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Information Sharing Scheme Using AoI for DTN-based Evacuation System

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Abstract

In recent years, Japan has frequently experienced natural disasters such as earthquakes and typhoons, necessitating the rapid and accurate acquisition of evacuation support information. However, during such disasters, communication infrastructure may be damaged, making information sharing difficult. To address this issue, Delay/Disruption Tolerant Networking (DTN) technology has garnered attention. In this study, we propose a new information-sharing scheme for evacuation support systems using DTN. The proposed scheme leverages the Age of Information (AoI) to assess the freshness of information, discarding information that exceeds a certain AoI threshold. This ensures that evacuees can act based on the most recent and accurate information. Furthermore, by predicting the occupancy of evacuation centers in advance, the proposed scheme helps prevent situations where evacuation centers reach full capacity and can no longer accept evacuees, enabling a smoother evacuation process. Specifically, the scheme combines two prediction mechanisms: the first mechanism that estimates the number of evacuees based on the rate of increase information provided and transmitted by evacuation centers and the second mechanism that utilizes DTN to share estimated arrival times among evacuees to predict the number of evacuees in the destination evacuation center. This approach facilitates more appropriate selection of the destination evacuation center. We evaluate the effectiveness of the proposed scheme through simulation experiments using real geographical information. Additionally, we discuss the impact of the proposed scheme on evacuation time, the number of evacuees, and the average evacuation time. Consequently, it is confirmed that the proposed scheme could provide shorter evacuation time with evacuees.

Keywords: DTN, AoI, Evacuation System, Simulation

1 Introduction

In recent years, many regions have been damaged frequently by the natural disasters such as earthquake and heavy rains. In such situations, local residents require the accurate evacuation information quickly to move to the evacuation center for their evacuation. Concretely, there are impassable routes and the capacity of evacuation centers as evacuation information. It is important for local residents to obtain these evacuation information in a shorter time and move to the evacuation center through short and secure evacuation routes. However, in the event of a disaster, there is the possibility that network infrastructure is temporality disrupted due to damage by disaster, making it difficult to provide the information to local residents.

In order to solve the problem, the DTN (Delay/Disruption Tolerant Networking) [1,2] technology is an important role as an information sharing scheme. DTN and DTN-based technologies are attracting attention for the data transmission scheme to share evacuation information among local residents in the disaster situation [3–6]. However, the previous scheme does not consider the freshness of evacuation information. Evacuation information that is not up-to-date might be disseminated for a long time. Thus, this may increase the network overhead and reduce communication efficiency. In addition, local residents might move to the evacuation center based on the out-of-date information so that it takes much longer time to arrive there.

We have proposed a new DTN-based information sharing scheme using AoI (Age of Information) [8,9] which indicates the freshness of information [7]. AoI represents the elapsed time from when the information was generated to the current time and it is used to evaluate the freshness of information. In the proposed scheme, the interval of sharing information among mobile terminals of local residents is dynamically adjusted based on the value of AoI. The interval of sharing information becomes shorter when the AoI value is small (that is, the information is new), while it becomes longer when the AoI value is large (that is, the information is not new). As a result, the dissemination of out-of-date information is suppressed. In addition, the proposed scheme introduces the way to discard the out-of-date information. The information with the AoI value which is more than the specified value is judged as low credibility. Many local residents might evacuate based on the accurate and up-to-date information without receiving out-of-date information. For instance, if the evacuation information on impassable areas that have already become passable are disseminated and shared for a long time, some residents might take redundant evacuation route, but the proposed scheme can reduce such situation.

In addition to the sharing of passable and impassable areas, local residents have to pay attention to the number of evacuees of the evacuation center. When the destination evacuation center is so crowded, they must move to another evacuation center. Therefore, this paper propose a mechanism for the DTN-based information sharing scheme using AoI to predict the number of evacuees in the near future in evacuation centers to which local residents are heading. If the evacuation center will be expected to become full, they change the evacuation route and then move to another evacuation center. This paper proposes two mechanisms for the proposed sharing scheme to predict the number of evacuees in the near future in the evacuation centers and select the appropriate evacuation center. The first mechanism is that the destination evacuation center to which local residents are heading is changed based on the rate of increase in the number of evacuees transmitted from evacuation centers. In the first mechanism, the rate of increase is calculated based on the increased number of evacuees by receiving the disaster information transmitted from evacuation center at the regular interval, and then it is predicted whether the evacuation center will be full or not before arriving there. The second mechanism is that the destination evacuation center to which local residents are heading is changed based on the sharing information among local residents. In the second mechanism, local residents share the destination evacuation center and the estimated arrival time to the evacuation center among them. They can predict the number of evacuees who can arrive there before they themselves arrive and change the destination evacuation center as needed.

Finally, we conduct simulation experiments using network simulator ns-3 [10] to show the effectiveness of the proposed scheme and observe the behavior of AoI values and evacuation time.

The rest of the paper is organized as follows. Section 2 explains Age of Information which is used as the indicator of the freshness of information. Sections 3 and 4 explain the evacuation system that we have proposed to provide evacuation routes with evacuees and the information sharing scheme for the evacuation system. In Section 5, we describe the proposed DTN-based information sharing scheme using AoI. In Section 6, we propose the mechanisms to predict the number of evacuees in the proposed DTN-based information sharing scheme. Section 7 presents the simulation experiments to show the effectiveness of the proposed scheme. Finally, Section 8 concludes this paper with future works.

