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A Resilient Network for Large Scale Disasters from Experience Based on the Great East Japan Earthquake

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Summary

Recently serious natural disasters such as earthquakes, tsunami, typhoons and hurricanes have occurred in many places around the world. The Great East Japan Earthquake on March 11, 2011 brought more than nineteen thousand victims and destroyed huge number of houses, buildings, roads and seaports over the wide area of Northern Japan. Information networks and systems and electric power cables were also severely damaged by the great Tsunami. Functions in the highly developed information society and residents' safety and security were completely compromised. Thus, through the lessons from this great earthquake, the construction of a more robust and resilient information network has become one of the topical issues. This paper focuses on our information network recovery activity after the Great East Japan Earthquake. Then the problems of current information network systems are analyzed in order to improve disaster information network and system through our network recovery activity. Finally, we suggest systems and functions required for future large scale disasters.

Key words: Disaster Information Network, Great East Japan Earthquake, Never Die Network, Resilient Network.

JEL classification: C6, C63, C8, C81, D8

1. Introduction

Due to the geological conditions of the Japanese Islands, many serious natural disasters such as earthquakes, tsunamis and typhoons have occurred in history. A huge number of people, buildings and communication infrastructure get completely destroyed. In particular, the Great East Japan Earthquake inflicted huge damage on March 11, 2011[1] as can be seen in Fig. 1. Many Information network infrastructures were destroyed and traffic was seriously congested. Even today, four and a half years later, many people are still missing.

Many Japanese coastal residential areas were also geologically isolated [2]. Communication networks such as the Internet, cellular phones and fixed phones were out of order after the huge quakes. Furthermore there was a widespread

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Fig. 1. The East Japan Great Earthquake in Iwate Prefecture, Japan

blackout over northern and central Japan [3][4]. The inability to transmit disaster-related information caused delay in rescuing victims, taking people to shelters, confirming the safe evacuation of residents and urgent medical treatment just after the disaster.

In order to quickly recover the communication infrastructure in several local government offices and the evaluation places in the disaster areas, our disaster volunteer team which was organized by our network research laboratory students of Iwate Prefectural University went out to the disaster area one week just after the occurrence of the disaster. We recovered the network infrastructures of those local government offices using our own wireless LANs, mobile access routers and satellite IP networks. Our network recovery activity was covered by several mass media. Our recovery activity allowed us to identify serious problems with the information network and system in the coastal areas and we realized that a new robust and resilient communication means was strongly required to transmit the significant information even though huge disasters, such as Nankai Trough Quake and Tokai earthquake and Tokyo epicentral earthquake which are forecast to occur in the foreseeable future, might be stronger than the Great East Japan Earthquake.

In this paper we introduce a resilient network and information system for larger scale disasters by relying on our experience gained through the recovery activity in the Great East Japan Earthquake. The proposed resilient network is based on Wireless LANs, mobile routers and satellite IP networks.

Further in the paper our disaster-related information network recovery activities in the several disaster-hit areas in the Great East Japan Earthquake are shown in section two. Next, through the recovery activity and posteriori investigation in the disaster areas, the problems of information network means on disaster are discussed in detail in section three. Finally, effective communication means on disaster are discussed in section four.

2. Problems of Information Network during Disaster

The East Japan Great Earthquake caused many problems related to rescue, food distribution, and evacuation responses. Malfunction of information network system was a part of major problems after the earthquake. In particular, the lack of disaster information such as life safety for evacuated residents, damage scale and degree to which houses, buildings, land, roads, bridges, seaports get damaged, brought much confusion to various activities. The following table I is the summary of various information networks and their functional conditions in Iwate Prefecture obtained through our network recovery activities.

2.1 Fixed Telephone Network

Most of the residents, local government offices, enterprises in the disaster area used both fixed telephones in their business and personal life and cell phones. The telephone lines and switches were completed damaged and disconnected as a result of the huge earthquake and several months were spent to recover them. Even in the areas away from the disaster telephone services were not available due to traffic congestion. Thus, it was found that fixed telephone networks are the weakest of all communication means in the event of disaster.

2.2 Internet

The Internet was used in various ways for many activities after the Great East Japan Earthquake. Although Internet was used at the rate of 74.7% before the earthquake in northern Japan, the rate sharply decreased to about 20% immediately after the earthquake. This was because many Internet services in Northern Japan area were unavailable as a result of the damage and overloading of the information networks. Then, it took about one to two weeks to reactivate temporary network services around Morioka, Iwate prefecture, Japan.

