Activity

Measures for Recovery from the Great East Japan Earthquake Using NTT DOCOMO R&D Technology

NTT DOCOMO Technical Journal Editorial Office

1. Introduction

On March 11, 2011, the largest earthquake on record in Japan, at a magnitude of 9.0, occurred, with epicenter near the east coast of Honshu, in Japan. As of March 12, 4,900 NTT DOCOMO base stations within the Tohoku region had to suspend services due to the effects of this earthquake and resulting large tsunami. This was caused by direct damage from the earthquake and tsunami as well as secondary effects such as cut optical fiber and other transmission lines or drained batteries due to extended power outages. As a result, mobile terminal services were not available over a wide area, mainly in Iwate, Miyagi and Fukushima prefectures.

The NTT DOCOMO Group disaster recovery organization consists of a force of approximately 4,000 people nationally, ten mobile satellite base stations, 21 mobile base-station vehicles and 30 power generator vehicles. It was able to recover services to almost pre-disaster conditions by April 26 (**Figure 1**).

The damage from this disaster was unprecedented, and in many cases, conventional recovery processes were not applicable. To recover the service area, departments involved in R&D and technical study (hereinafter referred to as "R&D related departments") provided logistical support for technical study, testing and operations in many cases.

In this article, we report on what sorts of studies were done and utilized in recovery measures for the disaster by NTT DOCOMO R&D related departments, and we give an overview of how we will approach initiatives for disaster recovery in the future.

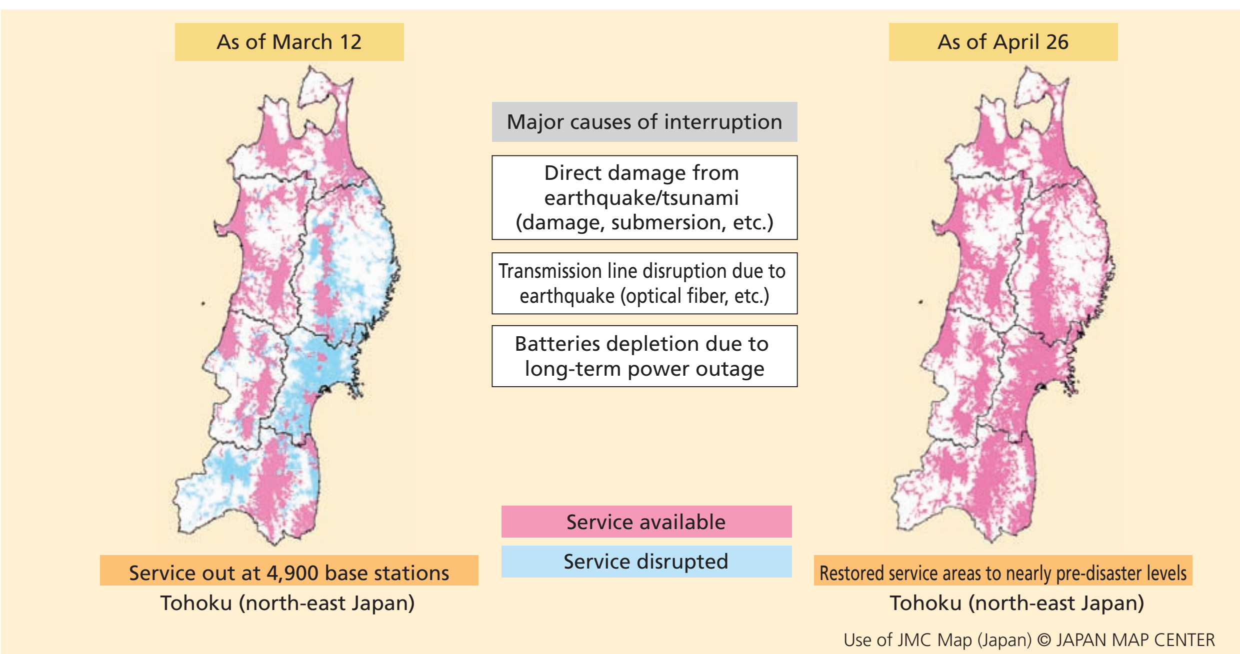

Figure 1 Great East Japan Earthquake service area restoration status

2. Earthquake Recovery Measures

The main approaches used to recover services at the 4,900 base stations in the Tohoku region where services were interrupted by the earthquake include use of (1) optical fiber and emergency optical fiber, (2) enlarged radio zones and (3) microwave transmission lines and satellite links in order to recover base station equipment.

In areas where the damage was relatively light, recovery was accomplished by installing emergency optical fiber or reconnecting existing optical fiber, or by having NTT DOCOMO install temporary optical concentrators when existing optical concentrators had been damaged (**Figure 2**). Depending on the conditions in areas with severe damage, the size of radio zones were increased so that one base station could cover the areas of several pre-existing base stations (**Figure 3**), emergency microwave entrance equipment was installed (**Figure 4**), or satellite entrance links (**Figure 5**), which are immediate and mobile, were deployed effectively to achieve recovery.

2.1 Area Recovery Support Activities by R&D-Related Departments

1) Fukushima Daiichi Nuclear Power Plant Area

In the area surrounding the Fukushima Daiichi nuclear power plant, communication area recovery was particularly necessary for response to the urgent power plant accidents. However, entry for work was prohibited within a 20 km radius of the power plant due to radioactive contamination, so extraordinary measures were needed.

Initially, we considered two ways: using high-gain antennas at a base station 40 km from the power plant, and at a mobile base station in J Village (20 km). However, simulations showed that both would be difficult. Further study lead to a decision to use a base station on a tower in view but 25 km from the Daiichi power plant (**Figure 6**).