2 AoI (Age of Information)

AoI is an indicator of the freshness of information for the user who received it and shows how much time has passed since the information was generated. AoI A_t at time t is defined as follows.

$$A_t = t - n_t, \tag{1}$$

where n_t is the time when the disaster information is generated. The freshness of information plays an important role in the event of the disaster because the degree of congestion in the evacuation center and the road condition to the evacuation center are changing with time. Users might take a detour to move to the evacuation center because they move based on incorrect information. So, the AoI value is the important factor especially in DTN communication.

3 Evacuation System

We have proposed an evacuation system to provide evacuation routes with evacuees to move to the evacuation center quickly and efficiently [11]. Each evacuee (user) has a mobile terminal (user terminal) and the terminal can obtain evacuation information along with user's movement. In this system, the MANET-based communication [12, 13] is introduced as an information sharing scheme to share the disaster information among users. The user terminal derives the evacuation route to the evacuation center based on the evacuation information which are obtained from the other mobile terminals, and then the user move there according to the evacuation route determined by the mobile terminal.

In the evacuation system, the geographical information of OpenStreetMap (OSM) [14] is utilized to derive an evacuation route. Road information of OSM is represented by the graph which consists of nodes and links. In this system, nodes, which are one of the elements that configure the road information of OSM, are classified into the following four types depending on their status.

- **Normal node** is a node that users can safely pass through and is not an intersection.
- **Intersection node** is an intersection. Intersection nodes have the information of neighboring intersection or shelter nodes which users move next from the node as the next nodes.
- **impassable node** is a node which users can not pass through due to disaster.
- **Shelter node** is a node that is placed at the entrance of the evacuation center. When users arrive at shelter node, it means that their evacuation is complete. Shelter nodes also have the information of neighboring intersection or shelter nodes which users move next from the node as the next nodes. In addition, the capacity of evacuation centers is set at shelter nodes. It means that users cannot enter the evacuation center after the number of users that arrived here is more than the capacity.

User terminals obtain the information of nodes and links from OSM and retain it as graph information to derive evacuation routes. They select the shortest path from the current location to the nearest evacuation center by Dijkstra's algorithm, and then users move to evacuate according to the derived evacuation route. In case that users arrive at impassable nodes or shelter nodes where the number of evacuees is more than the capacity, they update the graph information and reselect the evacuation route. The new evacuation information that users obtained is transmitted to the other users to share through DTN communication. Users that received the new evacuation information also update the graph information and reselect the evacuation route like the user who found and transmitted the new evacuation information.

4 Information Sharing Scheme

In this paper, the evacuation system adopts DTN communication as an information sharing scheme to share the information among users. Each user terminal transmits a Hello message at the regular interval in order to obtain the information of the nearby nodes in the network, and then establish a connection with them. A Hello message includes the metadata which is the list of data stored in the user terminal. In this system, the number of evacuees in the evacuation center and the location of impassable area are disseminated as disaster information. The data size of these disaster information is not large, so they can be contained in the metadata. User terminals which received the Hello message compare the AoI value of each information contained in the metadata with the AoI value of information that they store. If the AoI value of the metadata is smaller, the disaster information is updated. In case that a new disaster information is contained in the metadata, it is added as a new information. On the other hand, if the user terminal which sent the Hello message has the disaster information with the bigger AoI value, the user terminal which received the Hello message sends the disaster information with the smaller AoI value back to the source user terminal.

5 Proposed DTN-based Information Sharing Scheme Using AoI

The proposed scheme adjusts the interval of transmitting Hello messages (shortly, Hello interval) dynamically based on the AoI value of the received information. The reason why the proposed scheme employs the Hello interval adjustment method is that it is expected to disseminate new disaster information quickly by adjusting the Hello interval to shorter intervals in response to the change of disaster conditions such as detection of an impassable area. This can result in the shorter evacuation time. In case that the AoI value is less than the threshold value A_h, the Hello interval is set at the shorter interval. On the contrary, in case that the AoI value is more than A_h, the Hello interval is set back to the initial interval. In addition, when user terminals receive disaster information directly from the evacuation center and the disaster information with a smaller AoI value is contained, they transmits the disaster information immediately. It thus is able to disseminate the disaster information in a shorter time.

We explain the flow of exchanging the information between user terminals A and B (UT_A, UT_B) in the following.

1. UT_A and UT_B transmit Hello messages while moving to the evacuation center as an example.
2. UT_A receives the Hello message from UT_B.
3. UT_A compares the disaster information contained in the Hello message with its own disaster information.
    - If the information that UT_A does not store or the information with smaller AoI value is included in the disaster information of Hello message, UT_A update the disaster information. After that, UT_A transmits a Hello message to disseminate it immediately and change the Hello interval based on the AoI value of the new disaster information.
    - If the information that UT_B does not store or the information with larger AoI value is included in the disaster information of Hello message, UT_A transmits the disaster information to UT_B by unicast.

In addition, the proposed scheme judges whether an area is impassable or not based on the AoI value as follows.

- **In case that a user finds the impassable area directly,** it stores the location of impassable area and the time as the disaster information and transmit it using a Hello message. Then, it updates the graph information and reselects the evacuation route.
- **In case that a user receives the information of impassable area that it has already had,** if the AoI value of the information is smaller than that of the information of the user, the information is updated, and then disseminated immediately.

- **In case that a user receives the information of a new impassable area,** the user stores the information if the AoI value is smaller than the threshold value (A_d) that is set to discard a disaster information. Then, it updates the graph information and reselect the evacuation route. After that, it is disseminated immediately. On the other hand, if the AoI value of the received disaster information is larger than A_d, the information is discarded.

