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Smart Home Delay Tolerant Network for an Earthquake Disaster

Raito Matsuzaki[1,a)] Hiroyuki Ebara[1,b)]

Abstract: In a previous paper, we proposed a rescue support system for victims buried in an earthquake disaster by constructing an *ad-hoc* network using home-server smart homes. However, this system has the following two problems: i) it cannot ensure sufficient density of home servers for a WLAN communication range, ii) the system does not consider areas in which home servers cannot be used such as in parks and factories, for example. In this research, we propose a new method using a delay tolerant network (DTN) technique. In this method, rescuers with mobile devices relay information between disconnected networks by walking around during rescue activities. For a performance evaluation, we performed simulation experiments using a map of Abeno-ku, Osaka. From our results, we show that the proposed method increases the information acquisition rate, and the network can be maintained. In addition, we quantitatively show the penetration of the smart home needed for our system.

1. Introduction

In Japan, earthquake disasters are frequent. Problems during an earthquake disaster include communication blackouts and damaged infrastructures which cause traffic jams due to building collapse. Because of these problems, security companies and public institutions such as the fire department, often experience delays in their rescue activities. In the Great Han-Shin Awaji Earthquake, the survival rate within 24 hours was about 75 %, but only 15 % in 72 hours [1]. Making quick rescue activities is essential because the survival rate decreases with the passage of time.

In [2], we proposed a smart home network built with *ad-hoc* networks using home servers for smart homes, and a rescue support system for buried victims by making a rescue request map using this network in an earthquake disaster. The smart home manages various systems in the same way as home servers realizing a comfortable home environment through sensing. In the smart home network, home servers contain a wireless LAN (WLAN) and battery functions. Thus, this network will work even in the case of infrastructure blackouts and outages in the area because each home server forms an *ad-hoc* WLAN network. To use this network, a home server detects the presence of buried victims by information of their presence in collapsed homes and buildings, and sends neighboring home servers this information. Each home server makes a rescue request map based on this information. The rescue request map displays information of victims on the map. In addition, rescuers get this map from near home servers from rescuers with mobile devices. Therefore, we can identify the position of victims and rescue them quickly.

The smart home networking system (we previously devised), however, has a few problems. First, we have to ensure sufficient density of home servers for the WLAN communication range, and introducing this service into rural area is difficult. Therefore, this system is useful only in urban residential areas, and then only with a low penetration. Second, we consider places such as parks, factories, schools, and wide load trucks, not available to home servers. Thus, we proposed to set repeaters to aid communication between home servers in [2], but such repeaters are highly expensive.

In this research, we propose mobile device rescuers that can bring relay information to communicate between disconnected home servers. Mobile devices are introduced as a data exchange method in a delay tolerant network (DTN). The DTN communication system can transfer data with a long delay, but with some confidence even in environments of interruption and disconnection for communication during an earthquake disaster. The 'carry and forward' technique commonly used with DTN can exchange information between nodes. In a smart home network, this technique can relay information among disconnected home server groups because rescuers with mobile devices walk around and obtain information during a rescue activity. In this way, we can solve the problem of communication between disconnected home servers without the repeaters.

2. Delay Tolerant Network

In Epidemic Routing for Partially-Connected *Ad Hoc* Networks [3], techniques have been developed to allow message delivery in cases where a connected path from a source to a destination is not available in mobile *ad-hoc* networks. The authors show that Epidemic Routing achieves eventual delivery of 100 % of messages with reasonable aggregate resource consumption through an implementation in the Monarch simulator. Epidemic routing is generally used with DTN routing such as [4].

1 Kansai University, Yamate, Suita, Osaka 3-3-35, Japan
a) luigilike8rai@yahoo.co.jp
b) ebara@kansai-u.ac.jp

Delay Tolerant Networks (DTNs) [5] [6] are designed to overcome limitations in connectivity due to conditions such as mobility, poor infrastructure, and short-range radios. In fact, there are experimental projects such as the TIER [7] and the KioskNet [8] due to internet connection in sparsely populated areas without communicational infrastructures. However, missed contact opportunities among nodes decrease throughput and increase delay in the network. By using capacity Enhancement with Throwboxes in DTNs [9], the authors of this article have proposed the use of Throwboxes to enhance network capacity in mobile DTNs. Furthermore, this capacity increased the transmission opportunities as well as throughput between nodes. The authors performed an extensive evaluation of their algorithms by varying both the underlying routing and the mobility models.

