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On Information Sharing Scheme for Automatic Evacuation Guiding System Using Evacuees' Mobile Nodes

Nobuhisa Komatsu, Masahiro Sasabe, 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,kasahara}@is.naist.jp`
`http://www-lsm.naist.jp/index.php/top-e`

Abstract. We have proposed an automatic evacuation guiding scheme based on cooperation between evacuees and their mobile nodes. In the previous work, we assume that information about blocked road segments is shared among mobile nodes through Epidemic routing, which is a Delay Tolerant Network (DTN) routing protocol. In this paper, we propose an information sharing scheme called On-Demand Direct Delivery, which can reduce the network load compared to Epidemic routing. Since each evacuee moves to a safe place, he/she will require the information about blocked road segments in the region from the current position to the safe place. The proposed scheme selectively retrieves the information about blocked road segments in that region, through Direct Delivery. Through simulation experiments, we show the proposed scheme can keep the effectiveness of evacuation guiding with reduction of network load to about 1/36, compared to Epidemic routing.

Keywords: Automatic evacuation guiding, mobile nodes, On-Demand Direct Delivery

1 Introduction

The 2011 Great East Japan Earthquake highly damaged communication infrastructures. As a result, 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., smart phones [10]. When disasters occur, disaster victims have to evacuate quickly to near safe places for their own safety. Although they can acquire static information, e.g., map and locations of safe places, in usual time, they cannot grasp dynamic information, e.g., damage situations, in advance.

To tackle this problem, we have developed an automatic evacuation guiding system based on implicit cooperation between evacuees and their mobile nodes [9]. In [9], each mobile node tries to navigate its evacuee by presenting an evacuation route. At the same time, it can also trace the actual evacuation route of the evacuee as the trajectory by measuring his/her positions periodically. Thus, it can automatically estimate a road segment, which yields the difference between recommended route and actual evacuation route, as a blocked raod segment. As a result, it can recalcualte an alternative evacuation route, which does not include blocked-road-segments discovered. In addition, mobile nodes also share such information among them, with the help of Delay Tolerant Network (DTN) [3].

In [9], we evaluated the effectiveness of evacuation guiding in terms of average/maximum evacuation time, but did not consider network load caused by information sharing. As in [4,5], the evacuation guiding scheme in [9] applies Epidemic routing for information sharing. In Epidemic routing, when two mobile nodes can directly communicate with each other, one tries to send information about blocked road segments that the other does not possess, and vice versa. Thus, the network congestion will occur with the increase in the target region and/or in the population of evacuees. Since each evacuee moves to the safe place, he/she will improve his/her own evacuation by the information about blocked road segments in the region, called *view*, which spreads over before him/her. Note that the view of each evacuee keeps changing during his/her evacuation. In such situations, DTN routing will not work effectively because the information to be shared between mobile nodes will change per meeting.

In this paper, we propose an information sharing scheme, called On-Demand Direct Delivery. When a mobile node can communicate with other node, i.e., a mobile node or a server on the cloud system, it tries to obtain necessary information based on its view from the node. Actual data transfer among nodes can be achieved by Direct Delivery [6]. Through simulation experiments, we evaluate the effectiveness of the proposed scheme in terms of both evacuation time and network load.

The rest of this paper is organized as follows. Section 2 gives related work. After introducing the overview of automatic evacuation guiding system in Section 3, Section 4 describes the proposed scheme. In Section 5, we show the simulation results. Finally, Section 6 provides conclusions and future work.

2 Related Work

It has been expected that Information and Communications Technology (ICT) can effectively support evacuation guiding [4, 5, 7, 9]. Iizuka et al. propose an evacuation guiding system using an ad hoc network, which can present evacuees with both evacuation routes and timing to avoid crowds of evacuees [7]. When a large-scale disaster occurs, it may be difficult to maintain an ad-hoc network, which tries to keep connectivity among mobile nodes. There are several studies [4, 5, 9], which try to support evacuation guiding even in such poor communication environments, with the help of DTN.