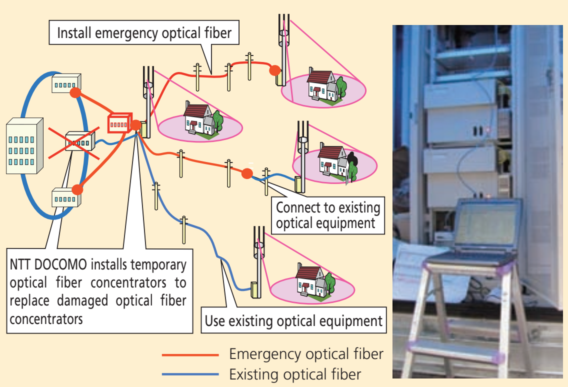

Figure 2 Facilities recovery using optical fiber/emergency optical fiber cable

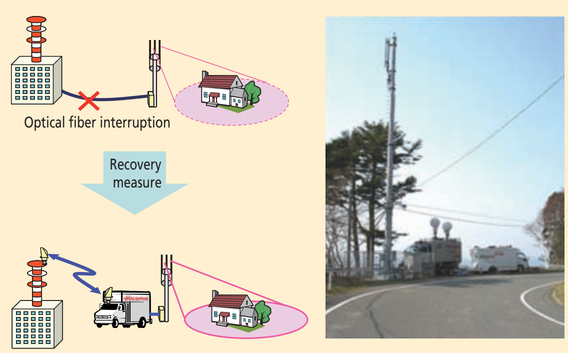

Figure 4 Facilities recovery using microwave-entrance

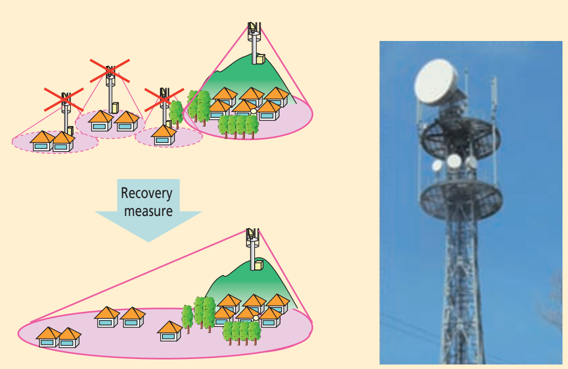

Figure 3 Facilities recovery by increasing zone size

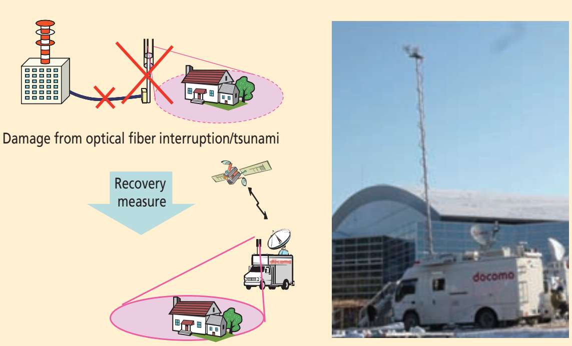

Figure 5 Facilities recovery using satellite entrance link

To implement this measure, the R&D Center's Radio Access Network Development Department and the Research Laboratories conducted a study selecting the antenna to use and how to install it. They evaluated the effectiveness of six possible antennas and three of them were found to be promising: a high-performance antenna (45-degree-beam base-station antenna), a parabolic antenna, and a Yagi antenna (**Figure 7**). The high-performance antenna (45-degree-beam base-station antenna) was selected because an antenna with too much gain focused on the powe plant would neglect recovery of the communication area along National Route No. 6. This antenna was also the lightest and easiest to install which would help complete on-site work as quickly and safely as possible. Installation high off the ground was done using rope and pulleys.

Work on April 13 was temporarily suspended due to an aftershock at about 10 am, but in the afternoon the base station was completed and began operation safely (**Photo 1**). At the same time, a vehicle base station was used to recover some area, and other stations were recovered by switching transmission lines. These efforts combined with the new antenna recovered the area within 20 km of the power plant (**Figure 8**).

2) New Satellite Links used for Entrance Lines

To recover locations where mobile communication ser-

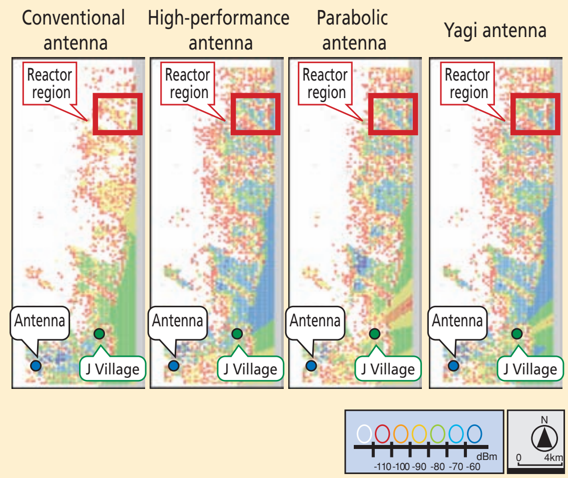

Figure 7 Antennas studied and simulation results

Photo 1 Conditions at antenna installation

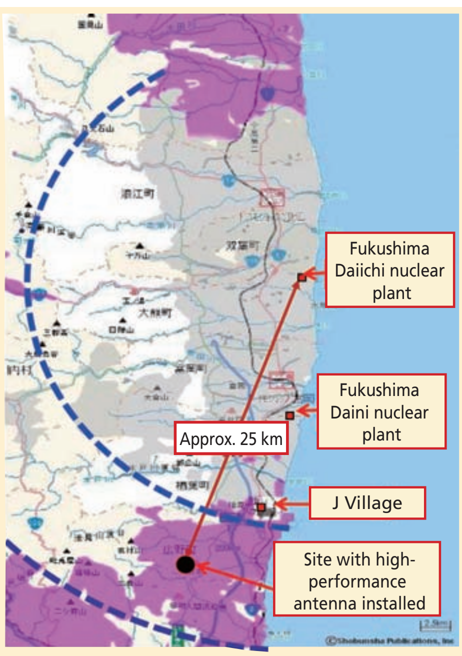

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Figure 6 Study of antenna installation location

