A Broadcast Distribution System for Delivering Emergency Bulletins to User Equipment Outside of eNBs Coverage

Yutaka Musaka
Graduate School of Systems Information Science
Future University Hakodate
Hakodate, Japan
g2117045@fun.ac.jp

Yoshitaka Nakamura
School of Systems Information Science
Future University Hakodate
Hakodate, Japan
y-nakamr@fun.ac.jp

Hiroshi Inamura
School of Systems Information Science
Future University Hakodate
Hakodate, Japan
inamura@fun.ac.jp

***Abstract*—When base stations in cellular networks break down due to a disaster, users may not be able to use mobile services such as calls, mail and SNS, and may have difficulty gathering information necessary for their protection and safety. It is therefore important to build an alternative network for delivering emergency bulletins about earthquakes and tsunamis. We propose a broadcast distribution system integrating the ETWS (Earthquake and Tsunami Warning System) and ProSe (Proximity Services) on LTE that delivers emergency bulletins to UEs outside eNB coverage and incorporates DTN to maximize the message arrival rate. We showed the effectiveness of our proposed system by carrying out an evacuation simulation using the system.**

Keywords—Emergency communication; Multi-hop communication; Delay tolerant networking; Earthquake and Tsunami warning system; Proximity Services;

I. Introduction

Nowadays, connected devices such as smartphones are widely used. The population penetration rate of smartphones in Japan was 64.2% in 2014. Advanced wireless access technologies are available and recent devices are deploying LTE (Long Term Evolution), a 3G wireless cellular technology. Using smartphones, users can make calls and access the Internet with high bandwidth, making the smartphone a very convenient tool to retrieve a variety of information on the go. However, the connectivity of a smartphone depends on the coverage of the eNB (eNB: evolved Node B).

Approximately 29,000 eNBs failed in the 2011 Great East Japan earthquake. The smartphones (UEs: User Equipment) near the failed eNB lost connectivity and communication capabilities, due to being outside the coverage of even other working eNBs, as depicted in Fig. 1. A warning system delivering emergency bulletins is operated when a disaster occurs. That warning system notifies users' UEs that are in the area in which an earthquake or tsunami is predicted to happen, some time before the disaster occurs. However, it is impossible to deliver an emergency bulletin to UEs in a situation where they are outside eNB coverage and the communication infrastructure in the area has already stopped functioning.

There are conventional technologies for constructing alternative networks, such as MANET (Mobile Ad-hoc NETwork) [1] and DTN (Delay Tolerant Networking) [2]. MANET is a form of autonomous distributed networking, where the participating nodes relay messages as well as sending and receiving reciprocally. DTN is a technique of transferring data to a destination by scattering data copies across the network and utilizing the movement of UEs. However, these technologies are information sharing methods in an environment isolated from the Internet in general, and do not consider the sharing of emergency bulletins delivered from eNBs. There is technology for direct communication between UEs on the LTE network, such as D2D (Device to Device) [3]. The eNB can centrally control UEs in D2D. There has been a study on using it as a public safety application so that the burden on the core network can be reduced by making UEs communicate with each other directly. In this way UEs outside eNB coverage can also participate in the network. D2D performs mutual communication using the synchronization signal emitted by the eNB, and it is efficient for distributing emergency bulletins.

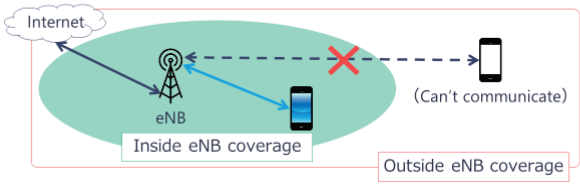

Fig. 1. About the eNB coverage

We realize the distribution of emergency bulletins to UEs outside eNB coverage, assuming an environment where delivery of emergency bulletins is difficult due to an outage caused by a large-scale disaster. We propose a system integrating the ETWS (Earthquake and Tsunami Warning System) [4], which is an existing broadcast distribution system, and ProSe (Proximity Services) [5], which is a LTE-based D2D technology. In addition, we incorporate DTN mechanism to relay the bulletin messages for geographically wider-range delivery. We also show the effectiveness of the system by evaluation in simulations carried out using the proposed system.

