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Reduction of communication demand under disaster congestion using control to change human communication behavior without direct restriction

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ABSTRACT

When a disaster strikes, many people make calls to their loved ones in the affected area. As a result, telephone networks become congested, making it difficult for people to contact each other. This congestion continues in the aftermath of a large-scale disaster. The sooner the congestion is eased, the sooner and easier people can contact each other. We accomplish this by reducing communication demand without directly restricting call duration. We propose a congestion control method, called the road space rationing (RSR) method (RSR was originally designed for transportation and restricts access to congested areas on the basis of the last digit of a vehicle's license plate or license number). Our RSR method only restricts the period in which to make a call on the basis of the last digits of calling parties' phone numbers (e.g., only people with phone numbers ending in 1 can make calls between XX:06 and XX:12). It not only avoids restricting the overall number of calling parties but also prompts people to reduce their call duration consciously despite it being unrestricted. It thus has a mechanism to change human communication behavior without directly restricting call duration. This consciously willed reduction is effective against disaster congestion because there are no redials to the same called parties. This reduction in call duration in turn decreases congestion. Experimental results revealed that the RSR method reduced call duration by 30%.

1. Introduction

When a large-scale disaster occurs, such as a massive earthquake, people call their friends and family in the disaster-affected area out of concern for their safety. Thus, calls over the telephone network are suddenly concentrated in the disaster-affected area. Such an abundance of calls easily overloads the network in that area. For example, NTT Docomo, which is the predominant mobile phone operator in Japan, estimated that 60 and 40 times the normal numbers of outgoing and incoming calls, respectively, were generated in the Tohoku area (the most devastated area) in the aftermath of the Great East Japan Earthquake in 2011 than around the same time on an ordinary day [1]. We have only these estimated numbers because direct measurement is impossible. Additionally, approximately 50 times as many calls as normal were directed to Niigata Prefecture from all over Japan just after the Chuetsu Earthquake in 2004 [2]. Similarly, approximately 50 times as many calls as normal in the busiest hour of the day (peak hour) on an ordinary day were directed to the Kobe area just after the Great Hanshin-Awaji Earthquake in 1995 [2,3].

Communication media, especially telephone calls, do not function satisfactorily for people in the aftermath of a disaster. A survey [4] given around March 14 in the immediate aftermath of the Great East Japan Earthquake showed that approximately 55% of respondents in four quake-hit prefectures (Iwate, Miyagi, Fukushima, and Ibaraki) and approximately 41% of respondents in the Kanto region (Tokyo, Kanagawa, Saitama, Chiba, Ibaraki, Gunma, and Tochigi) stated that they were unable to make phone contact at all.

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Although there are other communication media e.g., e-mail, web, social network services (SNSs), and services for the aftermath of a disaster such as the disaster emergency message service [5] and posting and reading message services [6], most people still prefer to make voice calls from fixed, mobile, and public phones and Internet telephony. The above survey [4] found that 74% of the first attempt media were voice calls even though 56% of respondents usually used e-mail more than voice calls in daily life while only 36% of respondents usually used voice calls more than e-mail.

Recovery is the most important task during this time [7] because even robust and reliable networks suffer damage; however, countermeasures against disaster congestion are important as well. Many methods have been proposed for improving the call completion ratio of voice calls in the aftermath of a disaster. They are roughly classified into four classes: restriction of demand (limitation of call attempts [8,9], limitation of call holding time (call duration) [10]), increase in available network resources by load balancing [11,12], and provision of alternative services.

Limitation of call attempts [8,9] enables us to use network resources efficiently because even unsuccessful calls consume network resources, for example, by undergoing signal processing. This limitation prevents ineffective call attempts from wastefully consuming these resources. Call gapping control [8] and call density control [9] effectively improve efficiency of public switched telephone networks; however, they are not sufficient countermeasures against disaster congestion.

Limitation of call duration [10] reduces the call attempt blocking rate. As a result, the call completion rate improves. Whether or not the dynamic holding time limit (DHTL) method [10] should be used practically was discussed in the study group on maintaining communication capabilities during major natural disasters and other emergency situations in the Ministry of Internal Affairs and Communications of Japan [1]. The group's final report [1] states that the DHTL method is seen as an effective countermeasure against congestion. However, it is not practical because terminating a connection would produce repeated call attempts [13], which wastefully consume resources.