Since most of the temporary houses for evacuation were located on mountain slopes, Internet services were not originally provided. Therefore temporary communication cabling was needed to construct network infrastructure for the area. There were many temporary housing areas where Internet service provided through wired networks such as FTTH could not be available even several months later. However, Satellite network and FWA were installed for those areas supported by Ministry of Internal Affairs and Communications.

2.3 Cellular Phones

One of the main problems of information network systems was the traffic congestion due to the rapid generation of cell phone systems. According to the Ministry of Internal Affairs and Communication, the number of calls on cell phones just after the earthquake increased almost tenfold and the maximum call control ratio of voice communication went up to 95% which means that only one person out of 20 could make a phone call [6].

In the northern part of Japan which was heavily damaged by the earthquake, the congestion of cell phone system was extremely heavy. The number o98ytof call requests surged and was about 8 times

Table 1. Large-scale Earthquakes around the World

System	Conditions	Details
Radio broadcasting	○	Local community FM stations, in particular, functioned well.
TV broadcasting	×	Cannot be watched due to large-scale blackouts.
Fixed phone	×	Line disconnection and damaged central offices and remote electronics.
Cell phone(voice)	×	Traffic congestion and damaged base stations.
Internet (wired, wireless and mobile networks)	• Δ	Worked depending on communication lines.
Local government information super 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	Δ	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

larger than the regular and the maximum congestion time was about 30 minutes just after the earthquake as shown Fig. 2.

Thus, the cellular phone services were not available for a long time after the earthquake and caused serious communication problems in large areas in Japan. As a result, not only the damage to network devices but also the congestion of cell phones are considered to be the reasons why there was serious lack of information concerning rescues, evacuation shelters, life safety information.

Moreover, in places in the disaster area such as the coastal city in Iwate prefecture, many wired networks and servers of the telecommunication companies were broken down by the huge Tsunami. Therefore, fixed phones, broadband Internet services, and even the local government network system were unable to function. The public Web services and email systems in Iwate prefectural office used as countermeasures were also down. This failure caused serious information problems in the coastal cities in Iwate prefecture.

2.4 Regional Government Network

The regional government network, the so called Iwate Information Highway, which was the wired backbone information infrastructure in Iwate prefecture and

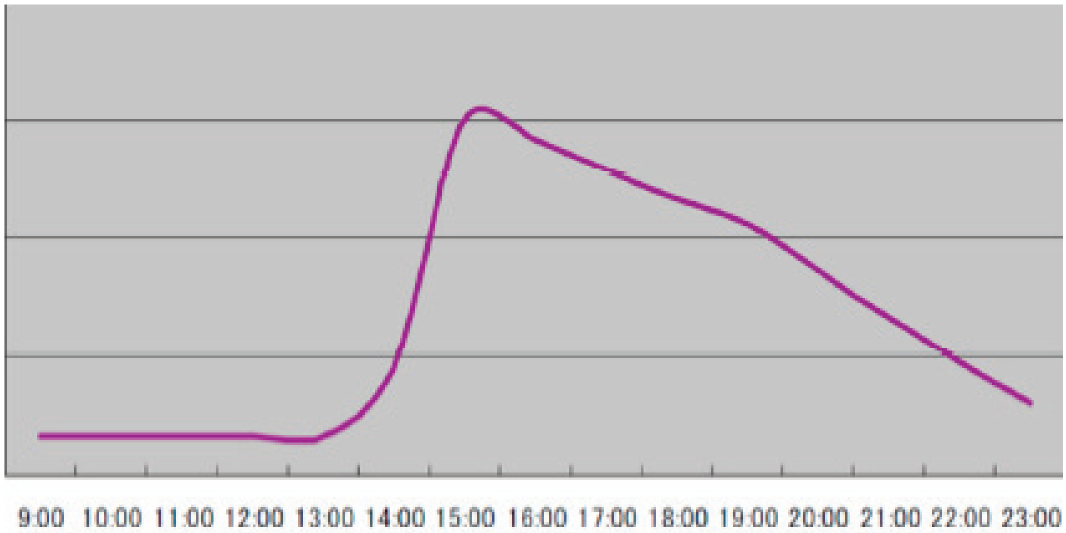

Fig. 2. The numbers of calls by cell phone on 3/11/2011 in Northern Japan

connected all of the local government offices, hospitals and schools 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. A temporal LANs was reconstructed to provide communication to the countermeasure headquarters in the prefectural office and to organizations such as fire stations, schools, hospitals, road surveillance offices. Moreover, since the majority of information servers at the local government offices were damaged, the disaster warning was not communicated to the residents in Iwate prefecture.