One type of research about the DTN routing technique is Data Routing for DTN Environments According to Data Size and Deadline [10]. In this research, the authors propose a technique to enable asynchronous communication between two points that cannot be used for infrastructures by the transport of data using a mobile device with which the user can move around. This proposed method uses the carry and forward techniques. In [10] the authors assume that each node introduces a small battery-powered server called an Infobox. Thus, they also assume that the Infobox and the mobile device are narrow-area wireless communication functions (WiFi, Bluetooth etc.), with enough storage, computing power, and memory to run the DTN. The novelty of this study [10], is not only improvement in the data arrival rate and shortening of the communication delay, but also consideration of the data size and the transmission deadline. Because the time a user has to communicate between nodes is limited in a real environment, users are not able to exchange all the data in time. Therefore mobile devices change the priority of the data to be sent by importance of data. This proposed method [10] can send and receive the higher value data and improve performance. In this proposed method, the authors performed simulation experiments in the Manhattan area. They show that the data arrival rate that considers the importance of data is higher than in other methods.

3. Smart Home Network with Delay Tolerant

In this section we give an overview of the smart home network and rescue support system, and propose a new method to improve connection in the smart home network. For more information about the smart home network and rescue support system, see [2].

3.1 Overview of Smart Home Network

In the smart home network, the home server operates a smart home system in the case of normal (non-emergency situations), and constructs *ad-hoc* networks by wireless functions between neighboring home servers in the case of a disaster. The smart home system shown **Figure 1** represents a system that realizes a secure home environment in terms of monitoring, consumer electronics operations by sensing, and security.

The smart home network uses Earthquake Early Warning (EEW) that exists in 2 types [11]. One type is for advanced users and another is for the general public. We use both EEWs in the smart home network, and we call the EEW for advanced users the first EEW, and the second type for the general public, the second EEW.

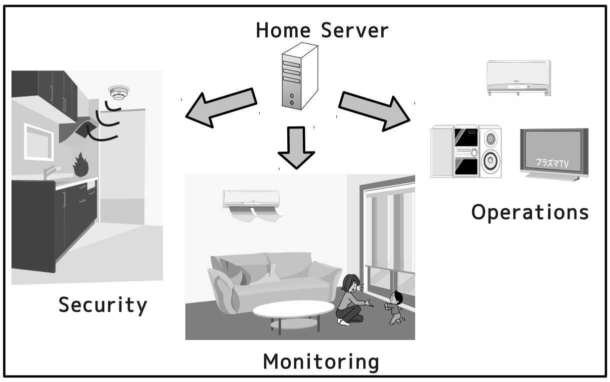

Fig. 1 Example of services by the smart home

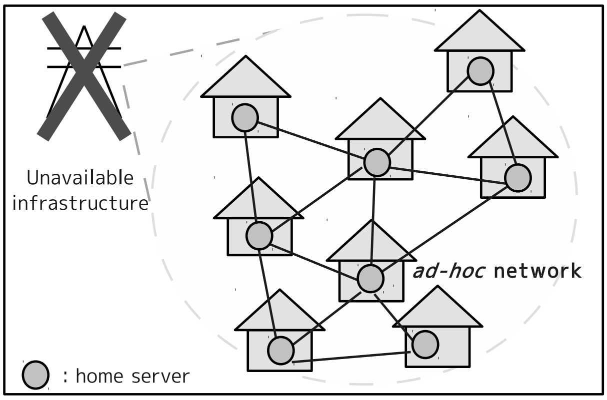

Fig. 2 Construction of *Ad-hoc* networks

We describe the behavior the smart home network in an earthquake disaster. Receiving the first EEW, each home server checks connections between neighboring home servers. Receiving the second EEW, each home server sends and shares information (such as home rescue etc.) using infrastructures such as the Internet. When a blackout occurs after an earthquake, each home server connects and communicates with neighboring home servers to maintain the system, as shown in **Figure 2**. Thus, each home server needs a battery to run the system while electricity supply stops.

