Analysis of and Proposal for a Disaster Information Network from Experience of the Great East Japan Earthquake

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ABSTRACT

Recently serious natural disasters such as earthquakes, tsunamis, typhoons, and hurricanes have occurred at many places around the world. The East Japan Great Earthquake on March 11, 2011 had more than 19,000 victims and destroyed a huge number of houses, buildings, loads, and seaports over the wide area of Northern Japan. Information networks and systems and electric power lines were also severely damaged by the great tsunami. Functions such as the highly developed information society, and residents' safety and trust were completely lost. Thus, through the lessons from this great earthquake, a more robust and resilient information network has become one of the significant subjects. In this article, our information network recovery activity in the aftermath of the East Japan Great Earthquake is described. Then the problems of current information network systems are analyzed to improve our disaster information network and system through our network recovery activity. Finally we suggest the systems and functions required for future large-scale disasters.

INTRODUCTION

The East Japan Great Earthquake on March 11, 2011 caused severe damage across the wide area of Northern Japan. A massive 9.0 earthquake destroyed a huge number of buildings and enormous amounts of equipment, and the devastating tsunami, more than 15 m , swept over cities, towns, villages, and coastal residential areas in the northern part of the country, as shown in Fig. 1. This tragedy shocked the world, and the numbers of about 15,841 dead and 3490 missing persons are still increasing today [1].

Many Japanese coastal residential areas were also geologically isolated [2]. The communication networks such as Internet, cellular phones, and fixed phones could not be used after the huge shakes. Furthermore, there was a widespread blackout over northern and central Japan [3, 4]. The loss of the ability to transmit disaster information caused delay in rescuing victims, conducting people to shelters, confirming safe resident evacuation and urgent medical treatment just after the disaster. In order to quickly recover the information infrastructure of several local government offices and evaluation offices in the disaster areas, our disaster volunteer team, which was made up of our network research laboratory students at Iwate Prefectural University, went out to the disaster area. Through the our recovery activity, we were able to find serious problems with the information network and system in the coastal areas, and we learned that a new robust and resilient communications method was strongly required to transport significant information even when severe disasters occur.

In the following, the scale of the Great East Japan Earthquake is explained. Next, our disaster information network recovery activities in several of the disaster areas are shown. Then, through a posteriori investigation in the disaster areas, the problems of information network methods in disasters are precisely discussed. After that, effective means of communication during disasters are discussed.

EAST JAPAN GREAT EARTHQUAKE AND TSUNAMI

In the history of of major earthquakes in world history, the Great East Japan Earthquake was the fourth largest earthquake, following the Great Chile Earthquake in 1960 (M9.5), Great Alaskan Earthquake in 1964 (M9.2), and Indian Ocean Earthquake and Tsunami in 2004 (M9.1) [5], as summarized in Table 1. Moreover, this large-scale earthquake also brought serious secondary disasters such as blackout, fire, nuclear crisis, and electrical power supply failure.

The disabling of information network systems also brought many serious problems over a wide area of Japan, such as the isolation of damaged cities, lack of communication means, and delay of rescue. Compared to recent historical severe earthquakes in Japan, such as the Hanshin-Awaji Great Earthquake in 1995 and Chuetsu Earth-

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quake in 2004, there were many different problems because lifestyles have been dramatically changed by the recent highly developed information society. Since cellular phone services have greatly increased over one decade, the damage and congestion of cellular phones caused serious problems for rescue activity, resident safety confirmation, food distribution, and medical treatment. The lack of disaster information is considered a main reason for these delayed activities. Moreover, the lack of fuel and electricity also caused the delay of rescue and support activities for the evacuators.

Information Network Recovery Activity

The authors' volunteer team was organized mainly by the graduate and undergraduate students in our research laboratory of Iwate Prefectural University for supporting evacuated local governmental offices and residents in the coastal areas just after the disaster in order to recover information networks and support residential lives in the evacuation shelters. They were well trained for reconstructing information networks, and setting client PCs and server systems to connect to the Internet using wired and wireless LANs, mobile 3G routers, and satellite IP network devices as shown in Fig. 2.