2.5 Satellite IP Network

On the other hand, some information network systems were considered useful in disaster areas. In our network recovery activities in the coastal area of Iwate prefecture, a satellite system for the Internet such as IPSTAR and wireless LANs could well function to reactivate the communication network systems. Although there were problems due to lack of electricity, both systems were used for the reactivation activities in some evacuation shelters and disaster countermeasures headquarters quickly.

2.6 Wireless LANs

Although a satellite system does not have higher speed compared with broadband network facility such as FTTH, the main traffic on the Internet in emergency was text-based contents such as email, Web based resident safety information and SNS. Therefore, the satellite system was practically useful despite the crisis situation because this system could be used anywhere even in the disaster places with portable power supply. Wireless LAN was also constructed for temporary network reconstruction since the inside of public buildings such as local governmental offices was damaged by the disaster.

2.7 Social Media

Disaster volunteers used the Internet as communication means for their various activities. They shared the disaster-related information via SNS, disclosing the lists with names of evacuated residents in each evacuation shelter by Web broads and confirming road condition by GIS maps. Compared with other previous Japanese earthquakes, there were many new attempts by disaster volunteers to use the Internet to report 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, the Internet is expected to perform a more important role as a communication tool not only in ordinary situations but also in emergency.

3. Required Systems and Functions for Large Scale Disaster

The events experienced during the Great East Japan Earthquake call for serious considerations concerning network connectivity and point out how important it is as it became obvious that the state of the network was worse than usual. Under the network conditions just after a large disaster, sending messages or packets by emails or twitter were very helpful and could reduce the whole network traffic. Furthermore the initial information about the disaster, for example resident safety information or information about the location of evacuation centers consisted mainly of small size texts.

Figure 3 shows the state of the network just after the disaster in Iwate Prefectural University. The network condition was gauged by issuing Ping packets with 64 bytes to www.google.com on every hour. The horizontal axis presents the total elapsed hours just after the first earthquake, and the vertical axis presents RTT (Round Trip Time, ms) and PER (Packet Error Rate, %). Just after the earthquake, the network condition worsened extremely to 100 - 150ms in RTT and 20 - 50 % in PER compared with 20ms and almost 0 % in the normal condition. Then, about 15 hours later, the network conditions became even worse. That was because

