Submitted version

Automatic Evacuation Guiding Scheme Using Trajectories of Mobile Nodes

Nobuhisa Komatsu, Masahiro Sasabe, Jun Kawahara, and Shoji Kasahara

Graduate School of Information Science, Nara Institute of Science and Technology
8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan
`{komatsu.nobuhisa.kg1,sasabe,jkawahara,kasahara}@is.naist.jp`
`http://www-lsm.naist.jp/index.php/top-e`

Abstract. When large-scale disasters occur, evacuees have to evacuate to safe places quickly. In this paper, we propose an automatic evacuation guiding scheme using mobile nodes of evacuees. Each node tries to navigate its evacuee by presenting an evacuation route. It can also trace the actual evacuation route of the evacuee as the trajectory by measuring his/her positions periodically. The proposed scheme automatically estimates blocked road segments from the difference between the presented evacuation route and the actual evacuation route, and then recalculates the alternative evacuation route. In addition, evacuees also share such information among them through direct wireless communication with other mobile nodes and that with a server via remaining communication infrastructures. Through simulation experiments, we show that 1) the effectiveness of the proposed scheme becomes high with the increase of degree of damage and 2) the effect of information sharing through communication infrastructures is higher than that through direct wireless communication.

Keywords: Automatic evacuation guiding, mobile nodes, trajectories

1 Introduction

In the 2011 Great East Japan Earthquake, both fixed and mobile communication networks had not been available for a long time and/or in wide areas, due to damage to communication infrastructures. As a result, it has been reported that disaster victims and rescuers could not smoothly collect and distribute important information, e.g., safety information, evacuation information, and government information, even though they carried their own mobile nodes, e.g., cellular phones and smart phones [9].

When disasters occur, disaster victims quickly have to evacuate to near safety places to keep their own safety. Under such situations, it is necessary to grasp the following information: safety places and safe routes to those places. Although they can acquire static information, e.g., map and locations of safety places, in usual time, they cannot grasp dynamic information, e.g., damage situations in disaster areas.

Quickly grasping damage situations will help evacuees to determine actions for evacuation, but it is not necessarily easy to grasp the damage situations, e.g., outbreak of fire, collapse of buildings, flood, and cracks in the ground. It is possible to detect the damage situations by cameras and/or various types of sensors, but it has a potential drawback of restriction of coverage area and breakdown of both such devices and/or communication infrastructures. Therefore, the larger the disaster scale is, the more difficult it is for public institutions to quickly investigate damage situations and to distribute such emergency information to the evacuees.

Under the background, Fujihara and Miwa proposed an evacuation guiding scheme that relies on cooperation among evacuees [3]. They use a Delay Tolerant Networks (DTN) [2], which is constructed by mobile nodes of evacuees, for communication among evacuees. When evacuees discover blocked road segments during their evacuations, they record the information on their nodes. After that, if they encounter other evacuees, they share these information through direct wireless communication between their nodes, such as Bluetooth and Wi-Fi Direct. Thus, they can find out evacuation routes without blocked road segments that have been already discovered.

This scheme is useful because it utilizes mobile nodes that evacuees usually carry and can work without communication infrastructures. It, however, requires evacuees' operations to record damage situations. Evacuees cannot afford to operate their mobile nodes in disaster areas because they may not be safe near the areas. They have to give top priority to their safety and avoid actions except evacuation until they finish evacuating.

To solve the issue, we propose an automatic evacuation guiding scheme using evacuees' mobile nodes, which can automatically grasp damage situations and guide evacuees. Evacuees can obtain the surrounding map and locations of safety places by preinstalling applications for evacuation guiding in their mobile nodes. When disasters occur, the applications calculate evacuation routes with these local information and navigate the evacuees using the routes. In addition, the applications can also grasp the actual evacuation routes of the evacuees, i.e., their trajectories, by measuring their positions periodically. With the help of the interaction between evacuation guiding by mobile nodes and evacuees' actual evacuations, the applications can automatically estimate blocked road segments and recalculate evacuation routes by using the estimated information of the blocked road segments (See the details in section 3).

