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TELECOMMUNICATIONS PERFORMANCE IN THE M=9.0 OFF-SHORE EAST COAST OF JAPAN EARTHQUAKE AND TSUNAMI, MARCH 11, 2011

Alexis KWASINSKI[1], and Alex K.TANG[2]

[1] Assistant Professor, Department of Electrical and Computer Engineering, The University of Texas at Austin, USA, akwasins@mail.utexas.edu
[2] President, L&T Consultant, Mississauga, Ontario, Canada, alexktang@mac.com

ABSTRACT: Telecommunication networks are one of the most important lifelines in a post disaster environment. Early assessment of the damages and rescue dispatches in a timely manor require telecommunication tools. Invariably telecommunication services in the impacted areas are usually hit by above normal demands, which put the service providers in an emergency operation situation even when there is no damage to the facilities and the network. Lessons learned from the special operations in this great event that covered a huge area will enhance future post disaster performance of telecommunication systems. Hardening of hardware, such as facility buildings and equipment resistance, to strong shaking based on experiences from past earthquakes has resulted reduced loss in buildings and functional equipment. However, network interconnection links that are not upgraded to the latest NTT practices are still under extensive stress from geological factors – such as ground deformation, liquefaction, land slides, etc.

This paper intends to share information relating to telecommunication facilities visited during our field trip in June 2011 in the earthquake and tsunami impacted areas along the east coast of Japan Main Island. The information collected by talking and meeting with locals and NTT engineers will also be included. In addition to the findings, analysis and assessments of the system performance will be provided. The interdependence factor of lifelines will be discussed.

The performance of the telecommunication services in emergency response and restoration phases of this great event will also be part of this paper.

Key Words: Lifelines, infrastructure, telecommunication, lifeline interdependence, emergency response, restoration, backup electric power

INTRODUCTION

Since the privatization of NTT (Nippon Telegraph and Telephone) in 1985, like all the developed countries Japan has an open telecom market that service providers can compete in all telecom services.

The major network services are landline, wireless (aka cellular), and Internet. With advances in technology, many service providers are entering the TV market, as well. NTT DoCoMo is the largest wireless service provider in Japan, followed by KDDI au and Softbank wireless (formerly Vodafone). Majority of landline services is also captured by NTT (NTT East and NTT West). In this paper, we will focus our discussions based on the performance of NTT, because of its dominant market position and we were not able to obtain information from the other service providers relating to their performance in this disaster.

Japan has implemented an earthquake warning system that provides people a few short life-saving seconds notice of strong shaking. Therefore it is extremely important to maintain a functional telecom network to alert people of an incoming earthquake. The few seconds allow people to be prepared before the strong shaking arrives. While after an earthquake, keeping communication networks operating is important for many obvious reasons. One of those is alerting people of ensuing aftershocks.

NTT, fortunately or unfortunately, has many opportunities to learn how to make the network perform under stress to reduce anxiety and loss. Although not every aspect of the network performed to expectation, however under the circumstances (earthquake combined with tsunami) the overall system performance including recovery and emergency response was very good.

The preliminary findings and analysis within this paper are limited to the locations visited by TCLEE[1] reconnaissance team and the information collected through meeting with NTT at Sendai. It is very common that more information relating to telecom lifeline performance will be available. We intend to keep on collecting more information for the benefit of improving security of telecom lifeline in future disasters to reduce losses.

SUMMARY OF SYSTEM PERFORMANCE

The performance of the three major components of a telecom network/system will be summarized. Details of damages of each component will be discussed in the sections below. Due to page limit, only a selected number of photos will be included.

Effects on communication networks beyond the Tohoku Region were limited. In Tokyo, the iconic Tokyo Tower had its tip bended by the earthquake shacking, but this damage was not service affecting. Operations at the important communications hub at the Telecom Center in the Odaiba area in Tokyo may have likely been somewhat affected by a fire that broke out in a building under construction located a few meters away. Heavy network traffic, a common service limiting factor in many disasters, was not an extremely critical issue during this earthquake thanks to implementation of some call placement restriction, and, specially, the use of the #171 Messaging System that re-routes most communications seeking information about a person affected by the earthquake away from the disaster area. With these two strategies, traffic increased about 8 to 9 times above normal levels did not impact overall system performance.

Regardless of the preparation effort, it is next to impossible to protect the telecom network/system. However, efforts such as redundancy, resilience, and emergency response planning do provide lots of benefits during and after the extremely large events (earthquake and tsunami) of 11 March. 1995 Kobe earthquake provided many lessons to improve the network resilience design, particularly the underground cabling system.