Even after a week after the earthquake, there was still less information on the coastal side of Iwate prefecture at that time. Tragic tsunami news were aired repeatedly, but there was a lack of information about many residential lives and damage in the area because phone, Internet, or email communication could not perform their functions in the coastal cities.

In our volunteers' activities, many problems had to be overcome to reach the severely damaged area. First of all, it was difficult to obtain gas for our truck. A lack of fuel, including gas and heating oil, had spread throughout northern and middle Japan, and the lines of cars waiting for gas became over 3 km long around our university. Thus, we spent one week obtaining fuel for our truck to go out to the disaster areas.

Second, sudden lower temperature froze mountain roads. Our university is located in the middle of Iwate prefecture, and it is about 100 km away from the coast. However, our truck had to cross over a mountain pass to get there, and the frozen road made it very difficult for many rescue vehicles to reach the disaster areas. Thus, the lack of gas and frozen roads delayed our rescue activities on the coast.

One week after the disaster, our volunteers could reach Miyako city, to participate in the activities conducted by the self-defense force at the tragic disaster scene. Our volunteer members could quickly recover the information network infrastructure in the local government offices and evacuation shelters in various cities. Particularly, our laboratory students could work well on setting up network devices and servers to connect to the Internet in the tragic disaster scene, although some of our students suffered from post traumatic stress disorder after going back home.

Figure 1. *The East Japan Great Earthquake in Iwate Prefecture, Japan.*

Year	Disaster	Magnitude	Fatalities
1960	Great Chile Earthquake in 1960	9.5	2231
1964	Great Alaskan Earthquake	9.2	131
2004	2004 Indian Ocean Earthquake and Tsunami (off the west coast of northern Sumatra)	9.1	220,000~
2011	Japan Earthquake and Tsunami	9.0	Dead 15,841 Missing 3490 (12 21, 2011)
1952	Kamchatka Earthquake	9.0	0
2010	Great Chile Earthquake in 2010	8.8	525
1906	Ecuador-Colombia Earthquake	8.8	1000
1965	Rat Islands Earthquake, Alaska	8.7	0
2005	2005 Sumatra Earthquake, Indonesia	8.6	1346

Table 1. *Large-scale earthquakes in the world.*

Through the recovery activities, we found and encountered many problems with information network infrastructure in disaster areas. The main problems of our network relief activities in disaster areas are:

- Fuel shortage for cars delayed the rescue activity.
- Electricity power supply and batteries for information network systems were damaged.
- Network devices and servers were damaged.
- Wired networks were completely disconnected.
- The cellular phone system was damaged and congested.
- The Government Disaster Radio System broke down

Figure 2. *Network recovery by Iwate Prefectural University students.*

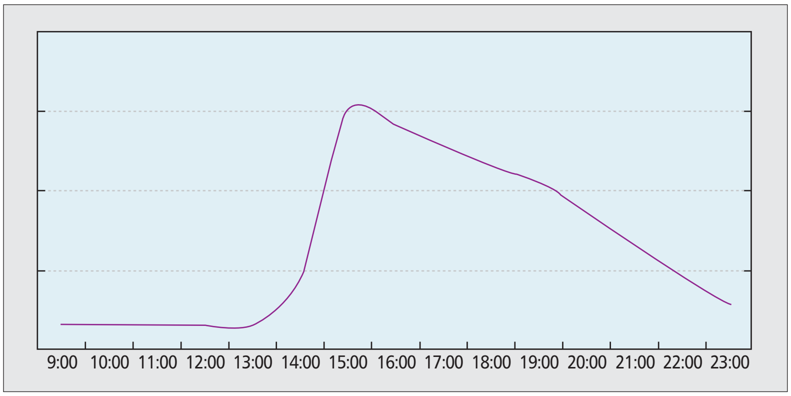

Figure 3. *The numbers of calls by cellular phone on March 11, 2011 in Northern Japan.*

- TV broadcasting could not be watched.
- Resident safety information and disaster information were reported only by handwritten papers at many evacuation shelters.

These problems should be precisely investigated and analyzed to improve the current disaster information system.