As in [3], evacuees share the information about blocked road segments among them through direct wireless communication with other mobile nodes and that with a server via remaining communication infrastructures. Note that we deploy the server on cloud systems to protect the server itself from disasters. Such shared information about blocked road segments will help evacuees who are late for evacuations.

Fig. 1 illustrates the overview of the proposed evacuation guiding system. The system consists of following three functions: 1) Mobile nodes of evacuees measure evacuees' trajectories, present evacuation routes, and estimate blocked

Submitted version

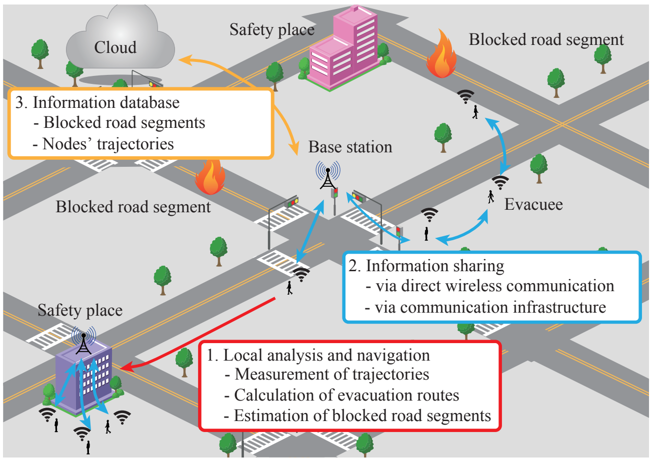

Fig. 1. Overview of evacuation guiding system

road segments; 2) They share these information through direct wireless communication with other nodes and communication infrastructures; 3) Cloud systems maintain the obtained information. We evaluate the effectiveness of the proposed scheme through simulation experiments.

The rest of this paper is organized as follows: Section 2 gives related work. Section 3 describes the proposed scheme. The simulation results are shown in Section 4. Finally, Section 5 provides conclusions and future work.

2 Related Work

ICT support for evacuation in disaster areas can be classified into evacuation planning and evacuation guiding. Evacuation planning is suitable for disasters which are predictable at a certain level, e.g., flood, hurricane, and typhoon. On the other hand, for disasters whose extent of damage is not easy to predict, e.g., earthquake, evacuation guiding in response to damage situations also becomes important.

There are several existing studies on evacuation planning [7,10]. Lim et al. formulate planning of evacuation routes in case of hurricane disasters as a network flow problem and proposes an algorithm that can derive optimal solutions [7]. Takizawa et al. propose a method to partition appropriately a region into small areas such that a unique evacuation center is located in each area [10]. Considering the difficulty in predicting damage situations caused by an earthquake, e.g., the outbreak of fire and collapse of buildings, they propose a method to enumerate all partitioning patterns.

On the other hand, evacuation guiding has also been studied [3, 4]. Iizuka et al. propose an evacuation guiding system using an ad hoc network whose connectivity is almost always guaranteed [4]. It can present evacuees with both evacuation routes and timing to avoid crowds of evacuees. As in the proposed scheme, Fujihara and Miwa propose an evacuation guiding scheme using a DTN,

Submitted version

which is more inferior to an ad hoc network [3]. Note that the existing scheme in [3] requires evacuees' operations to their mobile nodes to record information about blocked road segments, while the proposed scheme can automatically estimate the blocked road segments without any evacuees' operations.