3.2 Overview of the Rescue Support System

It is very important for rescuers to rescue buried victims in an earthquake. However, such rescue operations to identify the location of buried victims are often difficult. In fact, the way rescuers now often find victims is by hearing the rescuers when they call for help. In this research, home servers create a rescue request map to quickly identify the location of buried victims.

The type of information needed to create a rescue request map is as follows:

- Rescue request information - a direct rescue request
- Home information - the number of people in a home
- Information of various sensors - the sensing signals of several sensors in the smart home system
- Information of disconnected home servers - home servers disconnected from the network by some abnormal reason

Table 1 The amount of data needed to create a rescue request map

information	amounts [bit]
rescue request information	1
home information	4
information of various sensors	7
complete rescue information	1
coordinate information	51

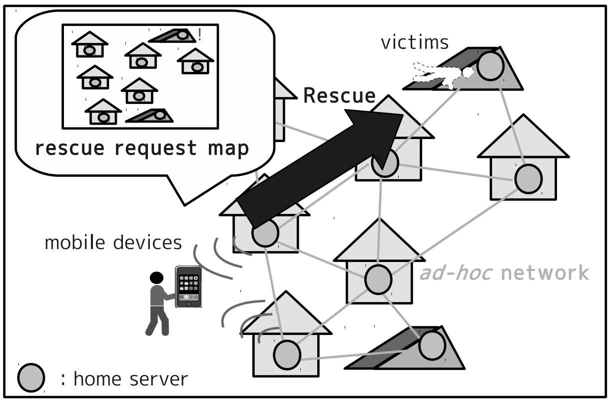

Fig. 3 Getting a rescue request map

emergencies, for example

- Complete rescue information - information to be sent by mobile devices after the rescuer rescues the victim
- Coordinate information - positional information of the home server

Deciding the amount of data for each piece of information needed to create a rescue request map is necessary. In **Table 1** we show the amount of data needed to create a rescue request map. Rescue request information and complete rescue information need 1 bit (switching ON/OFF); home information needs 4 bits because the number of people in home is usually less than 15. The information about various sensors requires up to 7 bits, which can be used for up to 7 sensors. Coordinate information requires 51 bits because of GPS information. The longitude is 25 bits, and the latitude is 26 bits in the coordinate information. From Table 1, we assume the information required to create a rescue request map that needs at the minimum 8 Bytes.

We describe next how a home server creates a rescue request map. Home servers send information to create a rescue request map to each other, and share this information. Based on this information, each home server creates a rescue request map, and checks connections between neighboring home servers. If a home server updates information or receives new information, the home server sends it to a neighboring home server. The home server doesn't send duplicated information. The rescuer with mobile devices can get a rescue request map from the home servers, as shown in **Figure 3**.

3.3 Mobile Device Relay

To achieve the smart home network, we should consider two major problems. First, because the communication range of WLAN is small, the home server cannot connect to neighboring home servers. Second, cities have large areas such as mentioned before in which the home server cannot be used. Not putting a home server in these areas, causes several small home server groups. These problems cause a reduction in the connection rate

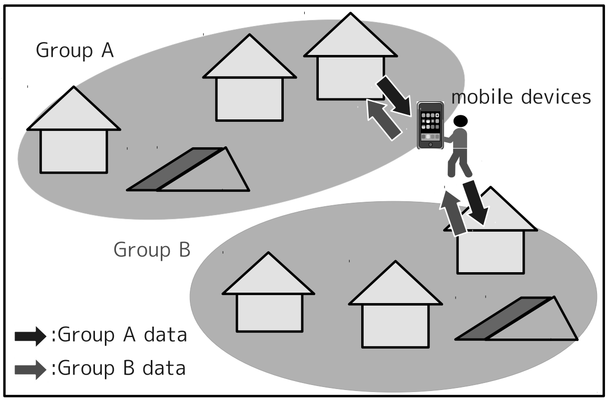

Fig. 4 Example of the mobile device relay

if the smart home network is introduced. Therefore, we propose the mobile device relay to communicate between disconnected home servers in the smart home network, as shown **Figure 4**. Mobile devices have a data exchange method used in DTN, called a 'carry and forward' technique, so mobile devices can save information to create a rescue request MAP and pass it to other home servers. If a rescuer with mobile devices gets information to create a rescue request map from one home server group and moves to another home server group, the mobile devices can communicate with the home server group and share information between home server groups.