Problems of Information Network Means on Disaster

The East Japan Great Earthquake caused many problems such as rescue, food distribution, and evacuation responses. Malfunction of information network systems was a part of major problems after the earthquake. In particular, the lack of disaster information such as the safety of evaluated residents, damage scale and degree of houses, buildings, lands, roads, bridges, seaports, and so on brought much confusion to various activities. Table 2 is a summary of various information networks and their functional conditions in Iwate Prefecture obtained through our network recovery activities.

Cellular Phones

One of the main problems of information network systems was traffic congestion due to the rapid traffic generation of the cellular phone system. According to the Ministry of Internal Affairs and Communication, the numbers of call requests on cellular phones just after the earthquake were more than 10 times larger than the usual case, and the maximum call control ratio of voice communication went up to 95 percent, which means that only one person out of 20 people could use phone service [6].

In the northern part of Japan, heavily damaged by the earthquake, the congestion in the cellular phone system was severely heavy. The numbers of call requests went to about eight times larger than the usual case, and the maximum congestion time was about 30 min just after the earthquake as shown in Fig. 3.

Thus, cellular phone services were not available for a long time after the earthquake and caused serious communication problems in a wide area of Japan. As a result, not only the damage of network devices but also the congestion of cellular phones are considered as the reasons the serious lack of disaster information, such as about rescues, evacuation shelter, and safety information occurred.

Moreover, in the disaster area such as the coastal area of Iwate prefecture, many wired networks and servers of the telecommunication companies were broken down by the huge tsunami. Therefore, fixed phone, broadband Internet services, and even the local government network system were out of service. The public web services and email systems in the Iwate prefectural office as the countermeasures headquarters were also down. This failure caused serious informatics isolation of the coastal cities in Iwate prefecture.

Satellite IP Network

On the other hand, some information network systems were considered useful in disaster areas. In our network recovery activities on the coast of Iwate prefecture, satellite systems for Internet such as IPSTAR and wireless LANs functioned well for reactivating the network communication systems. Although there were problems with lack of electricity, both systems were used to quickly reactivate in some evacuation shelters and disaster countermeasure headquarters.

Wireless LANs

Although a satellite system does not have higher speed than a broadband network service such as fiber to the home (FTTH), the main traffic on the Internet under the emergency situation information was text-based contents such as email, web-based resident safety information, and social network systems (SNS). Therefore, a satellite system was practically useful even in such an emergency situation because this system could be used anywhere, even disaster areas, with portable power supply. Wireless LAN also worked practically for temporal network reconstruction since the inside of public buildings such as local governmental offices were damaged by the disaster.

Radio Broadcasting

Radio broadcasting, especially local community FM broadcasting, was very useful. Since most of the evacuation shelters and offices did not have electricity just after disaster, radio broadcasting was the only way to obtain local disaster information. Community FM stations could broadcast the required information specific for the evacuators in the disaster areas such as residential safety information of families, medical and hospital information, food distribution information, and local administrative information, while major radio stations broadcasted more general disaster information such as lifeline information and transportation information in the wide areas.

Internet

The Internet was used in various ways for many activities in the Great East Japan Earthquake. Although the Internet utilization rate was 74.7 percent before the earthquake in northern Japan, the rate greatly decreased to about 20 percent just after the earthquake. This was because many Internet services in Northern Japan were unavailable due to the damage and congestion of the information networks. Then it took about from one to two weeks to reactivate temporal network services around Morioka, Iwate prefecture, Japan.

Since most of the temporary houses for evacuators were located on the mountainside, Internet services were not originally provided. Therefore, temporal communication cabling was needed to construct network infrastructure for the area. There were many temporal housing areas where Internet service by wired networks such as FTTH were not available even after several months. However, a satellite network and fixed wireless access (FWA) were installed for those areas supported by the Ministry of Internal Affairs and Communications.

Local Government Office Networks

The Iwate Information Highway, which was a wired backbone information infrastructure in Iwate prefecture and connected all of the local government offices in the cities, towns, and villages in Iwate prefecture, was severely damaged by the earthquake. The local government office networks of the cities and towns in the coastal areas were also completely damaged by the tsunami. They reconstructed temporal LANs to communicate with the countermeasure headquarters in the prefectural office and inside organizations such as fire stations, schools, hospitals, and road surveillance offices. Moreover, since most information servers of the local governments were damaged, disaster information was not available to the residents of Iwate prefecture. Therefore, they used the Internet to share disaster information through blogs and SNS a couple of days after the earthquake.