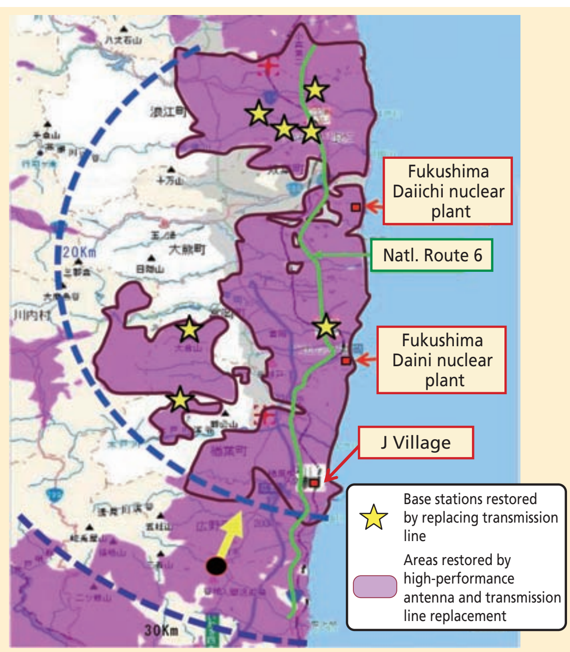

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Figure 8 Recovery achievements in areas surrounding reactors

vice was lost due to transmission line break down and these lines could not be restored quickly, new satellite entrance links were used. To start service from the base stations quickly, R&D related departments provided backup support for technical studies, testing and operation. A small earth satellite station was set up on the roof of the R&D Center to perform technical testing and to check configuration data and throughput for various types of equipment (**Figure 9**). Researchers took speed of installation and cost into consideration, studying the network structure and summarizing installation issues. As a result, services were put in place very quickly; in only two weeks from when the plans were finalized.

The configuration for using satellite links for entrance lines is shown in **Figure 10**. IP transmission was employed, in which Digital Divide Base Transceiver Stations (DD-BTS) could be used. A device which is easy to configure, support IP transport and were developed to eliminate the digital divide. Parameters were configured to handle delay and fluctuation in transmission paths using know-how and actual test results obtained from using the existing ATM satellite links for extending area coverage to island regions. This was the first area recovery making use of IP satellite links.

A new network configuration was designed to ensure security of the network. Also, the User Border GateWay (U-BGW) router, handling uplink QoS, which and the Digital Divide bridging GateWay (DD-GW) router, handling downlink QoS, were equipped to ensure service quality over relatively narrow-bandwidth channels. After putting the equipment into service, there were on site reports of voice interruption. Analysis revealed the cause to be fluctuation in delay exceeding the allowable values, so adjustments were applied to reduce delay fluctuation to within the allowable range, successfully eliminating interruptions.

3) Restoration Area Map

After the Great East Japan Earthquake, NTT DOCOMO published a "Restoration Area Map" on March 20. This service gave users access to important information about where mobile terminals could be used, in the form of a map that could be viewed from PCs, mobile terminals and smartphones (**Figure 11**).