In [4, 9], when evacuees and mobile nodes newly discover blocked road segments, they try to broadcast the corresponding information using Epidemic rout-

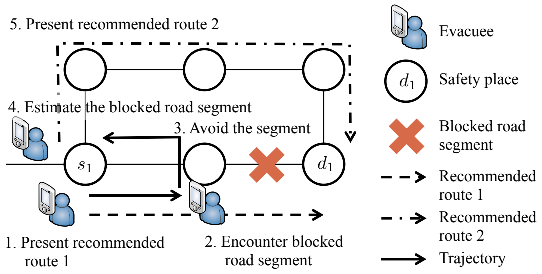

Fig. 1. Flow of evacuation guiding

ing. Note that the mobile nodes can automatically (resp. manually) discover information about blocked road segments in [9] (resp. [4]). Gorbil and Gelenbe propose a scheme that collects emergency information, i.e., hazard points and their discovered times (time stamps), from three kinds of sources: 1) fixed nodes, mobile nodes, and social networks among evacuees [5]. They also apply Epidemic routing but additionally introduce a prioritization mechanism based on the time stamps. The newer the time stamp is, the higher the priority becomes.

If network resources are abundant, Epidemic routing is effective in terms of bundle (message) delivery ratio and bundle delivery delay. Epidemic routing, however, also lays heavy burden on the network, because of its nature of broadcast. To alleviate the network load while keeping high bundle delivery ratio and short bundle delivery delay, there exist many studies on DTN routing protocols [2]. They are generally based on store-carry-forward paradigm where mobile nodes carry stored information and forward it to other nodes through direct wireless communication. Each DTN routing protocol tries to control the balance between bundle delivery ratio, bundle delivery delay, and network load.

In this paper, we focus on the fact that the necessary information for evacuees changes during their evacuations as mentioned above. In such situations, when two mobile nodes can communicate with each other, it is reasonable for them to share only the necessary information. For this purpose, we propose On-Demand Direct Delivery in the next section.

3 Automatic Evacuation Guiding System

In this section, we give the overview of automatic evacuation guiding system proposed in [9]. $G = (\mathcal{V}, \mathcal{E})$ 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 the set of all the nodes. Each node $k \in \mathcal{K}$ measures its own locations by using Global Positioning System (GPS) at a certain interval of I_{M} $(I_{\mathrm{M}} > 0)$.

Fig. 1 illustrates the flow of guiding one evacuee to a safe place. Note that the evacuee has to pre-install 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 safe places in usual time.

When disasters occur, the evacuee initiates the applications on his/her node. The application first finds out the nearest safe place d_1 from the location s_1 of node k, which was recorded on start-up. 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. 1.)

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. 1.), he/she will take another route by his/her own judgment. (Step 3 in Fig. 1.) The application can trace his/her actual evacuation route as the trajectory by measuring his/her positions periodically. Thus, the application can detect the road segment $e \in \mathcal{E}$, which yields the difference between the recommended route and the actual evacuation route. The application adds the road segment e to the set $\mathcal{E}^k_{\mathrm{NG}}$ of blocked road segments. (Step 4 in Fig. 1.) After that, the application recalculates the nearest safe 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. 1.) The succeeding flow is the same as that for the first recommended route $\widehat{p}^k_{s_1,d_1}$. (Note that $s_2 = s_1, d_2 = d_1$ in Fig. 1.) Evacuation guiding finishes when the evacuee reaches the safe place or the application cannot find out any evacuation route to any safe 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 4.) Then, it recalculates a new recommended route and present it to him/her.

4 Proposed Scheme

As mentioned above, the application of each mobile node $k \in \mathcal{K}$ automatically obtains the information about blocked road segments $\mathcal{E}^k_{\mathrm{NG}}$ on the way to the safe place. Evacuees may improve their own evacuation if they can share blocked road segments $\mathcal{E}^k_{\mathrm{NG}}$, which were acquired by other evacuees.

In this paper, we assume that there are two ways to share the information among nodes: direct wireless communication among nodes and communication with the cloud system via remaining communication infrastructures. As we stated in Section 3, mobile node k maintains the information about blocked road segments $\mathcal{E}^k_{\mathrm{NG}}$ on the application layer. When mobile node k can communicate with other node j ($k, j \in \mathcal{K}^+, k \neq j$), i.e., mobile node or the server on the cloud system, it tries to obtain the information from node j on demand. Note that $\mathcal{K}^+ = \mathcal{K} \cup \{0\}$ and the server's ID is set to be 0. In this section, we propose an information sharing scheme, called *On-Demand Direct Delivery*, which consists of two procedures: 1) selecting blocked road segments that evacuees may need, and 2) sending the selected information through DTN routing.

In what follows, we give the detail of On-Demand Direct Delivery.