II. Related Research

We describe existing work on networking for recovery from large-scale disasters using MANET and DTN.

A. Information sharing method with MANET and DTN combined

The study by Nishiyama et al. [6], proposes a multi-hop relay communication system using a network in which MANET and DTN are combined. The system of Nishiyama et al. is characterized by transferring messages to a destination while switching between two communication technologies according to the environment. The information transfer method assumes communication over a distance of approximately 100 m by Wi-Fi Direct. When a route to the destination is not found, the remaining battery level of the UE is below a certain level, or the UE is moving at high speed, the nodes communicate using DTN. In other cases, they communicate using MANET. Nishiyama et al. performed an experiment using a multi-hop relay communication system in Sendai city, in the north-east of Japan. As a result, they succeeded in sending messages to the UE over a total distance of 2.5 km via 27 UEs.

B. Evacuation guidance system using opportunistic communication

In the study by Fujiwara et al. [7], they propose an evacuation guidance system using opportunistic communication in DTN. Opportunistic communication is the exchange of information by ad hoc communication when another UE is detected within transmission range of the UE. The system performs opportunistic communications when evacuees encounter each other. In addition, it adopts store-carry-forward communication in DTN. The system automatically shares guidance information and navigates a new route to the evacuation center if the original route contains inaccessible roads. It assumes communication by Bluetooth within the range of several tens of meters, for sharing disaster area information. Performance evaluation was carried out with a network simulator. As a result, it has been confirmed that both the average and maximum evacuation time decreased with information sharing by opportunistic communication.

C. Disaster information system based on DTN

In the study by Kawamoto et al. [8], they propose a disaster information system based on DTN. A disaster information system is a network that collects information from people who come to evacuation shelters. In addition, it is a network that shares information among evacuation centers over a wireless network. It not only collects information from people gathered at evacuation centers but also collects information on people in need who are still waiting for rescue in the disaster area. This disaster information system adopts epidemic routing by store-carry-forward communication in DTN. In order to reduce the number of redundant transmissions, Kawamoto et al.adopted a method of ranking messages and discarding them starting from those with low rank, when the buffer overflows. They clarified the effectiveness of these methods by performance evaluation using a network simulator.

D. About related reserch

These methods were effective for sharing intra-regional information after a disaster. Consideration of the methods is based on the premise that emergency bulletins need to be distributed to UEs outside eNB coverage. Since Nishiyama's method of a multi-hop relay communication system uses Wi-Fi Direct, the transmission range of tens of meters up to a hundred meters means it is difficult to maintain communication between UEs that keep moving. For urgent communication such as evacuation directions, longer range coverage is an advantage in D2D. Furthermore, our aim of distribution of emergency bulletins, as in the ETWS, requires promptness, while Nishiyama's system does not consider the arrival time of the message at the UE. Fujiwara's evacuation guidance system with opportunistic communication may cause the evacuation of people who don't need evacuation, increasing road traffic congestion. We consider the use of epidemic routing in our system, based on the work of Kawamoto and Fujiwara. Considering the method of delivering emergency bulletins to UEs outside eNB coverage, it is important that the D2D communication should be capable of covering a longer range, and the messaging system should maintain the freshness of emergency bulletins.

III. Proposed System

We integrate ProSe, which is D2D technology available on LTE compliant terminals, into the ETWS broadcast distribution system operating on the LTE network. Then we propose a broadcast distribution system that can deliver emergency bulletins to UEs outside eNB coverage. Adopting ProSe, which has a transmission range of up to 1 km, as the communication standard, it is thought that the increased frequency of contact between UEs will improve both the arrival rate and the arrival time of the messages. The UE described below is assumed to be an LTE compliant terminal. A schematic diagram of the proposed system is shown in Fig. 2. The ETWS can only deliver emergency bulletins to UEs inside eNB coverage. The integration of ProSe makes it possible to relay emergency bulletins to UEs outside eNB coverage, by relaying between UEs inside eNB coverage that have established channels with eNBs. With multi-hop communication, delivery to UEs that are further away becomes possible. In addition, we realize improvement of the arrival rate and ensure the speed of delivery by adding DTN by ProSe when the UEs are not synchronized or UEs are outside D2D coverage.