Different colors were used to show service areas clearly,

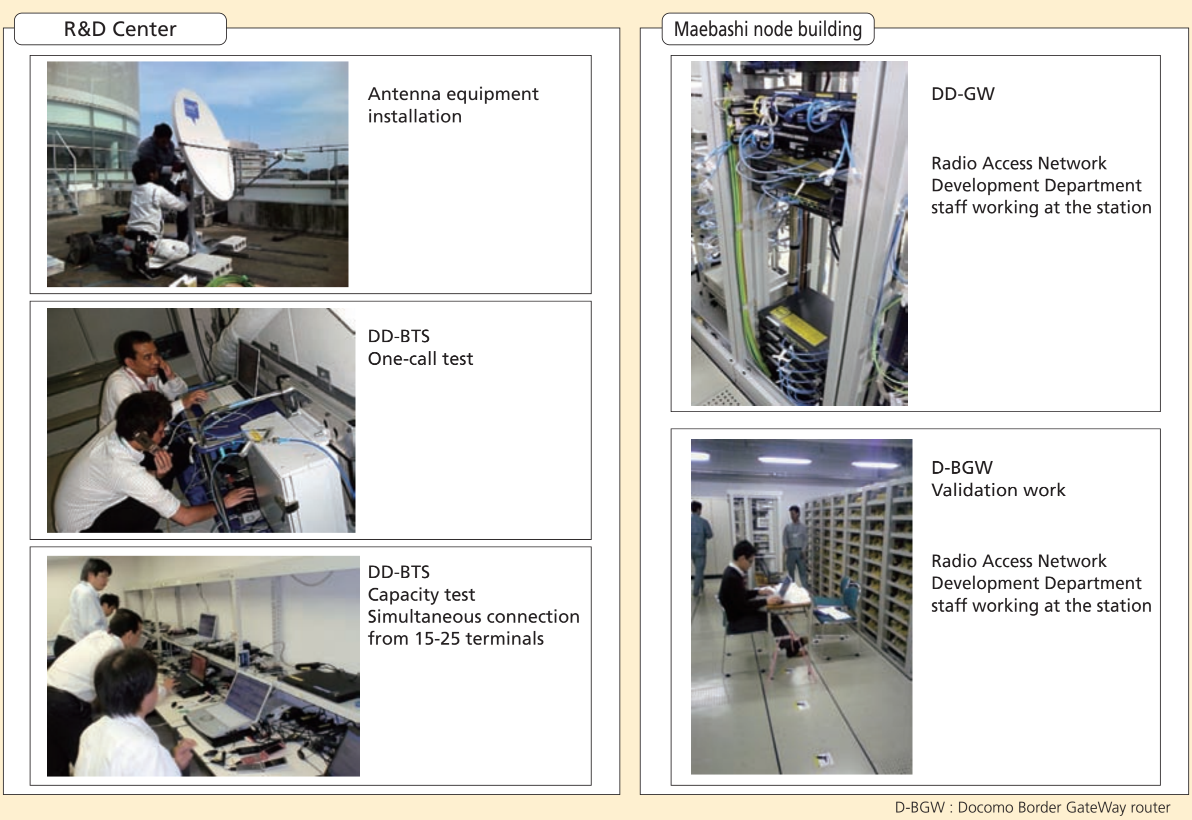

Figure 9 Satellite entrance test conditions

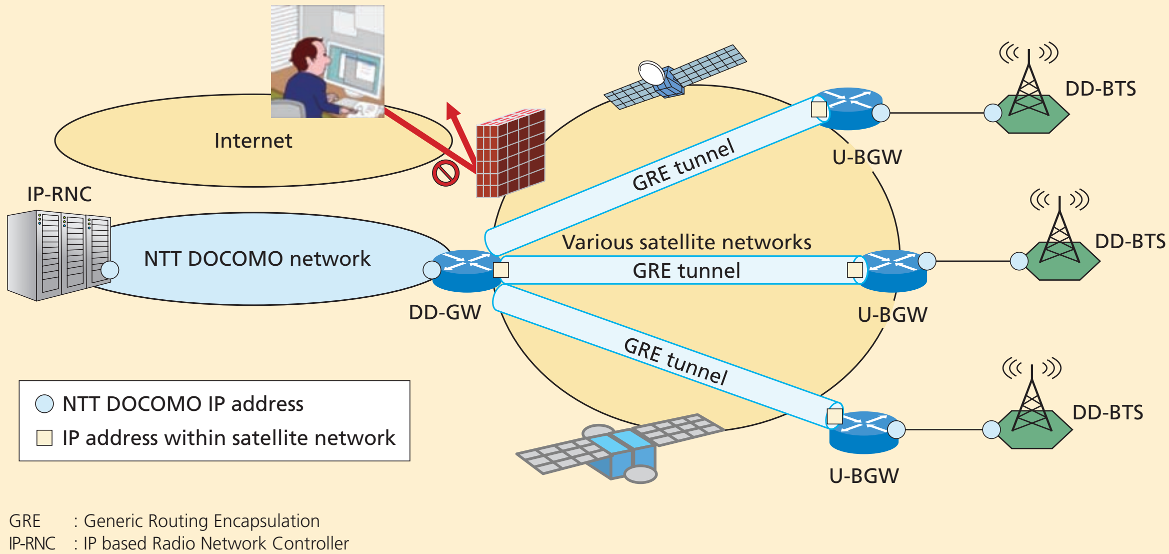

Figure 10 Overview of satellite entrance line configuration

with an eye-catching pink indicating where service was available. FOMA and FOMA Plus areas, which are shown in different colors in product catalogs, were shown together with the same color to indicate basic service availability at a first glance.

In this map, it was particularly important to indicate areas as having service on the map. Therefore, when a new mobile base station was established, the map was not updated until service was checked in every corner of evacuee shelters and the surrounding coverage areas to ensure the actual service availability.

The decision to offer the area map was made at a meeting of the NTT DOCOMO disaster recovery headquarters on March 18, one week after the disaster, and it was substantially developed in about two days. NTT DOCOMO has an internal system which maintains measurement and simulation database and this information is shared internally as part of the our area information infrastructure. By having this database updated by branch offices throughout the country, NTT DOCOMO was able to collect extraordinarily accurate data and consequently provide the Restoration Area Map very quickly.

2.2 Recovery Measures Studied

1) WIDESTAR II to Smartphone Connections Using Mobile Wi-Fi®[*1] Routers

We studied solutions using WIDESTAR II channels.

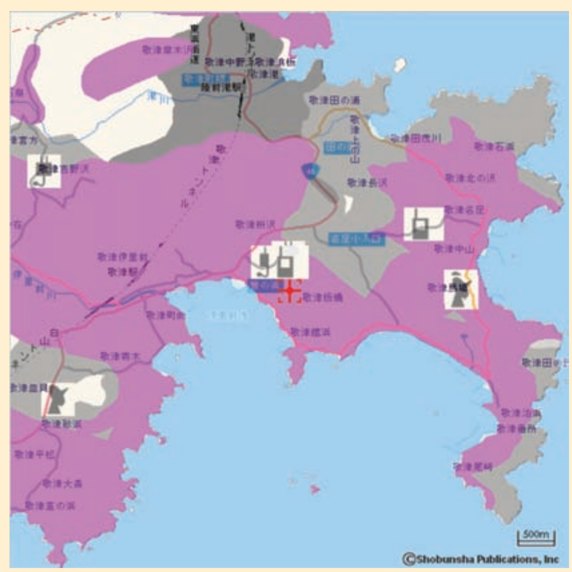

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Figure 11 Example of a Restoration Area Map

This method is highly disaster resistant because communication is achieved directly via satellites. Allowing smartphones and tablet terminals to connect to WIDESTAR II links using a Wi-Fi router is an effective way to provide users with access to an Internet connection, even in evacuee centers

*1 **Wi-Fi®**: A registered trademark of the Wi-Fi Alliance where the FOMA signal does not reach due to base-station damage (**Figure 12**).