4.1 Selection of Blocked Road Segments based on Evacuees' Views

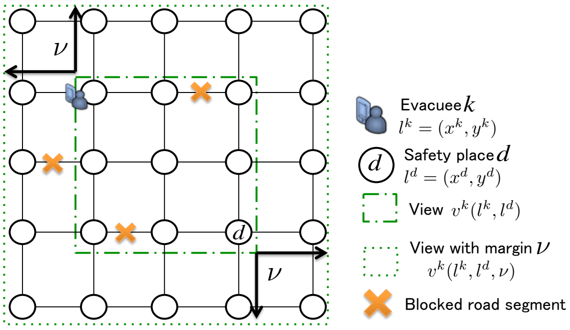

Fig. 2. Selection of Blocked Road Segments based on Evacuees' Views

Information sharing without any restriction will cause network congestion with the increase in the target region. Since each evacuee moves to the safe place, he/she will require the information about blocked road segments in the region from the current position to the safe place. Although there may be several ways to define that region, we apply the concept of *view* [1] because of its simplicity. Specifically, we define evacuee k's ($k \in \mathcal{K}$) view $v^k(l^k, l^d)$ as a rectangle whose diagonal vertices are current coordinates of evacuee k, $l^k = (x^k, y^k)$, and coordinates of its destination, $l^d = (x^d, y^d)$. Fig. 2 illustrates an example of the view.

Evacuee k basically tries to retrieve the information about blocked road segments in set $\mathcal{E}^k_{\text{view}}(l^k, l^d)$, which consists of the blocked road segments whose one (both) of the end points is (are) included in view $v^k(l^k, l^d)$. The current/future route, however, will be out of the view, depending on the locations of blocked road segments and the graph structure. To tackle this problem, we extend the range of view by adding margin ν ($\nu \geq 0$) to both x-axis and y-axis. Let $v^k(l^k, l^d, \nu)$ and $\mathcal{E}^k_{\text{view}}(l^k, l^d, \nu)$ denote evacuee k's view with the margin and the corresponding set of blocked road segments, respectively. Whenever mobile node k can communicate with other node j ($k, j \in \mathcal{K}^+, k \neq j$), it calculate $\mathcal{E}^k_{\text{view}}(l^k, l^d, \nu)$.

4.2 Communication through DTN Routing

When large-scale disasters occur, conventional TCP/IP may not work well due to the damage of communication infrastrucutures. In such situations, DTN, which is based on store-carry-forward routing, is expected to be a promising technique. Mobile nodes store and carry bundles (data), which are originally generated or received from others. When mobile nodes meet others, they first exchange summary vectors, which are lists of their possessing bundles. Then, the mobile nodes send part/all of others' unpossesing bundles to them, depending on DTN routing protocols.

One of the most typical DTN routing protocols is Epidemic routing [11]. Since Epidemic routing is a kind of flooding schemes, it achieves high reachability together with heavy network load. In our scenario, we assume that each bundle includes information about a blocked road segment. This also causes wasteful transfer of bundles, which are generated by different mobile nodes but include the information about the same blocked road segment. In addition, each evacuee requires the information about blocked road segments, depending on their current position and destinations, as mentioned in Section 4.1.

Taking account of these points, we propose the following information sharing scheme. When mobile node k can communicate with other node j $(k, j \in \mathcal{K}^+, k \neq j)$, i.e., a mobile node or a server, it sends node j coordinates l^k of the current position, coordinates l^d of its destination, and margin ν. Then, mobile node j calculates $\mathcal{E}^k_{\mathrm{view}}(l^k, l^d) \cap \mathcal{E}^j_{\mathrm{NG}}$ and sends it back to mobile node k. For this direct communication, we can use Direct Delivery [6], which is a DTN routing protocol where source nodes send their own bundles only to their destination nodes.

If node j is a mobile node, j can also obtain its necessary information from mobile node k in the same manner. On the other hand, if node j is a server, it sends mobile node k two coordinates, which describe the whole region, and $\nu = 0$, such that it can retrieve the information about blocked road segments in the whole region.

5 Simulation Results

Through simulation experiments, we evaluate the effectiveness of On-Demand Direct Delivery. First, we evaluate the appropriate value of ν. Next, we evaluate the effectiveness of On-Demand Direct Delivery in terms of the network load.