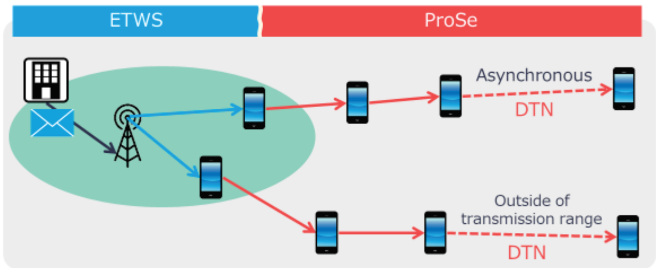

Fig. 2. Schematic of the proposed system

A. Earthquake and Tsunami Warning System

The ETWS is a technology for broadcasting an emergency bulletin to a specified region that is defined by a set of eNBs[9]. In the ETWS, the bulletin message is split into two parts, namely the Primary Notification and Secondary Notification. For example, the Primary Notification stating "Earthquake" is delivered to UEs in the shortest possible time, with pre-determined text explaining the type of disaster. The Secondary Notification is detailed information to supplement the Primary Notification, such as the seismic intensity and epicenter of the earthquake. The Primary Notification arrives at UEs in approximately 4 seconds from the start of distribution. The Secondary Notification arrives at UEs in approximately 10 seconds from the start of distribution of the Primary Notification.

The emergency bulletin is transmitted by a SIB (System Information Block), which is broadcast information. There are

SIBs from SIB 1 to SIB 13; the Primary Notification corresponds to SIB 10, and the Secondary Notification corresponds to SIB 11. When UEs receive a SIB including an emergency bulletin, the UEs execute an alarm and a popup on the display.

A detailed diagram of the sequence until the emergency bulletin using the ETWS reaches UEs is shown in Fig. 3. When an eNB receives the Write-Replace Warning Request, it transmits the ETWS indication to UEs using the PCH (Paging Channel). Upon receiving the ETWS indication, UEs start receiving the emergency bulletin using the BCCH (Broadcast Control Channel). UEs confirm the SIB 10 and provide the users with the emergency bulletin as the Primary Notification. The core network transmits the Secondary Notification in the same way as the Primary Notification.

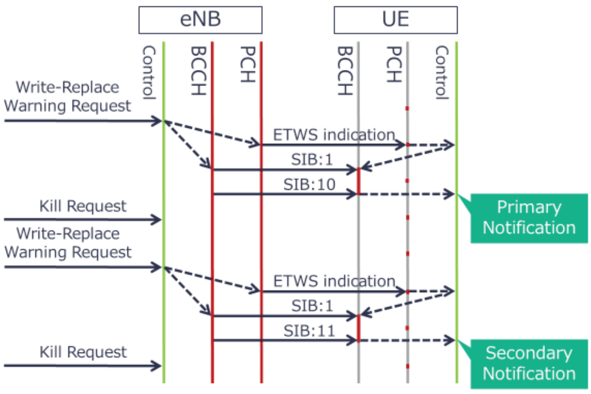

Fig. 3. Sequence for delivering an emergency bulletin by ETWS

B. *Proximity Services*

In the 3GPP (3rd Generation Partnership Project), ProSe specification that enables D2D not via the eNB using LTE uplink frequency band is standardized. ProSe has functions for direct communication and device discovery. direct communication can perform data communication, voice calls, etc. with another UE in proximity range. device discovery can perform surrounding UE discovery and service detection. Moreover, the communication distance in ProSe near-UE communication and proximity UE discovery is supposed to be 500 m to 1 km in the absence of obstacles. In this system, the function of direct communication is adopted to perform D2D.