Increase in available network resources by load balancing is possible thanks to Internet technology. Generally, a disaster does not strike nationwide but in parts of an area. Even the 9.0 magnitude Great East Japan Earthquake did not affect west Japan. Satoh and Ashitagawa [11] and Satoh et al. [12] proposed a network design to use network resources in non-damaged areas for communication demand in damaged areas by allocating users who are almost evenly located around the country to each session initiate protocol (SIP) server by using subscriber extension numbers. This user allocation enhances the capacity of SIP servers for the entire network by using multiple SIP servers in various locations and by not overusing the SIP server(s) located in the disaster area. However, this design is effective in only a SIP network that uses telephone numbers with area codes, i.e., landlines.

Provision of alternative services eases voice call congestion. Such services are classified into ordinary services and services for disasters only. The former includes e-mail services and social networking services (SNSs). The latter includes Disaster Emergency Message Dial (171) [5,14], Disaster Emergency Message Board (web171) [6,15], and a disaster status confirmation service [16]. These alternative services are beneficial; however, a considerable number of people still want to communicate verbally with their loved ones. The abovementioned survey [4] found that 60% of those who continued to make calls even under very high call blocking rates answered that they wanted to communicate verbally with their loved ones.

Kaneda et al. [17,18] proposed sending guidance messages to wait, change the communication medium, and move when there is a massive number of connection requests to a cellular network system. This method provides options for people to change their communication behavior, which is effective against voice call congestion (the other methods explained in the previous paragraphs have no such feature). However, it has no mechanism to change people's communication behavior; it only sends guidance messages. Those who receive the messages decide whether to change their behavior themselves. Thus, such a mechanism is required.

Network pricing [19] regarding congestion control may be effective. However, it is not appropriate as a mechanism to change people's behavior in the aftermath of a disaster because we believe that network pricing would be unethical to implement in such a situation.

There have been few studies on mechanisms other than the pricing schemes for a disaster or ordinary situation. Niida et al. [20] proposed a concept that allows people to choose an appropriate network by visualizing network usage history. Their mechanism to change people's behavior is an application for smartphones that visualizes network usage history through entertaining content, such as video games. Their field studies found that 28% of participants changed their behavior. We believe that changing people's behavior is an effective countermeasure against disaster congestion. It must also be more effective in a disaster situation than in an ordinary situation.

We focus on a countermeasure against voice call congestion because a considerable number of people will still want to communicate verbally with their loved ones. Our goal is to propose a method to change people's behavior to reduce call duration without repeated call attempts. The proposed method does not restrict call duration but blocks call attempts, i.e., it does not compel people to reduce their call duration. Directly controlling call attempts enables us to indirectly control call duration; people willingly reduce their call duration demand.

The rest of this paper is structured as follows. Section 2 presents our countermeasure method against disaster congestion. Section 3 discusses a survey we conducted to investigate willed reduction in communication demand from users, and Section 4 explains the experiments we conducted to investigate it. Section 5 shows the results on conscious reduction of the call duration demand, and Section 6 shows the results on the rate of repeated calls. Section 7 discusses the results and practical application of the proposed method. Finally, Section 8 concludes the paper with a summary.

2. Congestion control method by applying road space rationing

As stated in Section 1, there are problems with the conventional and existing countermeasures against disaster congestion. People have difficulty in contacting others through phone calls due to blocking of call attempts. Load balancing by using subscriber extension numbers is applied to only a SIP network that uses telephone numbers with area codes. Terminating a connection would produce repeated call attempts [13] although it is effective and applicable to any kind of voice call network.

Our method reduces call duration demand without incurring repeated call attempts. Reducing such demand is effective against disaster congestion because the network resource supply is difficult to increase. Reduction in call duration can moderately mitigate congestion sooner.

We propose a method for restricting the number of people making calls that involves assigning a group of users a specific time within a certain period (e.g., one hour) in which to make calls. To ensure that each group has the same number of users and that the locations of the users in a group are uniformly distributed, we use the last digits of subscribers' phone numbers to divide them into groups [12]. Users can answer the phone anytime but can call only in their assigned period. Call duration is not re-