We propose an algorithm for sending and receiving information of a rescue request map for the proposed method as follows:

Step1) When the rescuer with a mobile device moves with in the communication range of a home server, the mobile device sends rescue request map information to the home server.

Step2) If information the home server receives is new, the home server obtains this information.

Step3) If the home server has information the mobile devices do not have, the home server sends this information to the mobile device.

3.4 Assumptions necessary for Achieving the Proposed Method

To achieve the proposed method, it is necessary to consider several assumptions, described below.

3.4.1 Home Server

The home server has several functions in the smart home network as follows:

- Each home server has WLAN (IEEE 802.11) communications.
- Each home server can save all information to create a rescue request map.
- Each home server sends the differences in information to create a rescue request map.
- Each home server broadcasts between home servers, and broadcasts to mobile devices.

3.4.2 Mobile device

The mobile device of a rescuer has several functions as follows:

- Each mobile device has WLAN (IEEE 802.11) communications.

- Each mobile device gets information to create a rescue request map once.
- Each mobile device broadcasts to home servers (No transportable mobile devices).

The carry and forward technique needs to set a transmission deadline to avoid network congestion and waste of bandwidth. Nonetheless, rescuers with mobile devices do not discard information to create a rescue request map during the rescue activity. In addition, the size of information to create a rescue request map is small because it is less than the multiplication value of 8 Bytes by the number of home servers sharing information. Therefore, we do not need to worry about the transmission deadline for information to create a rescue request map, but only need to update new information sent to the home server.

In our proposed method, the mobile device can communicate with home servers, but cannot communicate with other mobile devices, called message passing communication. Using passing communication, mobile devices must always have an active communication function, which wastes the battery. Therefore, we assume that the mobile device only communicates with home servers.

3.4.3 Battery

When a large earthquake occurs, electricity supply is stopped because of damage to infrastructure functioning. Because the home server needs to supply it's own power, the home server has a large battery, or private power generation such as solar power. In addition, the home server is required to work for a minimum of three days. The sensor in the smart home and in the mobile device also needs to have enough battery to last for three days. We think, however, that battery capacity will increase through future technological development. Thus, we assume home servers, sensors, and mobile devices will have enough power supply to achieve the proposed method.

3.4.4 Movement of Rescuer

We assume rescuers move anywhere in areas in our simulation. Rescuers move freely in areas when mobile devices do not get the position of the victim. In our research, we assume that the free action of the rescuer follows a self-avoiding random walk [12] [13]. However, we propose that rescuers move a random distance up to one-tenth of the map in the same direction; otherwise, the random walk would be stuck in one place. When the mobile device gets the position of the victim, a rescuer can move there. If rescuers finish the rescue by finding the victims, then the rescuers can move freely again.

3.4.5 Communication Range of Home Server and Mobile Device

In our research, we assume that the communication range of the home servers and mobile devices is the same. We also assume that the communication range is equal in a circle. We assume that the communication range for WLAN is up to 30 m because we measured this range in [2].

4. Performance Evaluation

To show the effectiveness of the proposed method, we performed simulation experiments on an actual map. The simulator is implemented in Java.

Table 2 Parameters in simulations

items	parameters
simulation area	Osaka Abeno-ku
simulation range	1 km^2
communication protocol	WLAN (IEEE 802.11)
communication range	15 m and 30 m
the number of households	8000
simulation time	15 minutes - 2 hours
measurement range (arrival rate)	300 m

Fig. 5 Map of simulation area in Abeno-ku

4.1 Setting of Simulations

Table 2 shows the parameters in our simulations. We assume the simulation model is the residential area of Abeno-ku, Osaka, and the simulation area is within the range of 1 km square. The map of the simulation area is from the Geographical Survey Institute (GSI) [14]. The location of the home servers and the communication range are with respect to pixels*1. The number of households in the simulation area is obtained from the number of households divided by the area of Abeno-ku. The penetration rate is obtained from the number of home server installations divided by the number of households in the simulation area.