WIDESTAR II service covers all of Japan using two satellites located in separate geostationary orbits, establishing a stable and high quality system that is not easily affected by weather or disasters.

This provides a way of obtaining information, with an effective approach when communications capability is limited in times of disaster.

2) Video Transmission Solution Using Satellite Channels

We also studied a video transmission solution using the disaster-resistant WIDESTAR II system with existing and video transmission equipment from cooperating vendors. This would enable reporting on conditions through video (H.264: 50 kbps video transmission on the satellite uplink), even in areas where the FOMA network has been damaged (**Figure 13**).

This approach can be expected to provide real-time video relay between disaster sites and a base, to provide interaction with the location mixed with live video, and to connect multiple points simultaneously to share video and other information.

3) SIP Telephony Service Using Satellite Channels

We also considered a solution implementing four types of communication in a single FOMA terminal: (1) IP VoIP local extension calling in wireless LAN environments, (2) FOMA line calling (3) satellite link calling and (4) satellite data communications. This is done by combining WIDESTAR II links, which effectively guarantee communication in times of disaster or emergency, with FOMA terminals supporting wireless LAN, which have excellent portability (**Figure 14**).

This enables local private calling at evacuee centers or disaster sites, and also makes connection to the public telephone system through satellite links, so it promises to provide a local network easily in times of emergency.

4) Simultaneous Broadcast Transmission Service

We also studied a service enabling speedy communication with the base location by selecting FOMA or WIDESTAR II links, as appropriate at the time, for voice, e-mail, FAX or other communications.

Since the types of communication (voice, e-mail, FAX, teleconferencing) can be provided flexibly, as needed at the earthquake site, by the simultaneous broadcast service it can be expected to be used over a broad range from the initial stages after the earthquake until the reconstruction stages. Voice broadcasts can be done smoothly, in the same way as an ordinary full-duplex voice call, and simultaneous broad-

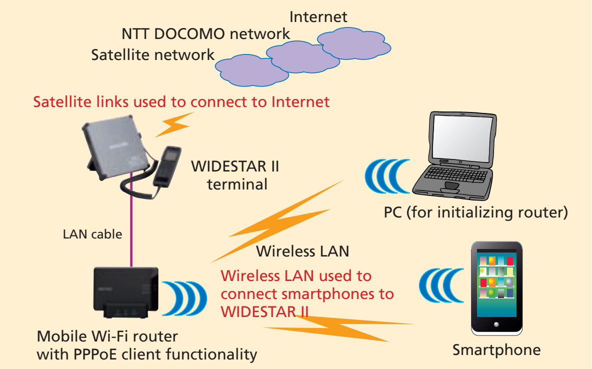

Figure 12 WIDESTAR II and smartphones connection configuration using mobile Wi-Fi routers

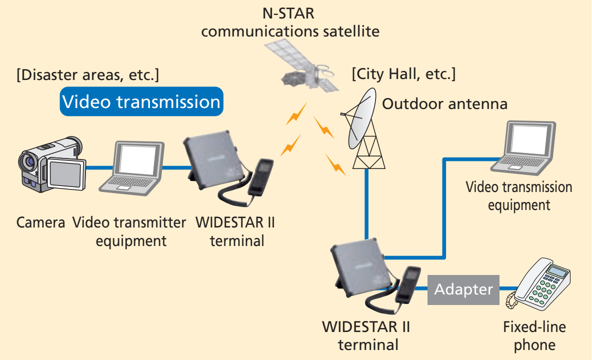

Figure 13 Overview of video transmission solution

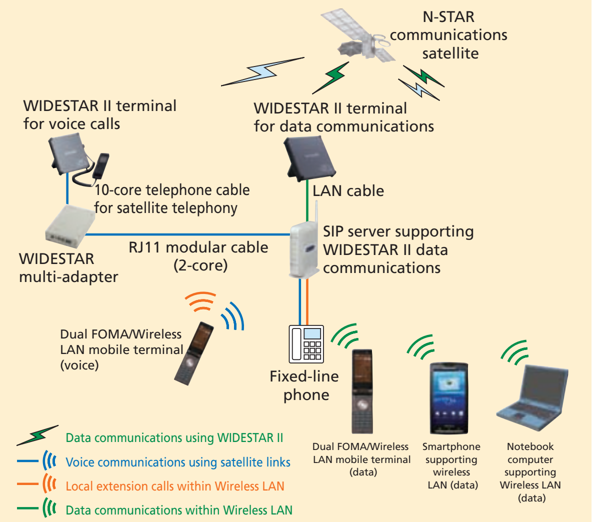

Figure 14 Overview of SIP telephone service using satellite links

cast of e-mail or FAX can be transmitted easily, just like an ordinary call. Substations belonging to a broadcast group (up to 200 people) can also be called simultaneously from the group center station, and a conference call can be held among the answering members.

3. New Disaster Recovery Measures

Utilizing the lessons learned from this great disaster, NTT DOCOMO is building a total of approximately 100 large-radio-zone base stations (**Figure 15**) nationally, each capable of transmitting radio signals over a 360º range and with a radius of approximately 7 km. These will be able to cover broad service areas when many base stations are damaged. Also, to ensure communication in important areas at the time of disaster such as local government buildings, we are promoting installation of uninterruptable power for base stations, incorporating their own power generators or 24 hour batteries (**Figure 16**).

R&D related departments continue to work for new disaster recovery measures that are expected to be taken beforehand in preparation for future disasters. Here, we will outline and describe some short-term countermeasures, to be brought to the market quickly, as well as some longer-term measures for farther into the future and involving more sophisticated technical development.

3.1 Short-term Recovery Measures

1) Disaster Voice Messaging Service

This service is a one-way, asynchronous voice communication service using the packet-switched network, which can make connections relatively easily when the circuit-switched network is restricted to control congestion due to a disaster. The service is intended for operation only during times of emergency such as a large-scale disaster (**Figure 17**).