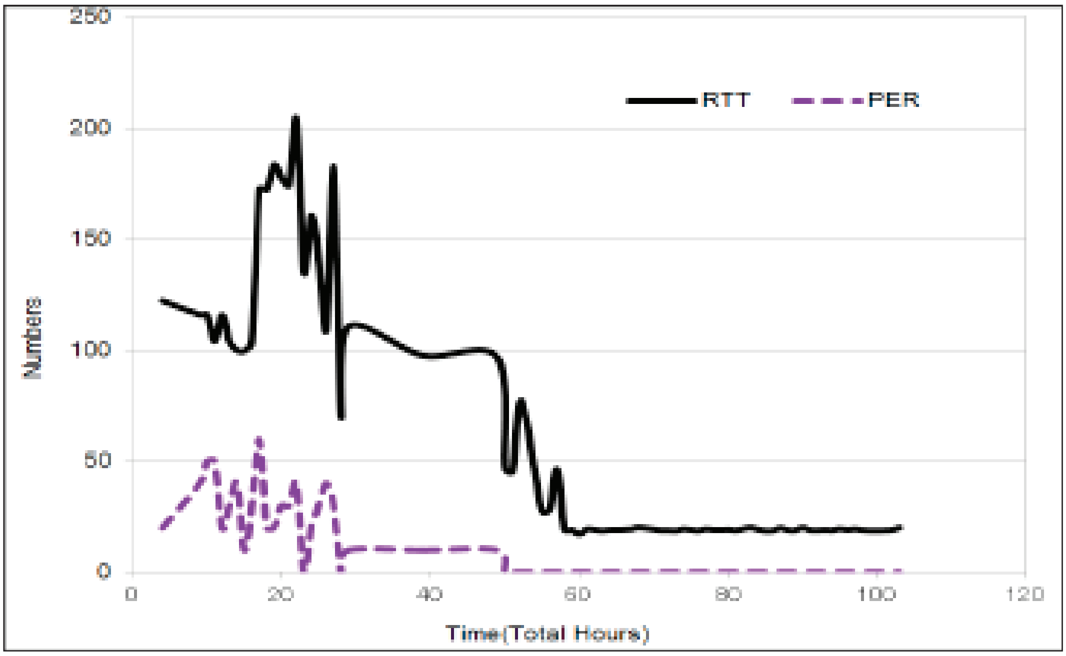

Fig. 3. Network Conditions in IPU under Disaster

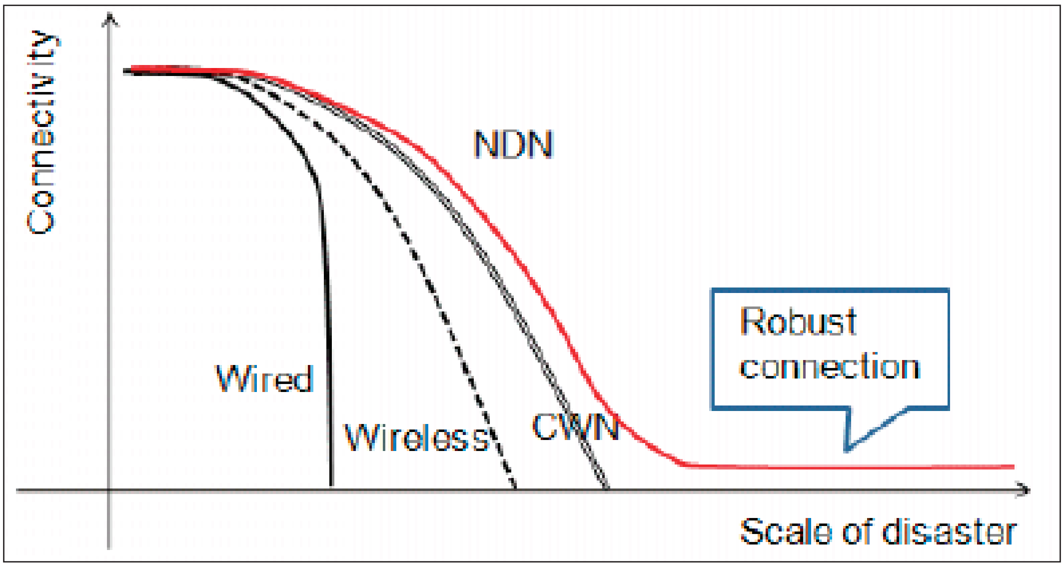

Fig. 4. Supported System Failure by Scale of Disaster

network access had increased from early morning in order to get disaster information by Web. However, mail and twitter services could barely be used during this period, and it was very helpful to collect and to send disaster-related information. Eventually, the electricity in Takizawa village was recovered and the network condition returned to the normal condition.

In terms of network conditions, network connectivity is of great importance for the disaster-related information system even with smaller throughput and lengthy delay. That means that data connections should be kept in robust condition as shown in Figure 4. This figure shows that wired network is easily influenced by disaster. Wireless network and CWN (Cognitive Wireless Network) are stronger than wired network, but get disconnected as the scale of the disaster increases considerably. On the other hand, the NDN(Never Die Network) which will be 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.

4. Never Die Network for Large Scale Disaster

Considering the above analysis, we propose a resilient disaster network, namely Never Die Network, simply NDN, for Japan island because 70% of Japanese terrotory is active mountain and is surrounded by large oceans. NDN mainly consists of three networks including fixed NDN, mobile NDN and air NDN self-power supplied fixed cognitive wireless network, mobile cloud computing nodes and self-power supplied wireless balloon stations as shown in Fig. 5.