Figure 5 shows the actual map of the simulations. The map is divided in monochrome by residential areas and not residential areas (home servers can be installed in the white spaces, but not in the black). The black areas represent places such as parks and factories as mentioned previously.

We simulate the information acquisition rate each of home servers and mobile devices in a simulation area. The information acquisition rate shows the rate of the information which the home server can get from others. We also simulate the arrival rate of a home server information in this area. This rate is the information acquisition rate measured the certain range with a focus on a home server, and this is because home servers should communicate in a narrow range to avoid large amount of information. We assume the certain range (the measurement range) is 300 m from preliminary experiments, as shown Table 2. Note that both the communication range and the measurement range are radiuses of a circle. If a mobile device communicates between disconnected home servers, both of the rates are added. In the simulation, the information acquisition rate for one home server (a single rate) is obtained from the number of other home server information divided by the number of households. The arrival rate for a single rate is obtained from the number of other home server information divided by the number of home servers in the measurement range. Then, we obtain the information acquisition rate and the arrival rate by taking average of a single rate in all home servers.

*1 Range of 1 pixel is 1.2 m (speed of people).

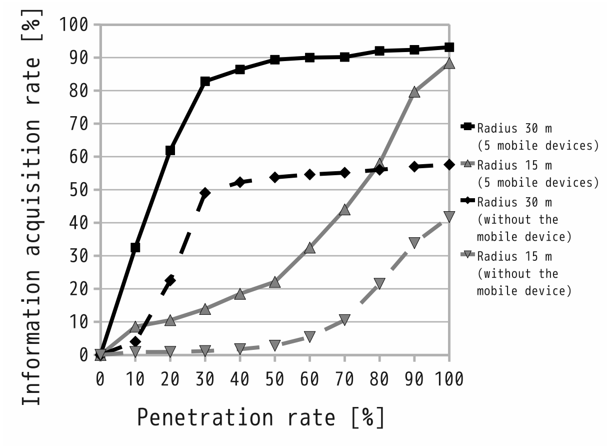

Fig. 6 Characteristics of the information acquisition rate for the home servers

We do the simulation a hundred times, and then take the average.

4.2 Results of Simulations

We describe the simulation results about the information acquisition rate for home servers and mobile devices. Moreover, we also describe the result about the arrival rate of the home server information.

Figure 6 shows the information acquisition rate for home servers in the smart home network. The horizontal axis represents the penetration rate, and the vertical axis the information acquisition rate. The result of no mobile devices measures only the home server, which is the connection rate (the connection rate is obtained from the maximum number of home servers connected to each other divided by the number of households). The result of 5 mobile devices is due to the proposed method. In the proposed method, the number of rescuers is 5 and simulation time is 1 hour. From Figure 6, we can see that the information acquisition rate (the connection rate) without the mobile device for both 15 m and 30 m was less than 60 % even if the penetration rate was 100 %. Because the area in which home servers cannot be put is too large, several small home server groups are needed for this area. However, the information acquisition rate of the proposed method (with 5 mobile devices) is significantly improved compared to without the mobile device. Moreover, this system needs about a 50 % penetration rate to get over a 90 % connection rate in a communication range of 30 m for each 1 hour.

Figure 7 and **Figure 8** shows the information acquisition rate of the mobile device relay for both home servers and mobile devices in the smart home network. The horizontal axis represents the simulation time, and the vertical axis the information acquisition rate. We simulate the penetration rate of the home server as 50 % and the communication range as 30 m, and simulation time is 2 hour. From both Figure 7 and Figure 8, the more the simulation time increases, the more information acquisition rates increase. Especially, the result of both 7 and 9 mobile devices is over a 95 % within 1 hour, we consider this value is enough to maintain the smart home network.