System	Conditions	Details
Radio broadcasting	○	Local community FM stations functioned particularly well.
TV broadcasting	×	Cannot be watched due to widespread blackout.
Fixed phone	×	Line disconnection and damaged central office and remote electronics
Cellular phone (voice)	×	Traffic congestion and damaged base stations
Internet (wired, wireless, and mobile networks)	△	Worked depending on communication lines
Local government information supper highway	×	Line disconnection, power supply failure, and damaged network devices
LANs in local government office	×	Line disconnection and damaged network devices.
Local government radio system for disaster	△	Damaged base stations and relay stations
Personal analog radio communication	○	Worked well between licensed users
WLAN and FWA	○	Quickly recovered information infrastructure after disaster
Satellite IP system (Internet)	○	Quickly recovered information infrastructure after disaster

Table 2. *Large-scale earthquakes in the world.*

Medical and Disaster Volunteers Networks

Medical organizations also used the Internet for temporal communication between local and central hospitals. Not only evacuation shelters. but also all local hospitals and central hospitals were disconnected from communication in Iwate prefecture just after the earthquake; then temporal LANs were quickly constructed between shelters, local hospitals, and central hospitals to enable use of the Internet.

Disaster volunteers used the Internet as the communication means for their various activities. They shared disaster information by SNS, disclosing the evacuated residents lists on each evacuation shelter by web broadcasts and confirming road conditions by a GIS map. Compared to the case of other previous Japanese earthquakes, there were many new trials using the Internet by the disaster volunteers on the earthquake. Because of the recent developments in information and communication technology such as smart phones, tablet terminals, wireless broadband services, web services, and SNS, were well functional. Thus, the Internet is expected to perform more important role as communication tools not only in normal state but also in emergent state.

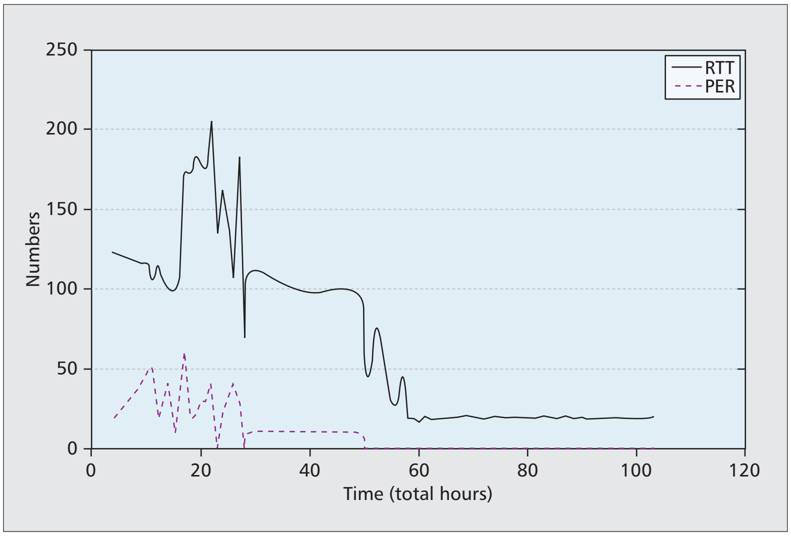

Figure 4. *Network conditions in IPU under disaster.*

Effective Communications Means in a Disaster

Although there have been many problems regarding the information network and system by the Great East Japan Earthquake, some communication means could effectively work in practice to reactivate the temporal network. This could be important for future studies of disaster information systems. The main useful network systems through our network recovery activities in Iwate prefecture are the following.