4.1 Fixed NDN

Fixed NDN is constructed of cognitive wireless LANs as shown in Fig.6 such as mobile 3G/LTE routers, IEEE802.11x, IEEE802.16 and satellite IP network including self-power supply such as a combination of a solar panel, window turbine and fuel battery

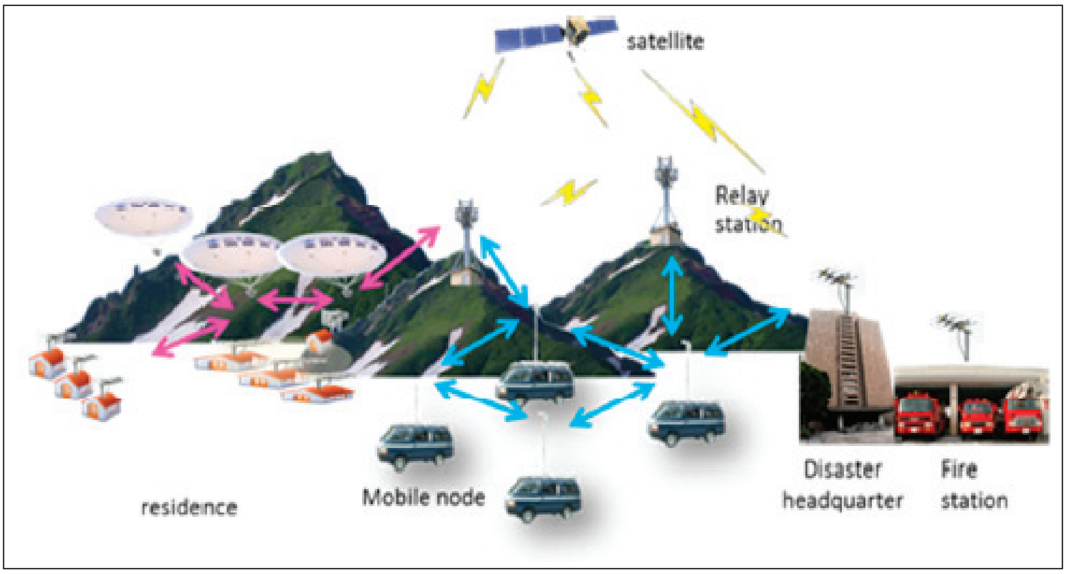

Fig. 5. Never Die Network

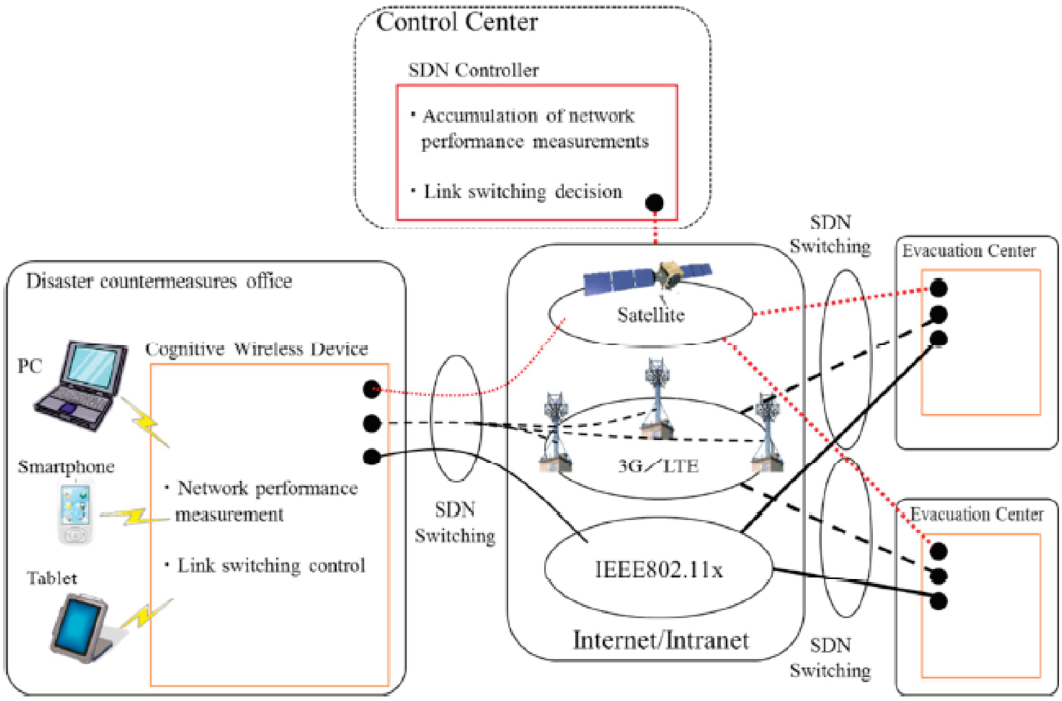

Fig. 6. Fixed Never Die Network

to generate electricity without time limitation as shown in Fig. 7. Those cognitive wireless network units are controlled by Software Defined Network (SDN) to be able to select the best wireless path and route depending on changes of network communication