The AoI value of disaster information is checked, and then the information is discarded if the AoI value is larger than A_d.

Time-to-live (TTL) value is often used to set the lifetime of an information. However, when a source terminal generates an information to transmit, time-to-live (TTL) value for the information is set by the source terminal. The information is discarded when TTL value of the information is expired. On the contrary, the AoI value is the indicator of the freshness of information for users who received the information. In the proposed scheme, the received users decide whether to disseminate the information or not. A_d is set as the criterion of the freshness of the information for each user. Therefore, each user can set A_d appropriately according to network environments and dissemination condition of the information.

6 Mechanisms to Predict the Number of Evacuees in the Proposed Information Sharing Scheme

If the evacuation center where users arrived becomes full, they have to move to another evacuation center. It means that it takes longer time for users to evacuate. Therefore, in the proposed mechanisms, users predict the number of evacuees in the destination evacuation center based on the sharing information so that they can select the appropriate evacuation center to evacuate with time and shorten the evacuation time.

6.1 Prediction Mechanism Based on the Information Transmitted from Evacuation Center

The first mechanism is that the number of evacuees in the near future is predicted by using the rate of increase in the number of evacuees. The rate of increase in the number of evacuees is transmitted from evacuation centers and is shared among users by DTN. Users calculate the estimated number of evacuees in the destination evacuation center based on the rate of increase in the number of evacuees and the estimated arrival time. If it is more than the capacity limit, they change the destination evacuation center. Otherwise, they move to the evacuation center without changing.

For example, consider the following conditions.

- The number of evacuees in the evacuation center is 90.
- The evacuee is expected to arrive there in 100 seconds.
- The rate of increase is 3 evacuees per second.

In this case, the number of evacuees who arrive in 100 seconds is

$$100 \times 3 = 300 \text{ evacuees.}$$

Therefore, when the user arrive at the evacuation center, the predicted number of evacuees is

$$90 + 300 = 390 \text{ evacuees.}$$

If the capacity limit is set at 350 evacuees, the user needs to consider the change of the destination evacuation center because there is the possibility that the evacuation center becomes full.

The advantage of the mechanism is simple because users utilize the information on the congestion situation transmitted from evacuation centers. However, in case that more evacuees than predicted number of evacuees arrive at the evacuation center, it is difficult to predict the number of evacuees accurately so that many evacuees change the destination and move from there to another one after they arrived at an evacuation center.

Table 1: Simulation environments.

Network simulator	ns-3 (ver.3.35)
Field size (m^2)	2,758 × 2,630
Number of users (initial number of users, number of additional users)	600 (300, 300), 1000 (500, 500)
User additional interval (sec)	1.1
Moving speed (m/s)	1.6
Transmission range (m)	100
MAC protocol	IEEE802.11g
Interval of transmitting message from evacuation centers (sec)	60
Regular/short intervals of sending Hello messages (sec)	60/20
AoI threshold value of A_h	60
AoI threshold value of A_d	200, 400

6.2 Prediction Mechanism based on the Information Sharing among Users

The second mechanism is that the number of evacuees in the near future is predicted by sharing users' information, which are destination evacuation center and estimated arrival time, among users in DTN.

The procedures are as follows.

1. Each user calculates the time required from the current location to the destination evacuation center as an evacuation information.
2. Users share the evacuation information among users through DTN.
3. Each user counts the number of evacuees who can arrive at the destination evacuation center earlier than the user.

For instance, a user can arrive at the destination evacuation center in 120 seconds and obtain the evacuation information that 50 evacuees are heading to the same evacuation center and in 30 of 50 evacuees the time required to the destination evacuation center is shorter than 120 seconds. In this case, the user can predict that 30 evacuees can arrive there earlier than the user. The user considers whether it changes the destination evacuation center based on the evacuation information because there is the possibility that the number of evacuees is more than the capacity limit before the user arrives.

7 Simulation Evaluation

First of all, we evaluate the adjustment of the Hello interval method in the proposed scheme described in Section 5. Then, we conduct simulation experiments to evaluate the effectiveness of the proposed scheme using real geographical information. In Experiment I, the evacuation rate at each A_d value is evaluated from the perspective of the number of users. In Experiment II, the evacuation time and number of evacuees are evaluated from the perspective of changes of conditions in simulation field. In Experiment III, the evacuation time is evaluated to investigate the effect of the prediction mechanisms. From Experiments I, II and III, we demonstrate that the proposed scheme improves the evacuation rate, evacuation time, and number of evacuees.

We implement the proposed DTN-based evacuation system on ns-3 (ver.3.35) and conduct simulation experiment for the performance evaluation. Table 1 shows the simulation environments. In the table, regular/short intervals of sending Hello messages is the Hello interval of the adjustment method in the proposed scheme. The Hello interval adjustment method sets the Hello interval at 20 (short interval) when the AoI value is less than A_h and at 60 (regular interval) when the AoI value is larger than A_h.