With this service, voice messages are recorded at the originating terminal, creating voice files. These files are then delivered to the destination terminal through a messaging center on the network, and they can be played back on the destination terminal. Thus, callers can send voice messages at their convenience, even if the receivers are temporarily unavailable due to network congestion, being out of the service area, low battery voltage or other reasons.

Callers can also specify the destination terminal by the phone number for the voice message, and can record voice messages on their terminals with receiving voice guidance and automatically send voice messages to the messaging center. We have devised a user-friendly interface so that users accustomed to voice calls can also use the service easily.

We plan to begin offering this service on March 2012.

2) Disaster Information Delivery System

We are studying construction of a disaster information delivery system. This system can extract Web articles, comment submissions and photos related to a disaster from user submissions to SNS sites. Moreover, this system can present them in a way that is easy to understand (**Figure 18)**.

The system filters content submitted to SNS for disaster-related keywords, and selects articles and user contributions of interest to users by measuring factors such as the number of submissions or extent of their propagation. We are also studying ways to estimate the credibility of submitted content and to present only submissions from users with a high credibility rating.

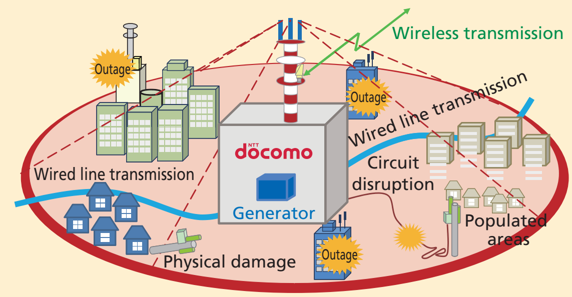

Figure 15 Large-zone base station equipment

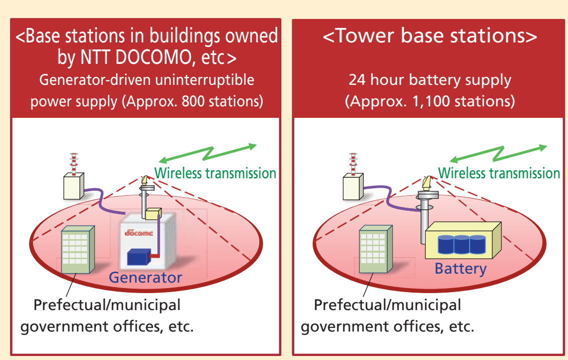

Figure 16 Base station uninterruptable power

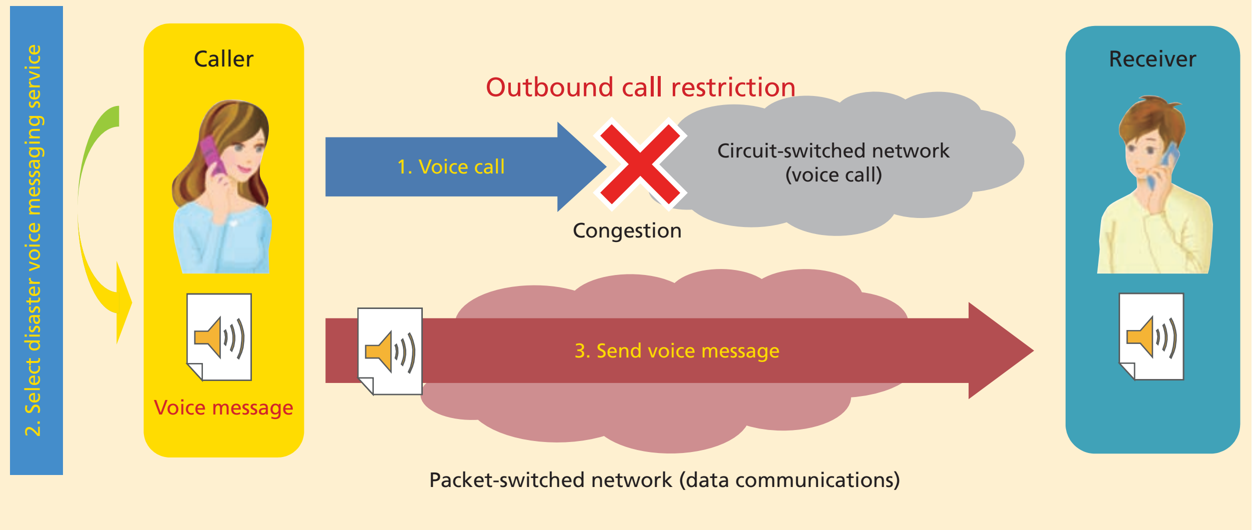

Figure 17 Overview of disaster voice messaging service

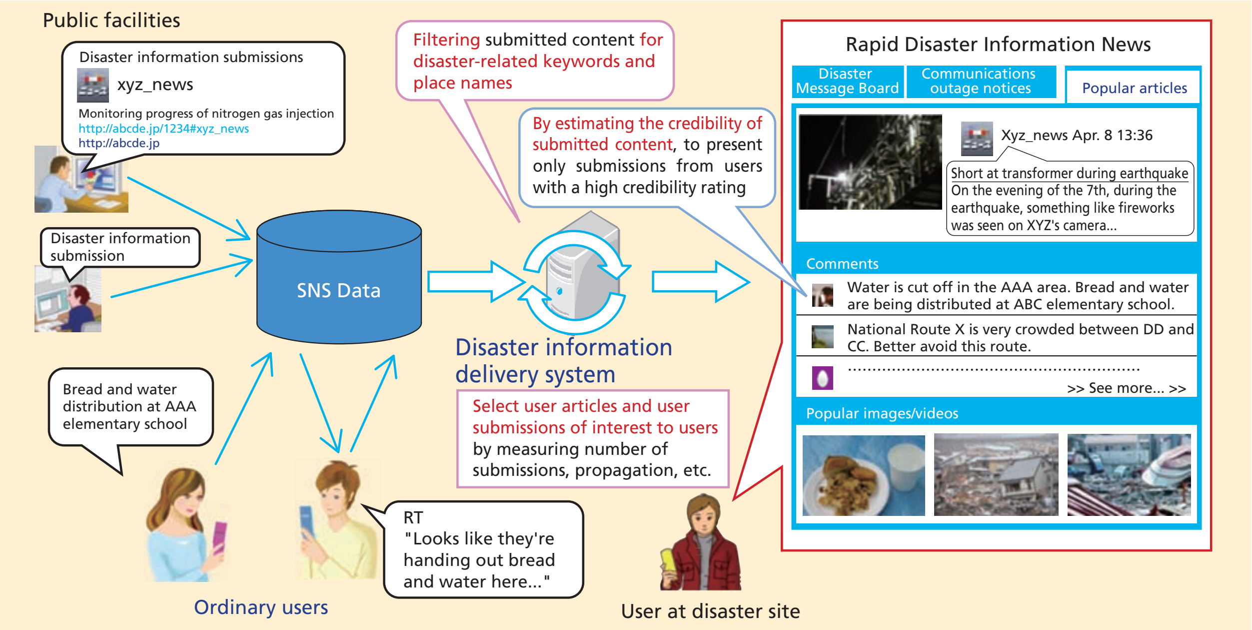

Figure 18 Disaster information delivery system

3.2 Long-term Recovery Measures

1) Next-generation Green Base Stations

Since guaranteeing base-station power is so important, it is being considered among short term measures as well as long term measures. The weight and volume of base stations must be limited when installing various locations. Therefore, it is not always possible to increase the number of lead-acid storage batteries or install a power generator. Thus, we are advancing R&D on disaster-resistant base stations that can guarantee power during power outages. For this purpose, power is collected from diverse sources such as solar, wind or fuel battery generators or off-peak time power, and stored in more-compact lithium-ion batteries. Our goal is to build base stations (**Figure 19**) that use environmentally friendly ECO power sources, convert commercial power to DC, use green power control technology that handles battery input and output power uniformly, and can handle fluctuations in generating capacity and load flexibly. These base stations will also be more environmentally friendly through use of ecologically generated power and less peak-time power.