Fig. 4 shows synchronization between the eNB and the UE, and between UEs, in ProSe direct communication. UEs inside eNB coverage transmit and receive D2D messages in synchronization with the PSS / SSS of the synchronization signal transmitted by the eNB[10]. On the other hand, if either or both of the UEs of the sender/receiver is outside coverage, the messages in D2D are transmitted and received in synchronization with the PSSS / SSSS (Primary/Secondary Sidelink Synchronization Signal) between the UEs. PSSS / SSSS signals are transmitted in a 40 ms period by UEs inside and outside eNB coverage. As shown in Fig. 4, the UE inside eNB coverage transmits PSSS / SSSS based on the synchronization timing of the eNB, so that the UE outside eNB coverage can also perform direct communication at the synchronization timing of eNBs. direct communication notifies the PSBCH (Physical Sidelink Broadcast Control Channel), as well as the PSSS / SSSS, of the D2D frame number, system bandwidth, TDD (Time Division Duplex) UL / DL subframe structure, etc.

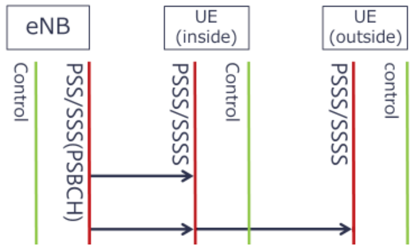

Fig. 4. Method and apparatus for synchronizing in direct communication

C. *Integrating the ETWS and ProSe*

Since the channel usage method of the ETWS and ProSe are similar, we consider a broadcast distribution system integrating ProSe into the ETWS. The ETWS is a widely used broadcast distribution system. ProSe has long communication distance in D2D and can transfer SIBs received by the ETWS without any special operation. In order for UEs outside eNB coverage to receive the Primary Notification, it is necessary for UEs inside eNB coverage to transmit the SIB 1 and the SIB 10 to UEs outside eNB coverage. The sequence of the communication is shown in Fig. 5. The process until UEs inside eNB coverage receive the ETWS indication and the SIB 10 is the same as in the ETWS. At that time, if the channel between UEs outside eNB coverage and UEs inside eNB coverage is established, the system places the SIB 1 on the PSBCH and transmits it to UEs outside eNB coverage. The SIB 11 sent in succession is placed on the PSBCH and transmitted to UEs outside eNB coverage. In this series of operations, it is considered that UEs outside eNB coverage can receive the emergency bulletin as well as UEs inside eNB coverage.

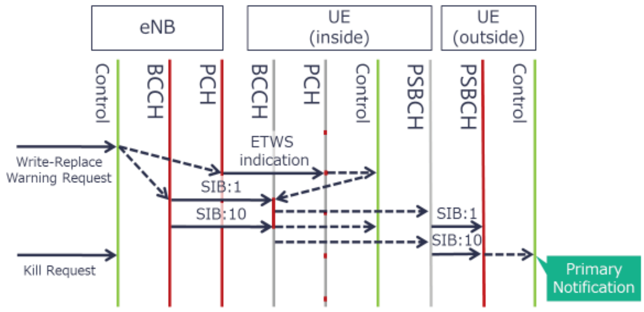

Fig. 5. Sequence for delivering an emergency bulletin

D. *Problem concerning integration*

We describe a problem caused by integrating ProSe into the ETWS. Fig. 5 shows that synchronization of the UE inside eNB coverage the UE outside eNB coverage has been established in advance. On the other hand, the sequence shown in Fig. 6 represents a situation in which the UE outside eNB coverage establishes synchronization with the UE inside eNB coverage after the delivery request of the emergency bulletin is canceled. When the request is canceled, UEs discard the emergency bulletin. Therefore, UEs inside eNB coverage cannot deliver the emergency bulletin to UEs outside eNB coverage. For example, if an eNB stops functioning due to an earthquake, it can't receive a tsunami warning delivered as a follow-up report, resulting in a situation where evacuation will be delayed.