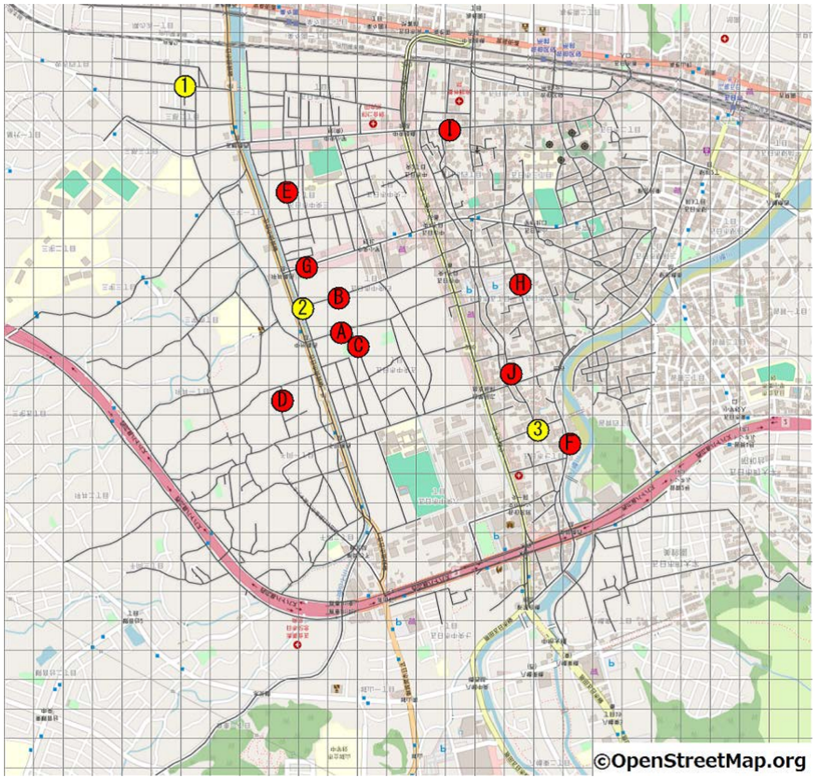

Figure 1: Simulation field: Itsukaichi area in Hiroshima City (2,758m × 2,630m).

Figure 1 shows the simulation field whose area is Itsukaichi area of Hiroshima City. In the field, three shelter nodes 1 to 3 and ten impassable node A to J are set as shown in Figure 1. Each of location and the other information of shelter and impassable nodes are shown in Tables 2 and 3.

7.1 Evaluation of Hello Interval Adjustment Method of Proposed Scheme

7.1.1 Simulation Plan

The proposed scheme adjusts the interval of transmitting Hello messages (Hello interval) as described in Section 5. We evaluate the impact of the Hello interval adjustment method on evacuation time. In the experiments, the proposed scheme does not utilize A_d value and discard the information to investigate the effect of the Hello interval adjustment method. We conduct simulation experiments to compare the Hello interval adjustment method with the methods in which Hello intervals are set at 20 and 60 seconds (Hello=20 and Hello=60). The Hello interval adjustment method sets the Hello interval at 20 when the AoI value is less than A_h and at 60 when the AoI value is larger than A_h. In addition, the Hello message is transmitted immediately when a new information is received.

In the simulation, the initial number of users is randomly placed on the field and one new user is added every 1.1 seconds from the simulation start until the number of new users is the number of additional users. We use 600 (300, 300) and 1000 (500, 500) as the total number of users (initial number of users, number of additional users). Users move to the nearest evacuation center for their evacuation based on the graph information. Evacuation centers distribute the message including the number of evacuees in the center at the 60 second interval.

We conduct two types of simulation experiments with/without setting the impassable nodes. Much more disaster information are generated and disseminated by setting the impassable nodes so that the number of transmitted messages among users increases. In the experiment with setting the impassable nodes, ten nodes become impassable nodes after 50 seconds passed from the start, and then become normal nodes at 600 seconds.

Table 2: Location of shelter nodes (evacuation centers) and the capacity of evacuees that can be accommodated.

Evacuation center	Location information	Capacity limit
1	(132.348, 34.3661)	5000
2	(132.352, 34.3729)	5000
3	(132.361, 34.3766)	50

Table 3: Location of impassable nodes (impassable areas) in the field.

Location name	Location information
A	(132.353, 34.3737)
B	(132.353, 34.3726)
C	(132.354, 34.3741)
D	(132.351, 34.3758)
E	(132.351, 34.3694)
F	(132.362, 34.3771)
G	(132.352, 34.3717)
H	(132.36, 34.3722)
I	(132.357, 34.3674)
J	(132.36, 34.3749)

7.1.2 Simulation Result

Table 4 shows the average evacuation time of users and the number of transmitted messages in each case. The Hello interval adjustment method could provide the shortest evacuation time in all cases. However, the number of transmitted messages becomes less than the other methods in case that the impassable nodes are not set and the number of nodes is 600, while the number of transmitted messages becomes more than Hello=20 in the other cases. The Hello interval adjustment method transmits the message immediately when users receive a new disaster information. Therefore, the number of transmitted messages increases in cases that the impassable nodes are set. In addition, in case that the number of users is 1000, the number of transmitted messages increases because the user density becomes higher and each user has more neighbors.

Figures 2 and 3 show the CDF of evacuation time in case that the numbers of users are 600 and 1000, respectively. As shown in both figures, the Hello interval adjustment method is the highest evacuation ratio. It transmits the Hello message in a shorter time than Hello=20 because users transmit the Hello messages immediately after they receive a new disaster information. Consequently, it can be confirmed that the Hello interval adjustment method in the proposed scheme works well from the viewpoint of evacuation time.

Table 4: Average evacuation time of users and the number of transmitted messages in cases of the Hello interval adjustment method (adjustment method), Hello=60 and Hello=20. (In the table, Time and messages show average evacuation time and the number of transmitted messages.)