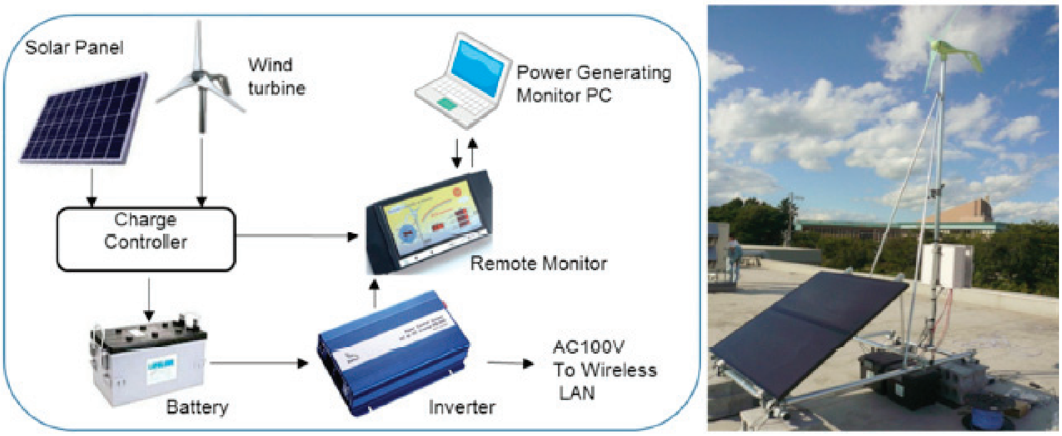

Fig. 7. . Self-Supplied Power System by combination of Solar and Wind Turbine

environment such as electric power density, throughput, delay, jitter and packet loss rate resulting from a disaster. Even though the worst case occurred where the conventional power supply and all of the wireless LANs and 3G networks were damaged, satellite IP network could reliably work and connect to Internet. The fixed wireless network stations are usually installed on the roof of local government offices and disaster headquarters and work as the central base station to cognitive mobile stations and wireless balloon stations.

4.2 Mobile NDN

Mobile NDN consists of different wireless LANs, 3G/LTE routers and satellite IP network and are used to provide communication