It has been pointed out that movement of evacuees and rescuers has a great impact on how information propagates through direct wireless communications among them [1,8,11]. Aschenbruck et al. propose a movement model which simulates rescuers' movement after disasters occur [1]. It shows that characteristics of end-to-end packet loss rate and delay are different between conventional random way point model and the proposed model. In [8] , Martín-Campillo et al. compare the performance of various DTN routing methods under the movement model proposed in [1]. Uddin et al. propose a crowd's movement model after hurricanes occur and evaluates inter-meeting time between mobile nodes and the number of neighboring nodes [11]. In this paper, we assume that evacuees try to evacuate according to the evacuation routes presented by the evacuation guiding applications but autonomously avoid blocked road segments on the routes by their own decisions.

There is a project that aims to construct a distributed regional network, called NerveNet, for robust communication infrastructures [5]. NerveNet can supply users with a local and stand-alone communication network, which consists of base stations that function as both wireless access points and servers. The proposed scheme can effectively navigate evacuees by deploying the cloud systems into this kind of regional networks.

3 Proposed Scheme

3.1 Preliminaries

$G = (\mathcal{V}, \mathcal{E})$ denotes a graph representing the internal structure of the target region, where $\mathcal{V}$ is a set of vertices, i.e., intersections, and $\mathcal{E}$ is a set of edges, i.e., roads in the map. There are K ($K > 0$) evacuees in the region and each of them has a mobile node. $\mathcal{K} = \{1, 2, \ldots, K\}$ denotes a set of the nodes. Each node $k \in \mathcal{K}$ measures its own locations by using Global Positioning System (GPS) at a certain interval I_{M} ($I_{\mathrm{M}} > 0$).

3.2 Fundamental Scheme in Evacuation Guiding Using Trajectories

Fig. 2 illustrates the flow of guiding one evacuee to a safety place. Note that the evacuee has to preinstall an application for evacuation guiding into his/her mobile node before disasters occur. The application obtains the surrounding map of the target region and the location information of the safety places in usual time. When disasters occur, the evacuee initiates the applications on his/her node. The application first finds out the nearest safety place d_1 from the location s_1 of node k, which was recorded on startup. Next, it calculates an evacuation route $\widehat{p}^{k}_{s_1,d_1}$ and presents him/her the route as a recommended route (Step 1 in Fig. 2).

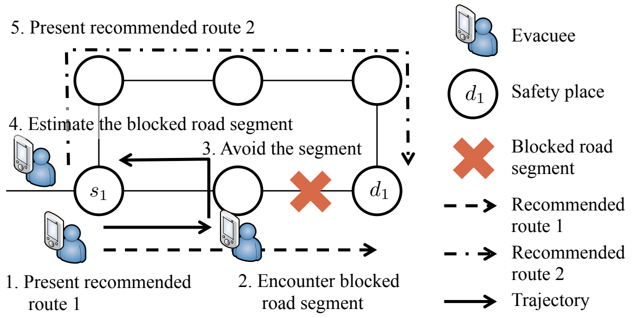

Fig. 2. Flow of evacuation guiding

The evacuee tries to move along the recommended route. When the evacuee discovers a blocked road segment during his/her evacuation along the recommended route $\widehat{p}^k_{s_1,d_1}$ (Step 2 in Fig. 2), he/she will take another route by his/her own judgment (Step 3 in Fig. 2). The application can trace his/her actual evacuation route as the trajectory by measuring his/her positions periodically. Thus, the application can detect road e, which yields the difference between the recommended route and the actual evacuation route (See the details in Section 3.3). The application adds road e to the set of blocked road segments (Step 4 in Fig. 2). After that, the application recalculates the nearest safety place d_2 from the current location s_2. Next, it also recalculates a new evacuation route, which does not include blocked road segments ($\forall e \in \mathcal{E}^k_{\mathrm{NG}}$), and presents him/her the route (Step 5 in Fig. 2). The succeeding flow is the same as that for the first recommended route $\widehat{p}^k_{s_1,d_1}$ (Noted that $s_2 = s_1, d_2 = d_1$ in Fig. 2). Evacuation guiding finishes when the evacuee reaches the safety place or the application cannot find out any evacuation route to any safety place.