# of users	Impassable nodes	Adjustment method		Hello=60		Hello=20	
		time (sec)	messages	time (sec)	messages	time (sec)	messages
600	none	684.91	17615	701.27	7018	691.45	20146
600	set	767.27	23191	807.14	8078	779.89	22795
1000	none	691.17	38379	710.95	11850	695.52	33776
1000	set	769.46	44450	804.60	13433	775.27	28871

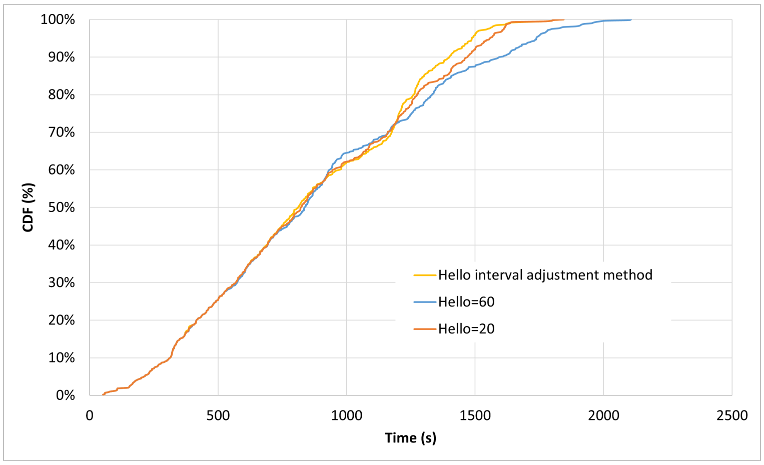

Figure 2: CDF of evacuation time (600 users, set impassable nodes)

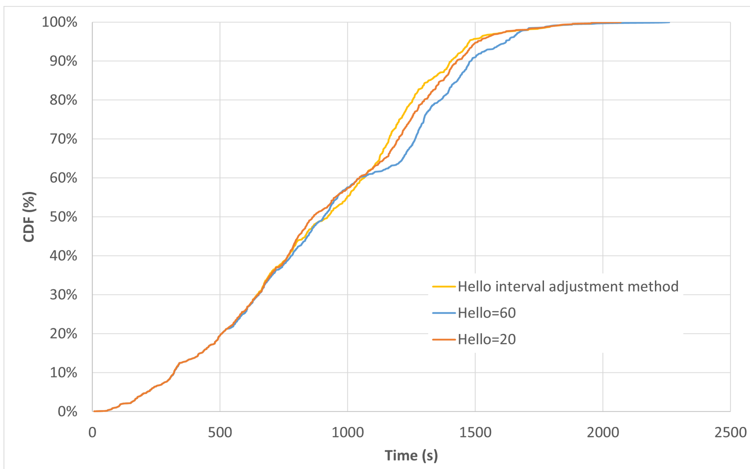

Figure 3: CDF of evacuation time (1000 users, set impassable nodes)

7.2 Simulation Experiment I

7.2.1 Simulation Plan

We conduct simulation experiments to evaluate the evacuation rate at each A_d value from the perspective of the number of users. From the results of preliminary simulation experiments described in [7], we use $A_d = 200$ and $A_d = 400$ for the proposed schemes.

In the simulation, users are randomly placed and a new user is added every 1.1 seconds from the simulation start until the number of new users is the number of additional users. We use 600 (300, 300) and 1000 (500, 500) as the number of users.

Users move to the nearest evacuation center for their evacuation based on the graph information. Evacuation centers distribute the message including the number of evacuees in the center at the 60 second interval.

7.2.2 Simulation Results

Figures 4 and 5 show the CDF of evacuation time with and without setting a capacity limit in case that the total number of users is 600. As shown in Figure 4, DTN-based schemes that are the proposed scheme and the scheme without utilizing AoI value (shortly, conventional scheme) provide

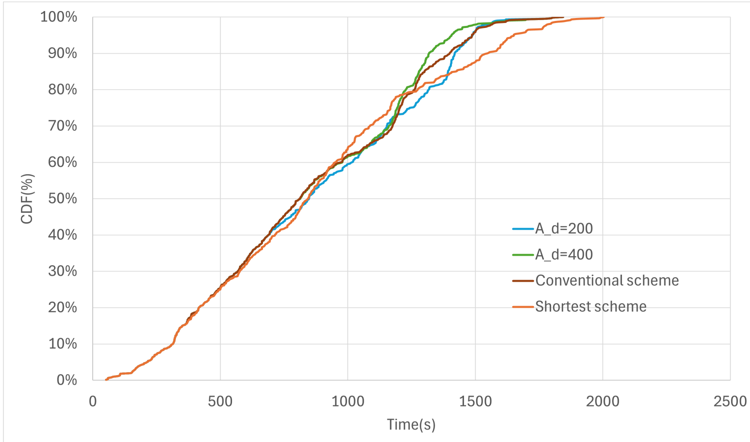

Figure 4: CDF of evacuation time (600 users, limited capacity) in Experiment I.