- The satellite IP system (IPSTAR) quickly recovered Internet communication in many disaster areas.
- A 3G router and a wireless network (IEEE802.11 b/g/n) were used for many governmental offices and evacuation shelters in temporal regions.
- A wireless network (IEEE802.11 b/g/j/n) could be used for covering the disaster area quickly.
- A satellite phone system was fully used (each local city government possessed two phones).
- A cognitive wireless router by NiCT was useful in the many shelters [5].
- Twitter, blogs, and SNS were practical for realtime information sharing such as gas station, transportation, foods, and ATM information.

The authors' volunteer team also used Twitter for sharing disaster information about Takizawa village in which our university is located, and Morioka city, which is the capital city in Iwate prefecture.

Through our Twitter services, we realized that electricity, fuel, food, and public transportation information as well as disaster information were strongly required for the residents. Thus, since most of the communication means were unavailable for a couple of weeks, the role of Internet usage was important for communicating and sharing disaster information in Iwate Prefecture.

Required Systems and Functions for Future Large-Scale Disasters

Connectivity Requirements for Disasters

Through our disaster recovery experience, we learned that network connectivity is very important, even though network conditions were worse than usual. Under the network conditions just after a large disaster, email and Twitter by sending small numbers of packets were very helpful and could reduce total network traffic. Besides, initial disaster information such as resident safety and evacuation place information mainly consisted of small text contents.

Figure 4 shows the network conditions just after the disaster at Iwate Prefectural University. The network conditions were measured by issuing Ping packets with 64 bytes to www.google.com every hour. The horizontal axis presents the total elapsed hours just after the first earthquake, and the vertical axis presents round-trip time (RTT) in milliseconds and packet error rate (PER) by percentage. Just after the earthquake, network conditions became extremely worse, 100–150 ms RTT and 20–50 percent in PER compared with 20 ms and almost 0 percent under normal conditions. Then, about 15 hours later, network conditions became even worse. This is because network access had been increased from early morning in order to get disaster information on the web. However, email and Twitter services could barely be used during this period, and it was very helpful to collect and send disaster information. Eventually, the electricity in Takizawa village was recovered, and the network conditions returned to normal.

Through observing the network conditions, network connectivity is the most important for a disaster information system even with smaller throughput and larger delay. That is, data connection should be kept robust, as shown in Fig. 5. In this figure, the wired network is easily affected by disaster. The wireless network and cognitive wireless network (CWN) are stronger than the wired network, but are disconnected as the scale of the disaster grows. On the other hand, the never die network (NDN), explained in the next section, can maintain robust data connection even if the scale of the disaster is quite huge.

For the proposed network, it is necessary to provide minimal data transmission for text data transmission, such as email or web services, even after disasters.

Required Resilient Network for Disaster

By considering the above analysis, we propose a resilient disaster network, the NDN, for Japan because 70 percent of Japan land is active mountains, and Japan surrounded by large oceans. The NDN mainly consists of self-powered fixed wireless network stations, cognitive mobile stations, and wireless balloon stations, as shown in Fig. 6.

Furthermore, the fixed wireless network stations are constructed by cognitive wireless LANs such as mobile 3G routers, IEEE 802.11b,g,n,j, IEEE802.16, and a satellite IP network including self-power, such as a combination of solar panels, wind turbines, and fuel batteries to generate electricity without time limitations.

The cognitive wireless network units are controlled by a software defined network (SDN) to be able to select the best wireless path and route depending on changes in the network communication environment, such as electric power density, throughput, delay, jitter, and packet loss rate, by disaster. Even though the worst case occurred where the conventional power supply and all the wireless LANs and 3G networks are damaged, a satellite IP network could reliably work and connect to the Internet. The fixed wireless network stations are usually installed on the roofs of local government offices and disaster headquarters, and work as central base stations to cognitive mobile stations and wireless balloon stations.

The cognitive mobile stations also consist of different wireless LANs, 3G routers, and satellite IP networks, and are used to provide communication between mobile stations or mobile station and the fixed wireless network station in the disaster area. In order to cover a wide communication area, SDN-based ad hoc and multihop functions are supported, and their antenna directions are dynamically controlled to maximize the electric power density using GPS data. The electric power for those network devices is supplied from the power generator on its car. Using the cognitive mobile station, the disaster information can be collected in the disaster area and transmitted to the disaster headquarters in real time.