In addition, the evacuee may encounter other evacuees and get a chance to communicate with infrastructures during his/her evacuation. Under these situations, the application will obtain new information about blocked road segments (See the details in Section 3.4). Then, it recalculates a new recommended route and present it to him/her.

3.3 Estimation of Blocked Road Segments

This section describes how the application estimates blocked road segments by using difference between the recommended route and the evacuee's actual evacuation route, i.e., his/her trajectory. Suppose that the application of node $k \in \mathcal{K}$ shows its evacuee recommended route $\widehat{p}^k_{s,d}$ between source $s \in \mathcal{V}$ and destination $d \in \mathcal{V}$ on map G. Recommended route $\widehat{p}^k_{s,d}$ is given by a vector of edges constructing the route, i.e., $(e^k_{s,m_1}, e^k_{m_1,m_2}, \ldots, e^k_{m_{H-1},d})$. Here, H denotes the number of edges in $p^k_{s,d}$. For simplicity in description, we assume that $s = m_0$ and $d = m_H$. Noted that $m_h \in \mathcal{V}$, $e^k_{m_h,m_{h+1}} \in \mathcal{E}$ $(h = 1, \ldots, H-1)$.

Next, we focus on the trajectory of node k. Let l^k_i denote location that node k measures at i-th $(i = 1, 2, \ldots)$ interval. l^k_i is a two-dimensional coordinate composed of latitude and longitude. We require to map l_i^k into graph G, because recommended routes are calculated over graph G. l_i^k is located on one of the edges, e_i^k, in graph G. As a result, the trajectory of node k can be expressed by the vector $(e_1^k, e_2^k, \ldots)$.

The following phenomena may happen according to the value of measurement interval I_{M}. If I_{M} is extremely small, e_i^k and e_{i+1}^k may be identical for some i. In this case, the application can obtain trajectory p^k of node k by eliminating the duplicate edges. On the other hand, if I_{M} is extremely large, e_i^k and e_{i+1}^k may not be connected on graph G. In this case, the application has to interpolate the route between them. As a result, the appropriate value of I_{M} should be determined according to both the distribution of edges' lengths and evacuees' moving speed.

For simplicity in explanation, we assume that $e_{s,m_1}^k = e_1^k$ and the evacuee judges at the vertex m_{h-1} whether road e_{m_{h-1},m_h}^k $(h = 1, \ldots, H-1)$ on the recommended route is a blocked road segment. When the evacuee finds out that the h-th road e_{m_{h-1},m_h}^k on the recommended route $\widehat{p}_{s,d}^k$ is a blocked road segment, he/she selects another road $e_{m_{h-1},o}^k$ $(e_{m_{h-1},o}^k \in \mathcal{E} \setminus \mathcal{E}_{\mathrm{NG}},\ o \neq m_h)$ rather than e_{m_{h-1},m_h}^k by his/her own decision. Here, the recommended route is given by

$$\widehat{p}_{s,d}^k = (\underline{e_{s,m_1}^k, \ldots, e_{m_{h-2},m_{h-1}}^k}, \underline{e_{m_{h-1},m_h}^k}, \ldots, e_{m_{H-1},d}^k)$$

and his/her trajectory is as follows:

$$p^k = (\underline{e_{s,m_1}^k, \ldots, e_{m_{h-2},m_{h-1}}^k}, \underline{e_{m_{h-1},o}^k}).$$

Thus, when the application compares the recommended route and the trajectory, it will obtain the list of consensus edges (dotted lines) followed by the different edge (solid lines). As a result, the application can estimate and record the edge e_{m_{h-1},m_h}^k on the recommended route as a blocked road segment.

3.4 Information Sharing

As mentioned above, the application of each node $k \in \mathcal{K}$ automatically obtains the information about trajectory p^k and blocked road segments $\mathcal{E}_{\mathrm{NG}}^k$ on the way to the safety place. If nodes can share these information among them, the information acquired by evacuees at the early stage of evacuation will help evacuees who delay in evacuating. There are two ways to share the information among nodes: direct wireless communication among nodes and communication with the server via remaining communication infrastructures.