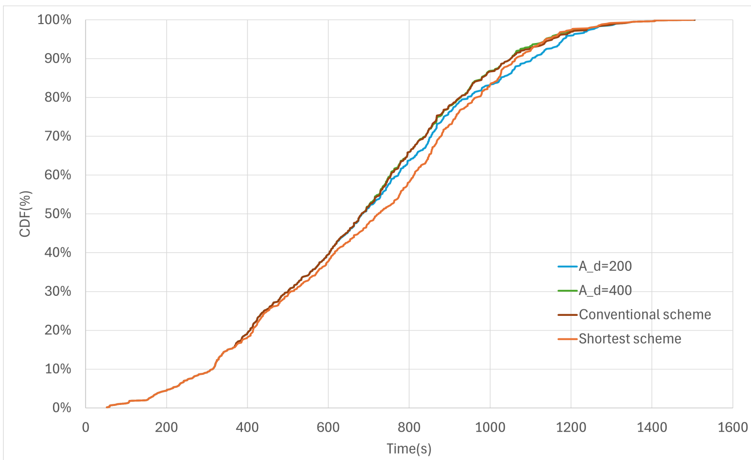

Figure 5: CDF of evacuation time (600 users, unlimited capacity) in Experiment I.

shorter evacuation time than the scheme in which users do not share disaster information among them and move along the shortest route (shortly, shortest scheme). The conventional scheme does not utilize A_d so that users store received disaster information without discarding them. Users can avoid impassable areas and take an alternative route because they share disaster information through DTN communication, resulting in the effectiveness of the disaster information sharing. In addition, the proposed scheme ($A_d = 400$) becomes better than the conventional scheme because the disaster information are discarded based on the AoI threshold value. In case that impassable areas become passable areas, users can take a shortest route by passing through those areas and evacuate in a shorter time. However, the proposed scheme ($A_d = 200$) becomes worse. Users who take a route including impassable areas increases because the disaster information was discarded in a shorter time. Therefore, some users take a detour route, resulting in longer evacuation time.

As shown in Figure 5, the proposed scheme ($A_d = 400$) and conventional scheme become higher than the shortest scheme, but there is no difference between them when the capacity limit is not set. In this case, the moving distance of users does not become longer because they are no need to change from the evacuation center where they arrived first to another evacuation center.

Figures 6 and 7 show the CDF of evacuation time with and without setting a capacity limit in case that the total number of users is 1000. As shown in Figure 6, the proposed scheme ($A_d = 200$) is better than the conventional scheme, but the proposed scheme ($A_d = 400$) is almost the same as the conventional scheme. Since there are so many users in this field and the disaster information is

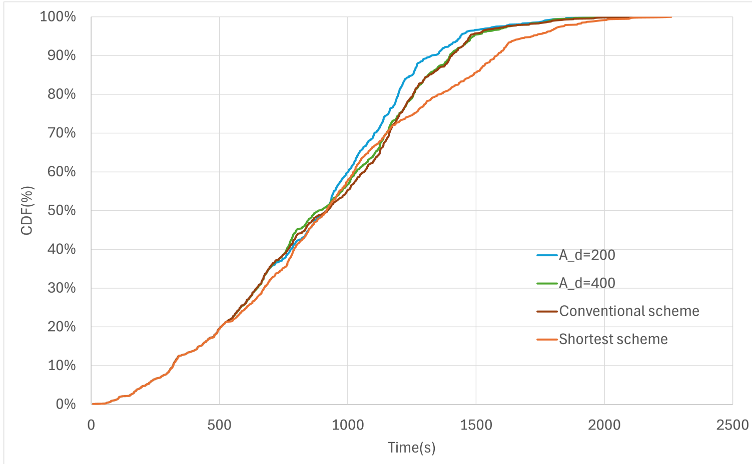

Figure 6: CDF of evacuation time (1000 users, limited capacity) in Experiment I.

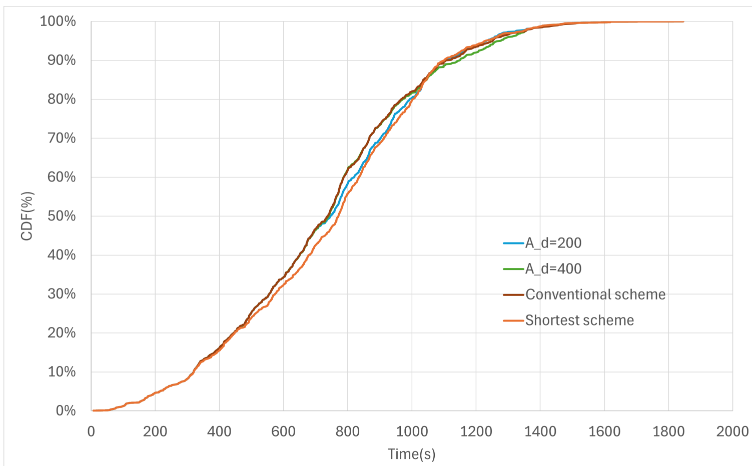

Figure 7: CDF of evacuation time (1000 users, unlimited capacity) in Experiment I.

widespread in a shorter time because of the high user density, no user takes the evacuation route including impassable areas.

Consequently, when there are 600 users, some users who have not yet received information about impassable areas head towards those passable areas, which results in an update of the AoI. However, with 1,000 users, the information spreads more easily, so users no longer head towards impassable areas, and the AoI is not updated from the time the impassable area is initially discovered. Since the AoI is not updated midway, outdated information may be discarded prematurely compared to the scenario with 600 users, even though the impassable area has not yet been cleared. As a result, users may head towards passable areas, leading to time loss. Moreover, with a larger number of users, there is a higher likelihood that impassable areas will be discovered just before they are cleared. Since the information is trusted for 400 seconds from the moment the impassable area is discovered, there would be little difference from the conventional scheme during that time. We can say that the AoI threshold value A_d should be smaller to shorten the evacuation time when the number of users is large.

In Figure 7, there is no difference between the proposed and conventional schemes as in Figure 5 when the capacity limit is not set. As a result, users are not affected by the impassable areas in this experiment in case that the capacity limit in the evacuation center is not set.