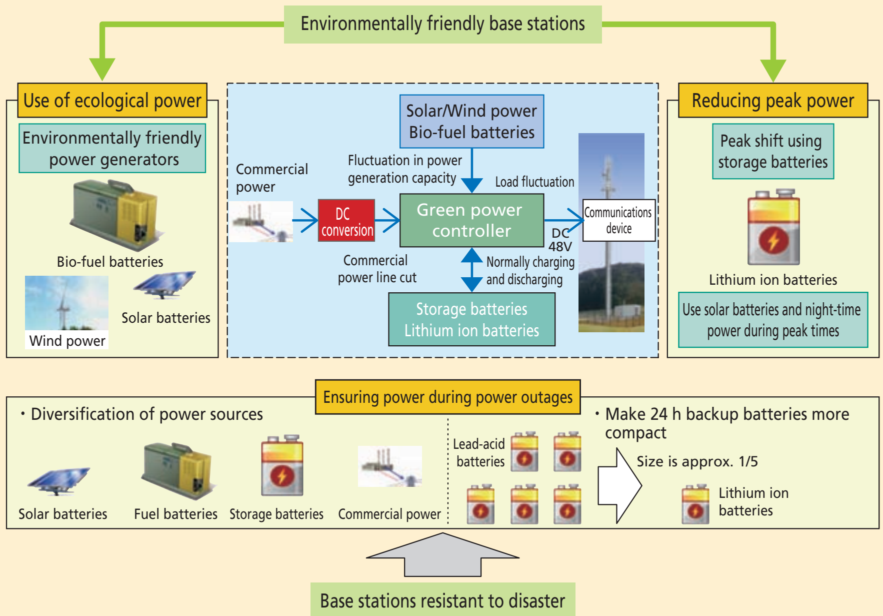

Figure 19 Overview of next-generation green base stations

We plan to complete development and evaluation of the system during FY2011, and to introduce it into some production stations in FY2012. We are also studying ways to maximize the amount of energy reclaimable from green base stations on the smart grid so that, for example, if it is sunny in Tokyo and raining in the Hokuriku region, any surplus energy in Tokyo can be sent to Hokuriku.

2) Network Virtualization

When a large-scale disaster occurs, not only do damaged facilities become unavailable, there is also additional network congestion due to the high volume of extraordinary communication such as emergency communication, evacuation instructions, and safety confirmations. Maintaining the maximum quality for this sort of communication immediately after a disaster is an issue. Network virtualization technology enables network resources to be allocated for this diversity of communication flexibly and as needed. For example, when a disaster occurs, resources can be allocated with priority for the basic communication needed for safety confirmations, and maintaining that type of communication to the extent possible (**Figure 20**).

Application of virtualization technologies to cloud computing has advanced recently, but further technical innovation is needed to apply it to communications networks, which require high performance and quality. NTT DOCOMO is advancing research toward virtual infrastructure technology that satisfies the real-time and high-availability requirements for application in communications networks.

3) Mobile Space Statistics

Mobile space statistics is an completely new initiative using mobile terminal networks, in contrast to the forementioned two measures aimed at enhancing the mobile network.

In order to allow mobile terminals to receive calls or e-mail at any time, wherever they are, the mobile terminal network periodically tracks which terminals are within the areas of each base station. Mobile space statistics infers statistical information about the population by counting the number of mobile terminals in each base-station area and making predictions using market penetration rates of NTT DOCOMO mobile terminals. As part of our contribution to society as a mobile operator, NTT DOCOMO is working with universities and public institutions to use these mobile space statistics for various public services.