Information Sharing Through Direct Wireless Communication Among Nodes: As in [3], information sharing through direct wireless communication can be achieved by existing DTN routings, e.g., epidemic routing [12]. When node k encounters node j $(k, j \in \mathcal{V}, k \neq j)$, they exchange the information about discovered blocked-road-segments and update their local databases with it. Note that the encountering applications need not exchange their trajectories, because they do not directly use the trajectories for evacuation guiding.

Information Sharing Through Communication Infrastructures: After disasters occur, communication infrastructures may be still available in the part of region. When the node can communicate with edge nodes of the communication infrastructures, e.g., access points of wireless LANs and base stations of cellular networks, it tries to access the cloud systems through the edge nodes. The cloud systems have databases to maintain information collected by mobile nodes, i.e., blocked road segments and trajectories. The application and cloud systems first exchange their own information of blocked road segments with each other.

In addition, the application can also upload the information about its own trajectory to the cloud systems because the transmission rate between the node and the communication infrastructures is sufficiently high. We plan to apply the trajectories collected in the cloud systems to global evacuation guiding, e.g., alleviation of congestion, as future work.

4 Simulation Results

Through simulation experiments, we evaluate the proposed scheme in terms of the following points: effectiveness of the proposed scheme, impact of degree of disaster, and effect of information sharing.

4.1 Simulation Model

We used the ONE simulator [6]. We also used the street map of Helsinki, which is included in the ONE. The size of the map is 4500 [m] × 3400 [m] and its internal graph structure is composed of 1578 vertices and 1986 edges. We assume that all of a hundred evacuees have their own mobile nodes and their initial positions are randomly chosen from the points on the streets of the map. In addition, we set one safety place near the center of the map, which has access to the Internet via communication infrastructures. We set the simulation time to be 7200 [s]. When the simulation starts, a disaster occurs and each of evacuees starts evacuating from their initial positions to the safety place at moving speed of 4 [km/h].

We set measurement interval I_{M} to be 10 [s], which is obtained at the preliminary experiments and small enough to avoid the trajectory disconnection problem as mentioned in Section 3.3. We assume that direct wireless communications among nodes are given by either BlueTooth or Wi-Fi Direct whose transmission ranges R_{D} are 10 [m] and 100 [m], respectively. We also assume that communications between nodes and servers are supported by Wireless LANs whose transmission ranges R_{S} are 100 [m]. Wireless LAN access points are located at $N \times N$ grids. We define *coverage* as the ratio of the area of roads included in the transmission ranges of the access points to the whole area of all roads. We can control the coverage by changing N.

We made damaged situations by randomly choosing a certain number of edges on graph G as blocked road segments. We evaluate the degree of disaster by *evacuation possibility*, δ $(0 \leq \delta \leq 1)$, which is defined by the probability that evacuation routes exist from arbitrary points to the safety place.

We use *evacuation time* and *evacuation ratio* as evaluation criteria. The evacuation time of an evacuee is the time interval from the evacuation start to the evacuation completion. We define the evacuation ratio as the ratio of evacuees have finished evacuating to all evacuees. The succeeding results are the average of 500 independent simulation experiments.

4.2 Evacuation Schemes for Comparison

We also evaluate the following two evacuation schemes, in addition to the proposed scheme.

- Evacuation guiding using successful routes
  In this scheme, nodes share the information about their trajectories instead of the information about blocked road segments with other nodes. On receiving new trajectories, they try to find out successful routes to the safety place under the constraint where only roads included in the trajectories are available for evacuation.
- Normal evacuation
  As normal evacuation where evacuees try to evacuate without the proposed scheme, we use the proposed scheme without information sharing. In this scheme, evacuees only use the map and the information about blocked road segments that are discovered during their own evacuation. Note that only 100σ $(0 \leq \sigma \leq 1)$ percent of the evacuees know the location of the safety place at the start of evacuation. If evacuees know the location of the safety place, they try to move to that place. Otherwise, they try to move to a place randomly chosen in the map. When evacuees meet other evacuees, they share their information about the location of the safety place, through conversation.