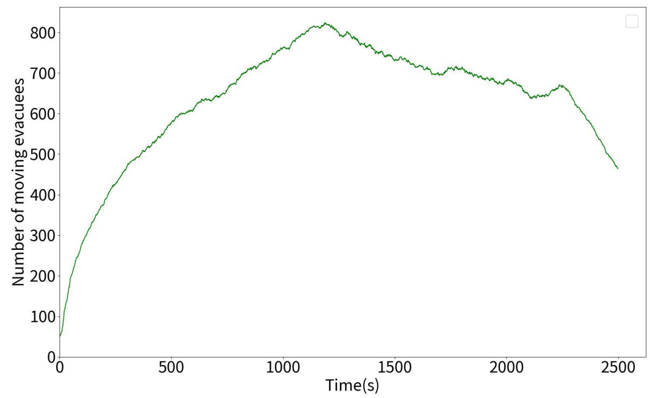

Figure 8: Number of moving evacuees ($A_d = 200$) in Experiment II.

Table 5: Location of impassable nodes (impassable areas) in the field and time when each of them become passable from impassable.

Location name	Location information	Time (s)
A	(132.353, 34.3737)	1526
B	(132.353, 34.3726)	1339
C	(132.354, 34.3741)	1285
D	(132.351, 34.3758)	1215
E	(132.351, 34.3694)	1120
F	(132.362, 34.3771)	1043
G	(132.352, 34.3717)	943
H	(132.36, 34.3722)	708
I	(132.357, 34.3674)	508
J	(132.36, 34.3749)	281

7.3 Simulation Experiment II

7.3.1 Simulation Plan

In Experiment II, impassable nodes become passable in turn although impassable nodes become passable at the same time in Experiment I. The impassable node is randomly selected every between 50 to 250 seconds and then becomes passable. In this experiment, the time when each of impassable nodes becomes passable is as shown in Table 5. In addition, one user is added every 1.1 seconds so the number of users in each simulation time is shown in Figure 8. The simulation is terminated at 2500 seconds. The other parameters in the simulation environment is the same as Experiment I. This experiment is conducted in case with setting the capacity limit in the evacuation center. From the results of preliminary simulation experiments described in [7], we use $A_d = 200$ and $A_d = 400$ for the proposed schemes and show the average evacuation time and the number of evacuees who arrived at the evacuation center.

7.3.2 Simulation Result

Figure 9 represents the time when users arrived at evacuation center every 100 seconds on the x-axis and the number of evacuated users in the past 100 seconds on the y-axis. Figure 10 represents the time required for evacuation of users (that is, it shows how long it took for users to move from the initial position to the evacuation center) every 100 seconds on the x-axis and the number of evacuated users in the past 100 seconds on the y-axis. As shown in Figure 9, many users arrived at

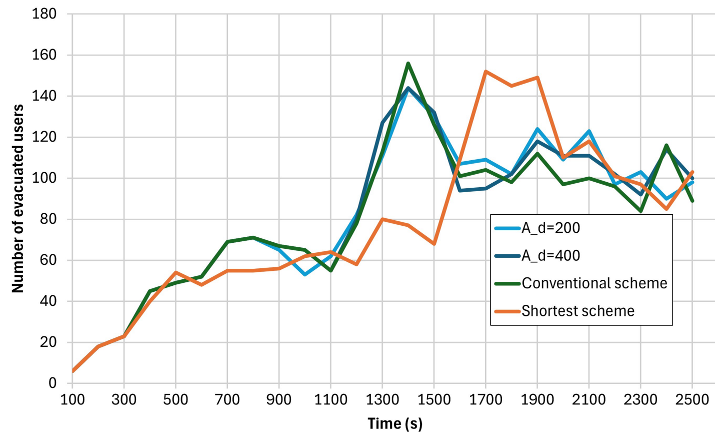

Figure 9: Time of arrival at evacuation center and number of evacuees in Experiment II.

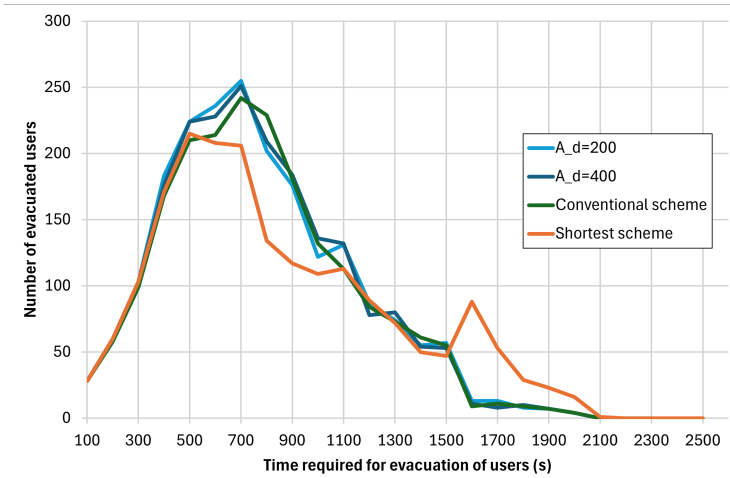

Figure 10: Time required for evacuation of users and number of evacuees in Experiment II.

the evacuation center within 1300-1399 seconds (1400 seconds depicted in the graph) in the proposed and the conventional schemes. 156 users completed evacuation within 1300-1399 seconds in the conventional scheme, whereas 144 users completed evacuation in the proposed scheme ($A_d = 400$).

On the other hand, as shown in Figure 10, from a standpoint of time required for evacuation of users, many users can evacuate within 600-699 seconds (700 seconds depicted in the graph)in the proposed schemes ($A_d = 200$ and $A_d = 400$). Since users try to pass through impassable areas to discard the disaster information based on the AoI threshold value in the proposed scheme, some users arrived at the evacuation center later than users in the conventional scheme.