Figure 9 shows the arrival rate for the home server information in the certain range with a focus on a home server as 300 m. The horizontal axis represents the simulation time, and the vertical axis the arrival rate. We simulate the penetration rate of the home server as 50 %, and simulation time is 1 hour. From Figure 9, the more the simulation time increases, the more arrival rates approach 100 % in a communication range of 30 m within 1 hour. Moreover, the larger the number of mobile devices, the earlier arrival rates approach 100 %.

The connection rate, therefore, is improved by our proposed method especially with in the communication range of 30 m. In

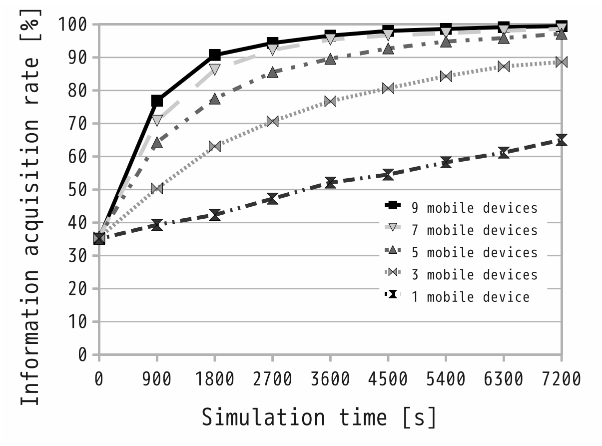

Fig. 7 Characteristics of the information acquisition rate for home servers by the simulation time.

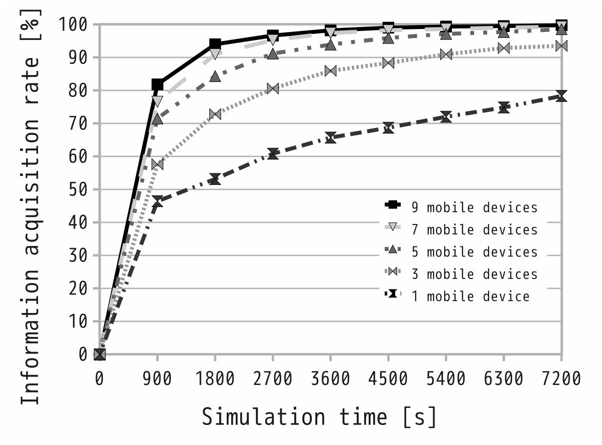

Fig. 8 Characteristics of the information acquisition rate for mobile devices by the simulation time.

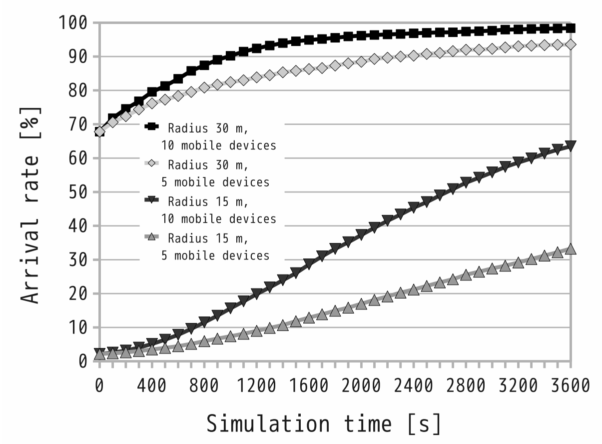

Fig. 9 Characteristics of the arrival rate for the home server information.

this range we showed a performance good enough to provide the system with connection rate of at least 90 %. We simulated the communication rate equally in a circle. However, we need to consider that the communication range isn't equal in a circle because of the difference in height of the terrain and the placement of obstacles in reality.

5. Conclusion

It is very important for victims to be rescued within 72 hours because this is generally how long victims can survive without help. To do this, rescuers must identify the location of buried victims. We proposed a rescue support system that creates a rescue request map. In our research, we proposed a method for a mobile device relay to communicate between disconnected home servers in the smart home network during an earthquake disaster. We showed that our proposed method is effective by performing an evaluation of the information acquisition rate.

We are currently implementing a communication environment to achieve a smart home network and a rescue support system.

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