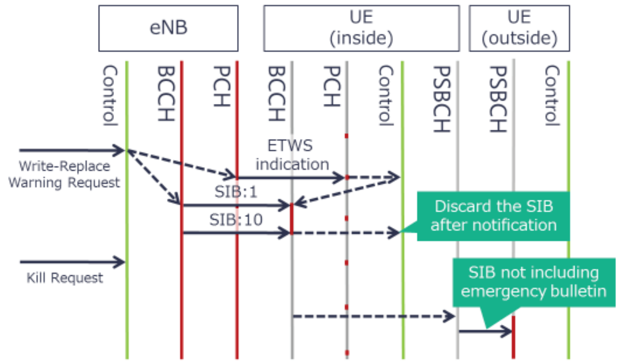

Fig. 6. Sequence in which the problem occurs

E. A method to enable asynchronous communication

The broadcast delivery system described so far is capable of relaying ETWS messages to a destination one hop away from eNB coverage via D2D. There is a problem in that it can't deliver messages to UEs outside eNBs coverage which are not covered in the communication range of D2D. In order to maximize the arrival rate of the messages to UEs, we add epidemic routing of DTN to the proposed system for UEs outside eNB coverage. For the incorporation of DTN, we need to add two extra features to the ETWS: message identification for routing and a timeout mechanism for ensuring message freshness.

In the first method, an ID to be used as an identification number for a bulletin is provided. The IDs will be collated for messages shared between UEs when they are connected by ProSe, and this enables epidemic routing working. Applying this method prevents reception of emergency bulletins that have already been received. In the second method, a 'Timeout' indicating expiration time is set in the emergency bulletin to be delivered. If it is before the expiration time, UEs retain the information of the emergency bulletin. Applying this method, it is possible to deliver to UEs that have not established synchronization in advance. In addition, it is possible to prevent unnecessary emergency bulletins from being scattered and to maintain the freshness of the emergency bulletin reports.

The sequence in the case of adding these two proposed features is shown in Fig. 7. A Timeout and ID are assigned to the emergency bulletin to be distributed and a distribution request is issued to eNBs. Then, UEs inside eNB coverage receive the SIB as the emergency bulletin from the eNB as usual, and retain the information of the SIB until the deadline set by the Timeout. When the UE outside eNB coverage issues a channel establishment request, it receives the ID retained by the UE outside eNB coverage, and if it does not receive the emergency bulletin corresponding to the ID, it sends a SIB distribution request to UEs inside eNB coverage. With this method, it is more widely possible to receive emergency bulletins. Also, since it can be predicted that the subsequent report after an earthquake occurs will be a tsunami warning and evacuation information, there will be some time before damage to one's own current location will occur. Therefore, it is not applied to SIB 10, which is a pre-determined text, but is only applied to SIB 11, which carries detailed information.

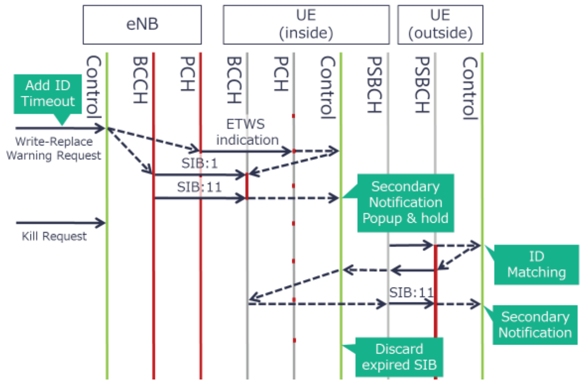

Fig. 7. Sequence for delivering emergency bulletins by the proposed system

IV. Evaluation Experiment

Emergency bulletins can be delivered to UEs outside eNB coverage by integrating ProSe into the ETWS and applying epidemic routing of DTN. We evaluate the improvement of arrival rate and speed of delivery when this proposed method is applied in a disaster area. In order to verify the effectiveness of the proposed method by increasing or decreasing the contact frequency, we compare and evaluate the proposed method using ProSe and the existing method using Wi-Fi Direct, in both cases where the number of UEs is large and where it is small. In addition, in order to verify the effectiveness of our system as a disaster tolerant network system, we evaluate it considering the failure range of eNB.