For example, the following case studies were done related to the disaster planning required if a magnitude-7.3-class earthquake occurred directly beneath Tokyo. Such an event is forecast to occur with 70% probability within the next 30 years.

(1) Estimate of the number of people with difficulty returning home from each area (**Figure 21**).

(2) Estimate of the number of people passing through each area while returning home on foot.

(3) Estimate of the number of residents with difficulty returning home.

Through this collaborative research, we confirmed the following three points regarding the usefulness of mobile space statistics for disaster planning.

- The numbers of people with difficulty returning home in each area can be estimated using the newest population statistics, and this can be used to study ways to support these people.
- The numbers of people passing through each area returning home on foot can be determined, and this can be used to study ways to support them.
- The number of residents away from home and having difficulty returning can be calculated, and used in studying ways to support them.

NTT DOCOMO will continue to work to make mobile space statistics more useful in supporting development of society, to realize a richer society utilizing the characteristics of mobile technology.

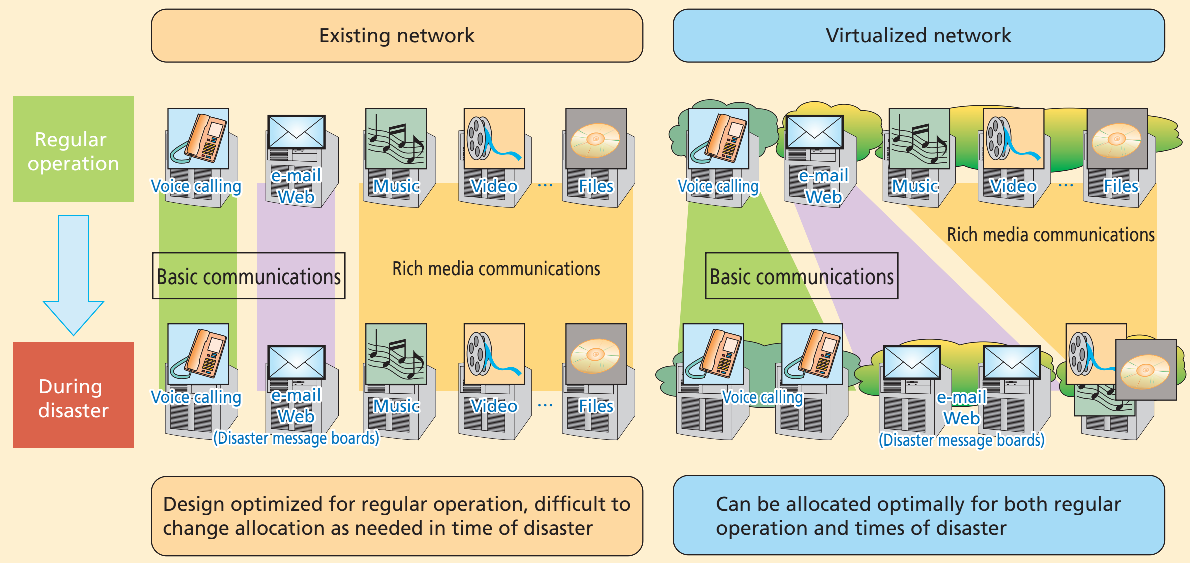

Figure 20 Disaster countermeasures using network virtualization

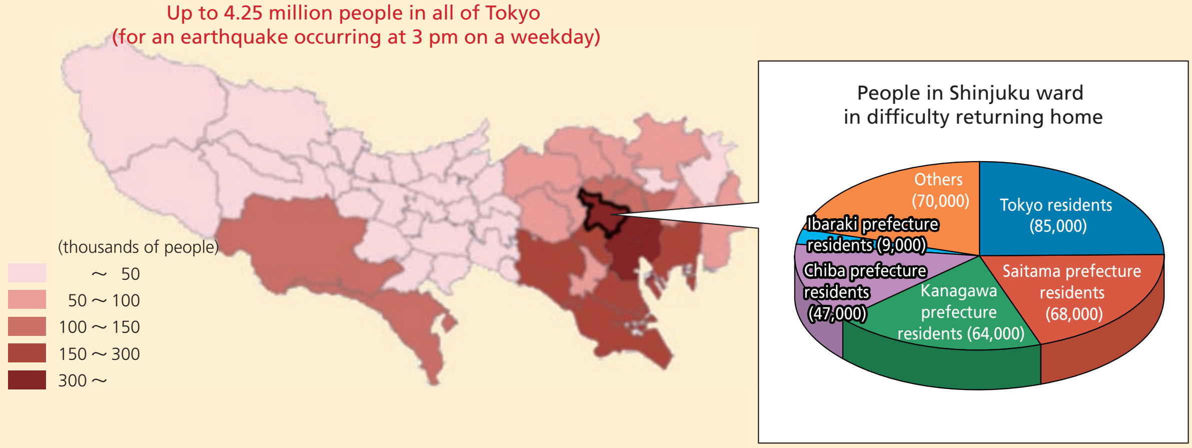

Figure 21 Numbers of people having difficulty returning home estimated using mobile space statistics

4. Conclusion

In this article, we have presented an overview reporting on how NTT DOCOMO R&D conducted technological studies and implemented practical measures for recovery after the Great East Japan Earthquake, and what kinds of techniques and initiatives we will undertake for recovery from future disasters.

NTT DOCOMO has also implemented new disaster recovery measures that include ensuring communications in high priority areas, rapid response in disaster areas, and improved usability in time of disaster. We will continue to be proactive in R&D activities related to these efforts under our mission of providing a communications network that ensures safety and security at all times.