4.3 Effectiveness of The Proposed Scheme

Fig. 3 illustrates the transition of evacuation ratio for the three evacuation schemes: proposed scheme, evacuation guiding using successful routes, and normal evacuation. Note that we set σ to be 0.8 and 1.0 in case of normal evacuation. The values of the parameters for this scenario are given as follows. The evacuation possibility δ is 0.6. The transmission range of direct wireless communication R_{D} is 100. The coverage of communication infrastructures is about 7 % where N is 5.

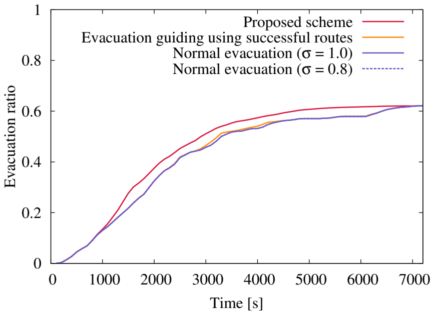

Fig. 3. Effectiveness of the proposed scheme

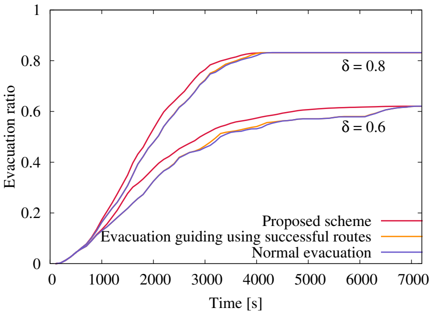

Fig. 4. Impact of degree of damage

First, we observe that some evacuees without initial knowledge of the location of the safety place cannot complete their evacuations in case of normal evacuation with $\sigma = 0.8$. This is because they cannot meet other evacuees who know the location of the safety place during their evacuations. Next, we compare the results of proposed scheme, evacuation guiding using successful routes, and normal evacuation with $\sigma = 1.0$. The evacuation ratio of the proposed scheme increases faster than those of other two schemes. As a result, the average (resp. maximum) evacuation time of the proposed scheme is 1940 [s] (resp. 2288 [s]), which is about 15 % (resp. 21 %) shorter than that of the normal evacuation.

We also find that there is almost no difference between the result of evacuation guiding using successful routes and that of normal evacuation. The information about successful routes can be obtained only from the trajectories of evacuees who have finished their evacuations. On the other hand, nodes can share the information about blocked road segments with other nodes even if they are in evacuating.

4.4 Impact of Degree of Damage

Fig. 4 illustrates the transition of evacuation ratio for the three schemes when δ is set to be 0.6 and 0.8. The values of the parameters for this scenario are given as follows. We set σ to be 1.0. The transmission range of direct wireless communication R_{D} is 100. The coverage of communication infrastructures is about 7 % where N is 5. As in Section 4.3 where $\delta = 0.6$, the evacuation guiding using successful routes shows almost the same result as the normal evacuation, in case of $\delta = 0.8$. We also observe that the evacuation ratio of the proposed scheme increases faster than those of other schemes, regardless of the degree of damage. Both average and maximum evacuation times of the proposed scheme are about 7 % shorter than those of the normal evacuation when δ is 0.8. Comparing the results of $\delta = 0.6$ and those of $\delta = 0.8$, we find that the larger the degree of damage is, the higher the effectiveness of the proposed scheme becomes.