A. Experimental composition

Evaluation was conducted using the network simulator ns-3 in order to confirm the effectiveness when the proposed system is operated in an affected area. We constructed the topology shown in Fig. 8 and performed a simulation. ProSe is not yet implemented in ns-3. In this experiment, it was decided that propagation loss of packets and collision of packets do not occur. Therefore, we extended the Wi-Fi Direct transmission range to 500m and treated it as a ProSe function. TABLE I shows the simulation parameters.

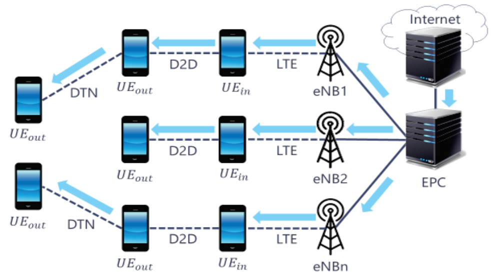

Fig. 8. Network configuration

TABLE I. Simulation parameters

Parameter	Assumption
Transmission speed	4 Mbps
Walking speed	5 km/h
Walk mode	shortest distance to the shelter
Packet size	8 bit * 2block
Simulation time	30 minutes
eNB transmission range	radius 500 m
ProSe transmission range	radius 500 m
Wi-Fi transmission range	radius 100 m

B. Experiment preparation

The assumed target area of this experiment is Hakodate City, Japan. Since this experiment assumes that an earthquake occurs and a tsunami will follow, we conducted an experiment on the Hakodate City neighborhoods of Otemachi, Irifune-cho and Sakae-cho, in the simulator. Fig. 9 shows the arrangement of 23 evacuation centers existing in the vicinity.

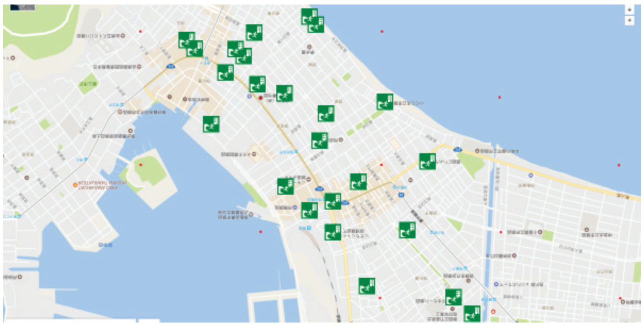

Fig. 9. Location of evacuation centers in Hakodate City

We describe the UE placement method. We arranged 5 UEs at random within a 500 m radius of each evacuation center, and prepared a pattern for 115 UEs in total. In addition, in order to verify the effect of the proposed system in an environment with low population density, we arranged 1 UE at random within a 500 m radius of each evacuation center, and prepared a pattern for 23 UEs in total.

This experiment works on the premise that some eNBs may fail due to large-scale disasters. We describe how those eNBs were arranged and the normal operation of the eNBs. As shown in TABLE I, the transmission range of the eNB is set to 500 m, and the transmission ranges are set in the shape of regular hexagons so as to avoid interference caused by overlap of eNB transmission ranges. Fig. 10 shows the arrangement of the eNB transmission ranges, with radii of 500m, in the area covered in the experiment. It can be seen that eleven eNBs labelled a to k are installed, and the portion colored green is the area within the transmission range of the eNBs. As for the normal operating point of the eNBs, in order to verify the effectiveness of the proposed method, we prepared a case where the eNBs stopped operating sparsely and a case where the eNBs stopped densely. In this experiment, arrangement A and arrangement B are scenarios where the eNBs stopped sparsely, as shown in TABLE II, and arrangement C is prepared as a case where the eNBs stopped densely.

