with shorter distance than to move a route with a longer but higher altitude.

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