A wireless balloon network station is used in areas where cognitive mobile stations cannot pass or villages are geologically isolated by the disaster. In order to cover a wide communication area, SDN-based cognitive wireless stations with several LANs are also attached to an oval shaped balloon to reduce the influence of the wind and launched about 40–100 m high in the sky. In addition, a cognitive wireless balloon station has an auto configuration function to horizontally and automatically connect to other wireless balloons based on the power signal density. Therefore, by launching multiple ballooned wireless network nodes, a horizontal ad hoc network is automatically organized in minimum spanning tree configurations depending on each power signal density in the sky. Thus, quick communication network infrastructure in a disaster area can be realized and connected to a fixed wireless network station. Eventually, the local governmental officers in the disaster area can access the local government headquarters, and the residents under the wireless balloon network can access the Internet.

By combining these three different stations, the information network infrastructure in a seriously damaged area can be recovered quickly and reliably even when the electric power supply and wired network are completely and severely damaged. Thus, the residents can communicate with each other using smartphones and tablet terminals, and local government officers can collect, send, and share the disaster information.

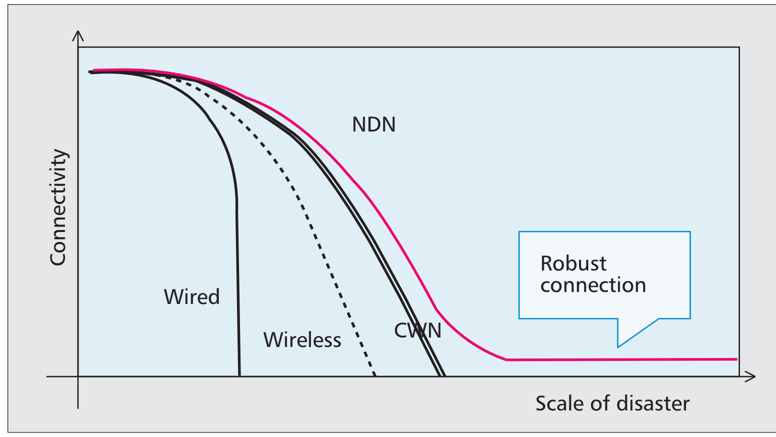

Figure 5. *Supported system failure by scale of disaster.*

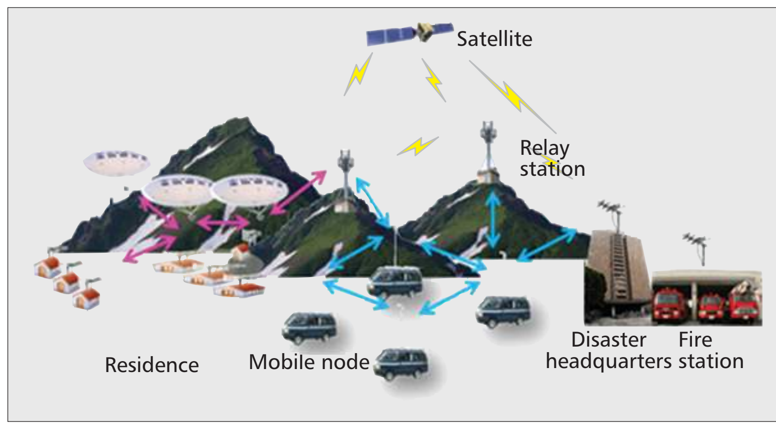

Figure 6. *Never die network.*

Conclusions

In this article, we describe the scale and characteristics of the East Japan Great Earthquake and Tsunami. We analyze the state of the information network and systems in the disaster areas through our information network recovery activity in the coastal areas just after the disaster. We found both the weakness of the current information networks, particularly wired networks, fixed and cellular phone networks, and the governmental information highways, and the usefulness of satellite networks and WLANs. It is clear that the connectivity of the information network is the most important for residents who evacuate to preserve their security and trust even though some of the information network and systems are damaged. Therefore, as we suggest in this article, disaster information networks in the near future should be constructed by combining wired, wireless, and satellite networks to realize a never-die-network environment in both normal and urgent cases.

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