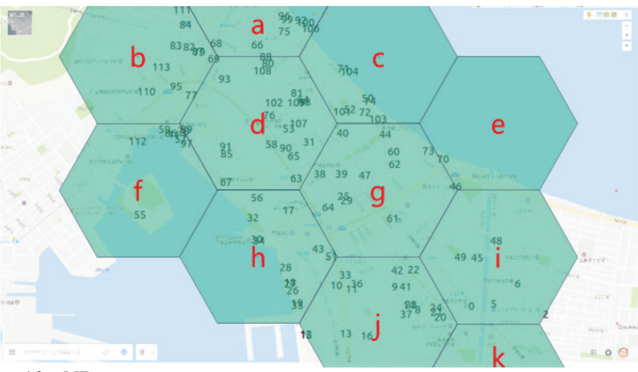

Fig. 10. eNB arrangement

TABLE II. Operating point of eNBs

eNB placement pattern name	Operating point of eNB
Sparsely stopped arrangement A	c, d, h, k
Sparsely stopped arrangement B	a, b, e, f, i, j
Densely stopped arrangement C	a, b, f, k

The mobility model of the UEs in the experiment adopts the walking mode of Google Maps API and moves over the shortest distance to the nearest evacuation center. As a baseline figure, assuming that all UEs received an emergency bulletin, when starting to move to a shelter the time for all UE users to complete evacuation was 20 minutes. According to the Hakodate Municipal Tsunami Evacuation Plan, the first wave arrival time in the experiment area was from 59 to 79 minutes. The first wave arrival time is the time from the occurrence of the earthquake until the peak of the first tsunami wave reaches the coast. Therefore, if it is possible to receive the tsunami warning within 30 minutes of the earthquake occurrence, users can safely be evacuated.

C. Experiment procedure

We assumed a large-scale earthquake and assumed that a tsunami warning would be delivered within 10 minutes after the earthquake occurred. In this experiment, since the tsunami warning was transmitted simultaneously with the start of simulation, the simulation time is set to a maximum of 30 minutes. A UE receiving the tsunami warning moves to the evacuation shelter with the shortest route. The experiment is terminated when the 30 minutes set as the expiration date of the tsunami warning have passed. Alternatively, the experiment is terminated when all UEs have effectively received an emergency bulletin. We evaluated the performance of our proposed system by measuring the reception time and arrival rate of the bulletins, for the UEs that received the tsunami warning within 30 minutes.

Based on the experiment scenario, experiments were carried out on arrangement A to arrangement C using ProSe when the number of UEs was 115, and on arrangement A using ProSe when the number of UEs was 23. Experiments were also carried out on arrangement C and arrangement A to arrangement C using Wi-Fi Direct when 115 UEs were used. In these experiments, the UE arrangement was random, and each experiment was conducted three times.

V. Experimental Results and Discussion

A. Experimental results with ProSe

The results of arrangements A to C when the number of UEs is 115 are shown in Fig. 11. The reception rate of the emergency bulletin delivered by the ETWS in arrangement A was 45%, and the reception rate reached 100% after approximately 7 seconds. The reception rate in arrangement B was 37%, and the rate reached 100% after approximately 5.5 seconds. The reception rate in arrangement C was 23%, reaching 100% after approximately 7 seconds.

The results of arrangements A to C when the number of UEs is 23 are shown in Fig. 12. The reception rate of the emergency bulletin delivered by the ETWS in arrangement A was 33%, and the reception rate reached 97% after approximately 337 seconds. In arrangement B, the reception rate was 40%, and the rate reached 100% after approximately 8.6 seconds. The reception rate in arrangement C was 20%, reaching 96% after approximately 235 seconds.