Because we randomly choose the blocked road segments in this scenario, evacuees can easily find alternative evacuation routes by themselves when they

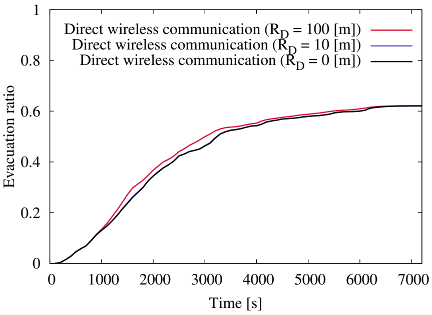

Fig. 5. Effect of direct wireless communication

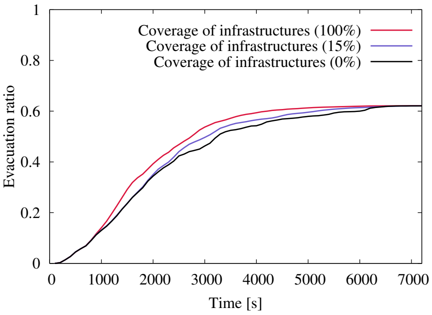

Fig. 6. Effect of communication infrastructures

encounter blocked road segments. We expect that the proposed scheme will be more effective when the blocked road segments are not randomly scattered but spreads over a certain region in the form of lines, e.g., cracks in the ground, or circles, e.g., outbreak of fire. In such kinds of damage situations, it will be difficult for the evacuees to find out alternative evacuation routes without the proposed scheme and information sharing among nodes will become more important. We plan to evaluate this point as future work.

4.5 Effect of Information Sharing

The proposed scheme can share the information through direct wireless communication and communication infrastructures. Evacuees can improve their evacuations by using the information about blocked road segments acquired by other evacuees. In this section, we evaluate the effect of information sharing based on direct wireless communication and communication infrastructures.

Fig. 5 illustrates the transition of the evacuation ratio of the proposed scheme when the coverage of communication infrastructures is set to be 0 % and the transmission range R_D of direct wireless communication is set to be 0, 10, and 100 [m]. Note that the proposed scheme without communication infrastructures and direct wireless communication ($R_\mathrm{D} = 0$) is equivalent to normal evacuation. We observe that the effect of direct wireless communication is slightly improved by the increase of R_D. Specifically, average (resp. maximum) evacuation times of the proposed scheme with $R_\mathrm{D} = 100$ and $R_\mathrm{D} = 10$ are 2054 [s] (resp. 5917 [s]) and 2184 [s] (resp. 6103 [s]), respectively, which are about 6 % (resp. 3 %) and 0.4 % (resp. 0.4 %) shorter than that of normal evacuation.

Although the increase of R_D leads to frequent meetings between nodes, the improvement of evacuation ratio is limited. This is because both the direction of evacuations and that of information propagation are identical due to the fact that the information is carried by the evacuees themselves. Evacuees can improve their evacuations only when they know whether the current evacuation routes include blocked road segments. This means that the direction of information propagation should be opposite to that of evacuations. The direction of evacuations will be reversed when evacuees have to retrace their evacuation routes due to blocked road segments.

Next, Fig. 6 illustrates the transition of the evacuation ratio of the proposed scheme when the coverage of communication infrastructures is set to be 0 %, 15 %, and 100 %, and the direct wireless communication is not used ($R_{\mathrm{D}} = 0$). Average (resp. maximum) evacuation times with 100 % coverage and 15 % coverage are 1836 [s] (resp. 4866 [s]) and 2062 [s] (resp. 5917 [s]), respectively, which are about 16 % (resp. 20 %) and 6 % (resp. 3 %) shorter than that of the normal evacuation. Comparing Fig. 6 with Fig. 5, we observe that the increase of coverage has larger impact on the improvement of evacuation ratio than that of the transmission range R_{D} of direct wireless communication. This is because the use of communication infrastructures is one of the ways to achieve the information propagation with the opposite direction to evacuations.