In addition, more users can evacuate in a shorter time than 700 seconds in comparison with the conventional scheme. Consequently, the proposed DTN-based information sharing scheme using AoI provides shorter evacuation time thanks to discarding the disaster information.

7.4 Simulation Experiment III

7.4.1 Simulation Plan

In Experiment III, the parameters of the evacuation centers, which are the location of evacuation centers and its capacity limit (Table 2), and the time when impassable nodes become passable nodes

(Table 5) are the same as Experiment II. The two cases of user density are set for the experiments to show the difference of the user density as the same as Experiment I. In the simulation, the initial number of users is randomly placed on the field and one new user is added every 1.1 seconds from the simulation start until the number of new users is the number of additional users. We use 600 (300, 300) and 1000 (500, 500) as the number of users.

We evaluate the prediction mechanisms based on the information transmitted from evacuation centers and based on the information sharing among users in comparison with the scheme without using the prediction mechanism. In the experiment, the proposed scheme does not utilize A_d and discard the information to investigate the effect of the prediction mechanisms. We also observe the difference of evacuation time between the two mechanisms.

7.4.2 Simulation Result

Tables 6 and 7 are the results of the prediction mechanism based on the information transmitted from evacuation centers and the prediction mechanism based on the information sharing among users. If the reduced evacuation time becomes less than 0, it means that the evacuation time becomes longer than that of the scheme without using the prediction mechanism.

Table 6 shows the simulation results for the prediction mechanism based on the information transmitted from evacuation centers. As shown in Table 6, in case that the total number of users is 600, the average reduced evacuation time is 4.37 seconds. In this case, it is confirmed that the prediction mechanism works effectively because the evacuation time becomes slightly shorter. In the simulation results, 31 users changed the destination evacuation center based on the prediction mechanism and the number of the users is small. 22 of 31 users can arrive at the destination evacuation center in a shorter time, while the evacuation time of 9 users become longer because they select the evacuation route including impassable areas. In the worst case, the minimum reduced evacuation time is -407.06 seconds and it means the evacuation time becomes much longer. On the other hand, in case that the total number of users is 1000, the average reduced evacuation time is 11.13 seconds. As a result, in this case, it is confirmed that the prediction mechanism works effectively because the evacuation time becomes shorter. In the simulation results, 105 users changed the destination evacuation center based on the prediction mechanism. 78 of 105 users can arrive at the destination evacuation center in a shorter time, while the evacuation time of 27 users become longer because they select the evacuation route including impassable areas and change the destination evacuation center. In the worst case, the minimum reduced evacuation time is -336.64 seconds and it means the evacuation time becomes much longer.

Table 7 shows the simulation results for the prediction mechanism based on the information sharing among users. As shown in Table 7, in case that the total number of users is 600, the average reduced evacuation time is -29.98 seconds. Even in case that the number of users is low, it is confirmed that the prediction mechanism does not work effectively. In case that the number of users is 1000, the average reduced evacuation time is 7.24 seconds. It is the same performance as the prediction mechanism based on the information transmitted from evacuation centers. However, as shown in the results of maximum and minimum reduced evacuation time, there is the big difference between them. The prediction mechanism based on the information sharing among users does not work for all users effectively as it shows that the minimum reduced evacuation time is -274.65 seconds.

Consequently, in case that the number of users is 600, because users do not have to change the destination evacuation route and the dissemination of the information is limited, the prediction mechanism based on the information transmitted from evacuation center has no impact on the evacuation time. On the contrary, in case that the number of users is 1000, it is confirmed that the both prediction mechanisms can work effectively because they can provide shorter evacuation time with users, but for some users the evacuation time becomes longer.

Table 6: Prediction mechanism based on the information transmitted from evacuation centers in Experiment III.

Number of users	600	1000
Average reduced evacuation time (sec)	4.37	11.13
Maximum reduced evacuation time (sec)	409.97	731.18
Minimum reduced evacuation time (sec)	-407.06	-336.64
Number of users who change the destination	31	105
Number of users whose evacuation time become shorter	22	78
Number of users whose evacuation time become longer	9	27

Table 7: Prediction mechanism based on the information sharing among users in Experiment III.

Number of users	600	1000
Average reduced evacuation time (sec)	-29.98	7.24
Maximum reduced evacuation time (sec)	343.67	409.97
Minimum reduced evacuation time (sec)	-453.49	-274.65
Number of users who change the destination	172	97
Number of users whose evacuation time become shorter	13	68
Number of users whose evacuation time become longer	159	29

8 Conclusion

From Experiment I, it was confirmed that when a capacity is set for evacuation centers, the proposed scheme achieves a higher evacuation rate than the conventional scheme. However, it was also confirmed that there is no significant difference between the proposed scheme and the conventional scheme when no capacity limit is set. Additionally, it was found that when the number of users is high, it is beneficial to set a smaller A_d value. From Experiment II, it was confirmed that the A_d value affects the evacuation time. By setting an appropriate value, it was confirmed that the proposed scheme is effective in reducing evacuation time. From Experiment III, it was confirmed that many evacuees could shorten the evacuation time because they change the destination evacuation center while evacuating by predicting the number of evacuees in the near future in the evacuation center. As a future challenge, we are planning to propose a mechanism to dynamically adjust the A_d value based on the number of users and the time of impassable areas detection. In addition, we are also planning to propose a mechanism to dynamically adjust A_h based on the density of users in the vicinity.

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