5.1 Simulation Model

We used the ONE simulator [8]. We also used the street map of Helsinki, which is included in the ONE. The size of the map is 4500 [m] × 3400 [m]. We assume that one hundred evacuees with their own mobile nodes start evacuating from initial positions, each of which is randomly chosen from the points on the streets of the map. In addition, we set one safe place near the center of the map. We set the simulation time to be 7200 [s]. When the simulation starts, a disaster occurs and all evacuees start evacuating from their initial positions to the safe place at moving speed of 4 [km/h].

We set I_{M} to be 10 [s]. Mobile nodes can directly communicate with other nodes through Wi-Fi Direct whose transmission range is 100 [m], and communicate with a server in the cloud system through Wi-Fi access points whose transmission range is also 100 [m]. We set Wi-Fi access points in a 5×5 grid manner, which can cover about 7 % area of all road segments. We made a disaster scenario as follows. We randomly set a certain number of edges on graph G to be blocked such that the probability that evacuation routes exist from arbitrary points to the safe place becomes 0.6.

We use *average/maximum evacuation time* and *network load* as evaluation criteria. The evacuation time of an evacuee is the time interval from the evacuation start to the evacuation completion. We define the network load as the

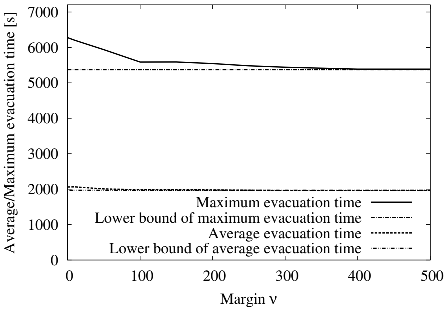

Fig. 3. Impact of ν on average and maximum evacuation times.

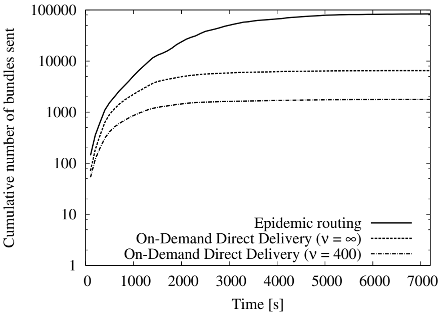

Fig. 4. Cumulative number of bundles sent.

cumulative number of bundles sent by all mobile nodes. The succeeding results are the average of 100 independent simulation experiments.

5.2 Appropriate margin of view

Fig. 3 illustrates average and maximum evacuation times of On-Demand Direct Delivery, when changing the value of ν. In addition, we also show the lower bounds of average and maximum evacuation times, which are given by On-Demand Direct Delivery with $\nu = \infty$. We observe that both average and maximum evacuation times monotonically decrease with ν and almost converge to their lower bounds when $\nu = 400$. Thus, we use $\nu = 400$ as an appropriate value. Note that the appropriate value of ν may change depending on the map structures and disaster scenarios. As future work, we plan to propose a scheme to determine the appropriate value of ν.

5.3 Network load

Fig. 4 illustrates the cumulative number of bundles sent. Note that the scale of the vertical axis is logarithmic. We observe that On-Demand Direct Delivery with $\nu = \infty$ can reduce the network load to about one twelfth compared to Epidemic routing. In Epidemic routing, when different mobile nodes discover an identical blocked segment, they generate their own bundles. These bundles include the same information but any DTN routing protocols in Bundle layer, e.g., Epidemic routing, cannot inspect the content of them and finally treat them as different bundles. This cause wasteful transfer of bundles. On the other hand, On-Demand Direct Delivery can avoid this problem. In On-Demand Direct Delivery, mobile nodes generate bundles on demand when they can communicate with other nodes. The bundles are generated according to the information about blocked road segments, which they have at that time.

In addition, we observe that On-Demand Direct Delivery with $\nu = 400$ can reduce the network load, by appropriately regulating the information about blocked road segments according to view. On-Demand Direct Delivery with $\nu = 400$ can reduce the network load to about one third, compared to that with $\nu = \infty$. The minimum ν, i.e, zero, can achieve the lowest network load but gives worse average and maximum evacuation times as mentioned in Section 5.2.

6 Conclusions

In this paper, we proposed an information sharing scheme, called On-Demand Direct Delivery, for the automatic evacuation guiding system. When two mobile node can communicate with each other, they try to obtain the information about blocked road segments in their own view, which are possessed by the opponent. Through simulation experiments, we showed that On-Demand Direct Delivery with appropriate ν can reduce the network load to about 1/36, compared to Epidemic routing. As future work, we plan to propose a scheme to determine the appropriate value of ν.

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