5 Conclusions

In this paper, we proposed the automatic evacuation guiding scheme using evacuees' mobile nodes to achieve quick evacuation after disasters occur. With the help of the interaction between evacuation guiding by mobile nodes and evacuees' actual evacuation, the proposed scheme can automatically estimate blocked road segments. Evacuees try to improve their own evacuations by sharing the information about blocked road segments through both direct wireless communication and communication infrastructures.

Through simulation experiments, we evaluated the effectiveness of the proposed scheme, the impact of degree of damage, and the effect of information sharing. We observed that the larger the degree of damage is, the higher the effectiveness of the proposed scheme becomes. We also found that the direction of information propagation should be carefully considered to improve the evacuation guiding.

As future work, we will evaluate the fundamental characteristics of the proposed scheme in continuous damaged situations, e.g., cracks in the ground and outbreak of fire. We also plan to propose global evacuation guiding scheme to alleviate traffic congestion by using the trajectories collected in the cloud systems. We will also extend the proposed scheme so that it can be adaptive to the transition of damaged situations.

Acknowledgement

This research was funded by Strategic Information and Communication R&D Promotion Programme (SCOPE) of Ministry of Internal Affairs and Communications, Japan.

References

1. Aschenbruck, N., Gerhards-Padilla, E., Martini, P.: Modeling Mobility in Disaster Area Scenarios. Performance Evaluation 66(12), 773–790 (2009)

2. Fall, K.: A Delay-Tolerant Network Architecture for Challenged Internets. In: Proc. of SIGCOMM'03. pp. 27–34 (2003)
3. Fujihara, A., Miwa, H.: Disaster Evacuation Guidance Using Opportunistic Communication: The Potential for Opportunity-Based Service. In: Bessis, N., Dobre, C. (eds.) Big Data and Internet of Things: A Roadmap for Smart Environments Studies in Computational Intelligence, pp. 425–446. Springer International Publishing (2014)
4. Iizuka, Y., Yoshida, K., Iizuka, K.: An Effective Disaster Evacuation Assist System Utilized by an Ad-Hoc Network. In: Proc. of HCI International 2011. pp. 31–35 (2011)
5. Inoue, M., Ohnishi, M., Peng, C., Li, R., Owada, Y.: NerveNet: A Regional Platform Network for Context-Aware Services with Sensors and Actuators. IEICE Transactions on Communications E94-B(3), 618–629 (2011)
6. Keränen, A., Ott, J., Kärkkäinen, T.: The ONE Simulator for DTN Protocol Evaluation. In: Proc. of the 2nd International Conference on Simulation Tools and Techniques. pp. 55:1–55:10 (2009)
7. Lim, G.J., Zangeneh, S., Baharnemati, M.R., Assavapokee, T.: A Capacitated Network Flow Optimization Approach for Short Notice Evacuation Planning. European Journal of Operational Research 223(1), 234–245 (2012)
8. Martín-Campillo, A., Crowcroft, J., Yoneki, E., Martí, R.: Evaluating Opportunistic Networks in Disaster Scenarios. Journal of Network and Computer Applications 36(2), 870–880 (2013)
9. Ministry of Internal Affairs and Communications: 2011 WHITE PAPER Information and Communications in Japan. `http://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2011/2011-index.html`
10. Takizawa, A., Takechi, Y., Ohta, A., Katoh, N., Inoue, T., Horiyama, T., Kawahara, J., Minato, S.: Enumeration of Region Partitioning for Evacuation Planning Based on ZDD. In: Proc. of of the International Symposium on Operations Research and its Applications. pp. 64–71 (2013)
11. Uddin, M.Y.S., Nicol, D.M., Abdelzaher, T.F., Kravets, R.H.: A Post-Disaster Mobility Model for Delay Tolerant Networking. In: Proc. of the 2009 Winter Simulation Conference. pp. 2785–2796 (2009)
12. Vahdat, A., Becker, D.: Epidemic Routing for Partially Connected Ad Hoc Networks. Tech. Rep. CS-200006, Duke University (2000)