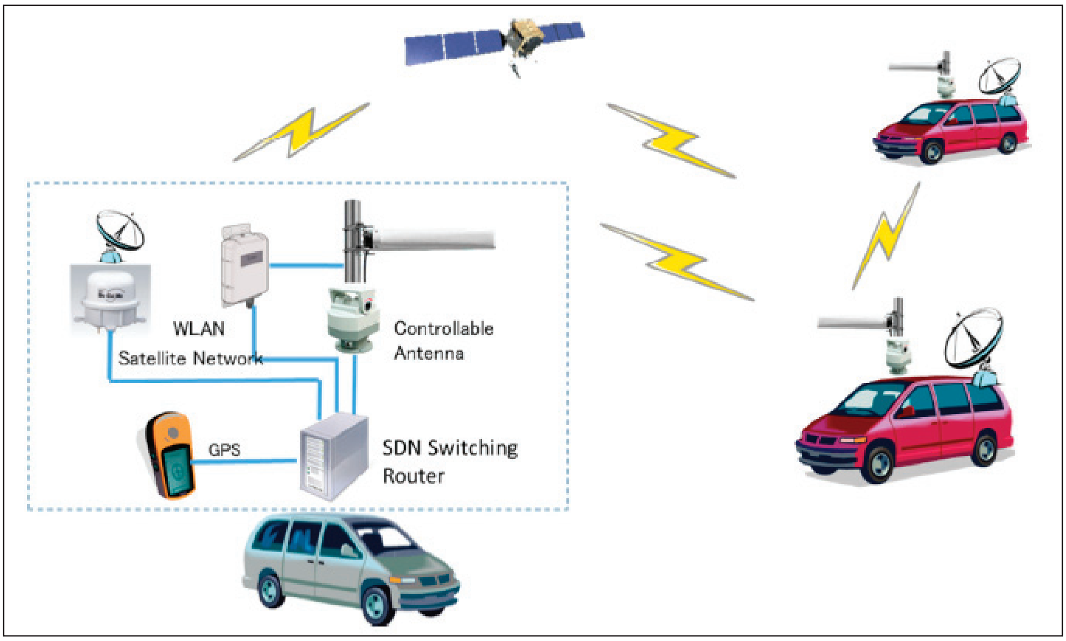

Fig. 8. Mobile Never Die Network

between mobile stations or a mobile station and a fixed wireless network station in the disaster area as shown in Fig. 8. In order to cover wide communication area, SDN based adhoc and multihop functions are supported and their antenna directions are dynamically controlled to maximize the electric power density using GPS positioning data. The power for those network devices is supplied by the power generator in the car. Using the cognitive mobile station, the disaster information can be collected in the disaster area and transmitted to the disaster headquarter in real time.

4.3 Sky NDN

Sky NDN wireless balloon network station is used in the area where the cognitive mobile stations cannot pass or the villages are geologically isolated by the disaster. In order to cover 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 is launched about 60-120 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, an adhoc horizontal network is automatically organized in minimum spanning tree configurations depending on each power signal density in the sky. Thus, the quick communication network infrastructure in disaster areas can be realized and connected to the fixed wireless network station. As a result the local governmental officers in the disaster-hit area can access the local government headquarters and the evacuated residents within the wireless balloon network can access the Internet.

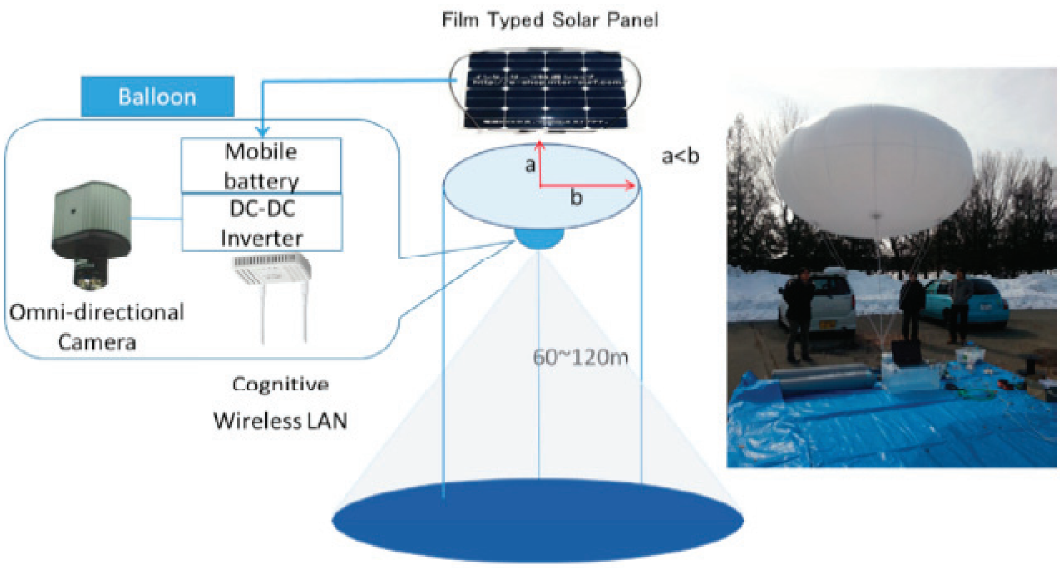

Fig. 9. Never Die Network

By combining those three different NDNs, the information network infrastructure in the seriously damaged area can be quickly and reliably recovered even if the electric power supply and the wired network are completely and severely damaged. Thus the residents can communicate each other using smart phones and tablet terminals and local government officers can collect, send and share information concerning the disaster.

5. Conclusions

In this paper, we described the scale and characteristics of the East Japan Great Earthquake and Tsunami. We analyzed the state of the information network and systems in the disaster-hit areas through our information network recovery activity in the coastal disaster-hit areas just after the disaster. We found both the weakness of the current information networks, particularly wired networks, fixed and cellular phone networks, governmental information highways and the usefulness of satellite networks and WLANs. It is clear that the connectivity of information network is most important to those residents who evacuate for safety reasons even though some of the information networks and systems are damaged. Therefore, as we suggested in this paper, the disaster information networks in the near future should be constructed by combining wired, wireless and satellite networks to guarantee the never-die-network environment in both ordinary and urgent situations.

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