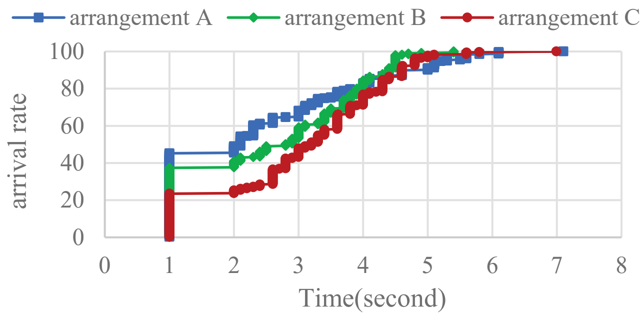

Fig. 11. Results of Experiments with ProSe (115 UEs)

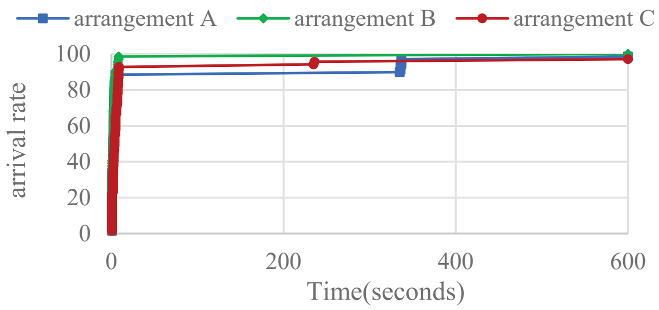

Fig. 12. Results of Experiments with ProSe (23 UEs)

B. Experimental results with Wi-Fi Direct

The results of arrangements A to C when the number of UEs is 115 are shown in Fig. 13. The reception rate of the emergency bulletin delivered by the ETWS in arrangement A was 45%, and the reception rate reached 82% after approximately 1041 seconds. In arrangement B, the reception rate was 37%, and the rate reached 83% after approximately 1040 seconds. The reception rate in arrangement C was 23%, reaching 73% after approximately 1467 seconds.

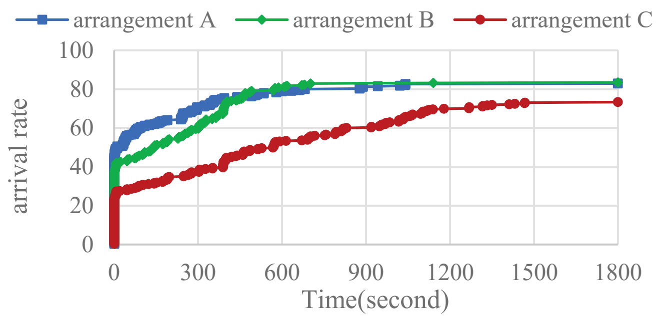

Fig. 13. Results of Experiments with Wi-Fi Direct (115 UEs)

VI. Discussion

As shown in Fig. 11, when ProSe is used, the time taken to reach the highest reception rate is approximately 7 seconds. In the results shown in Fig. 13, using Wi-Fi Direct, the time taken to reach the highest reception rate was 1467 seconds. Therefore, it can be seen that by adding multi-hop communication by ProSe the arrival time of the highest reception rate is shortened and quick delivery is achieved. This is due to the fact that ProSe increases the number of UEs discovered at a time, when compared to Wi-Fi Direct, and fewer messages are exchanged by DTN.

The results shown in Fig. 12 confirm that when the UE retaining the delivery message moves after 200 seconds, the message can be delivered to further away UEs that have not yet received it. Therefore, as DTN is added, asynchronous message delivery becomes possible and the arrival rate is considered to be improved.

As shown in the arrangements A to C, experiments were conducted by changing the fault location of the eNBs in multiple patterns. Even in situations where the population density, represented by 23 UEs per evacuation site, is extremely small, the arrival rate is over 96%, which demonstrates the effectiveness of our system as a disaster-tolerant network system.

VII. Conclusion

We proposed a system that integrates ProSe, which is a D2D technology available on LTE-compliant UEs, into the ETWS broadcast distribution system on the LTE network. Our evaluation revealed that we can deliver emergency bulletins to UEs outside eNB coverage and double the arrival rate up to 100%, and showed the effectiveness of our system as a network system in the case of large-scale disasters. For future work, we will study packet collision problems caused by using ProSe and improve the feasibility of the proposed method.

VIII. Acknowledgments

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