Landlines Network (PSTN[2])

Loss of service in the immediate aftermath of the earthquake was significant with outages peaking

[1] TCLEE = Technical Council on Lifeline Earthquake Engineering
[2] PSTN = Public Switching Telecommunication Network

at almost 1.5 million lines on March 13th. These figures exclude failures in outside plant lines. Although the number of service affected lines was cut by about a half to approximately 800,000 lines by the following day, 14 March, it took about two weeks, to 26 March, to restore service to 90 % of the peaked affected lines. Of the 1,800 NTT buildings of all types in the Tohoku Region, 1,000 were affected by the earthquake or tsunami, most of them by power outages. In total, on 12 March, NTT East reported that 945 equipment buildings (COs[3] and remotes) were without commercial power. 824 were on batteries, 34 were supported by mobile gensets[4], and 34 were powered by onsite backup power generators. Although problems at most of these buildings were addressed relatively quickly, power outages likely have been the cause of at least more than half of the telecom service outages observed on 13 March. As most of the remotes do not have on site backup power generator, they rely on the deployment of mobile or portable gensets before batteries are discharged.

Damaged roads generated difficulties to quickly deploy mobile or portable gensets, and for refueling backup power generators, which most likely caused service outages in many of these COs and remotes. In general battery reserve power are engineered to last 24 to 48 hours. On 28 March 55 of NTT East COs still had service affecting operational issues. 16 of these 55 were reported to have minor building damages and power equipment were inundated. Most of these 16 buildings are located in coastal areas affected by the tsunami, 5 of them (Kamiarisu, Shimo Omata, Sumita, Kesen Yokota, and Hikoroishi) are located a few kilometers inland, northwest of Ofunato and Rikuzentakata. The failure mode of these 5 COs is not clear because they were not directly affected by the tsunami. Their most likely failure cause was power related. TCLEE's damage assessments were able to examine 5 of the 11 COs within tsunami impacted area with minor damage to buildings and power supply issue: Miyako, Yamada, Otsuchi, Kamaishi, and Ofunato.

Although power outages were an important service affecting issue for the PSTN, direct damage caused by the tsunami also led to extensive communication outages. Of the 55 buildings with issues on 28 March, 26 of them were reported to be tsunami demolished exchange offices and facilities, with significant damage to relay transmission lines, and other equipment. Seven of them (Unosumai, Sanriku, Rikuzentakata, Shizugawa, Onagawa, Nobiru, and Shichigahama) were examined by TCLEE's reconnaissance team. One more in the town of Utatsu was not possible to be identified during the damage assessment because it had already been destroyed by the tsunami. In Sanriku, Shizugawa, Onagawa, and Rikuzentakata, the CO buildings showed relatively little external damage and were one of the few buildings standing in the town, which suggested an adequate CO building performance considering the tremendous magnitude of the earthquake and tsunami. The CO building in Onagawa amazingly held the remains of a home on its roof. In Unosumai, the CO building walls were destroyed but the foundations and inner supporting structure, such as metal beams and columns, remained in place. Nobiru CO building had all the upper third portion of its outer walls destroyed by the tsunami. Shichigahama a 2-floor concrete CO building was entirely uprooted from its foundations and carried 500 m inland by the tsunami. Almost all of the remaining COs, with similar failure mode, were located in the Miyagi Prefecture central eastern coast. Like in Shichigahama, COs in Okawa, Ogatsu, Aikawa, and Tokura had its buildings carried away several hundred meters by the tsunami from its original site. In other cases, like in Kitakami, the damage was similar to that observed in Unosumai. Service restoration—a regulatory requirement for basic wired telephony service even when the dwellings in the service area were destroyed—to the areas of these 26 destroyed COs involved a variety of approaches. One of those, implemented to restore service to priority circuits serving government facilities and emergency response sites in the city of Onagawa relied on digital loop carrier (DLC) systems (known in Japan as RSBM-F[5]) hosted by other exchange facilities that were not out of service—in the case of Onagawa it was the CO of Watanoha. Another of the restoration approaches used to restore service to destroyed CO, such as Shichigahama, was to deploy temporary

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[3] COs = Central Offices
[4] gensets = power generator sets
[5] RSBM-F = Remote Subscriber Module-Feeder

shelter with switching equipment at the original location of the CO building. Yet, another approach used in Rikuzentakata, was to host most of its switching services in a neighboring undamaged CO—in the case of Rikuzentakata, its switching services were transferred by Kesen Yokota CO, a small remote switching office.

TCLEE's reconnaissance team also identified important CO buildings that escaped damage thanks to their location at a protected site from the Tsunami. One of these COs is in Kesennuma, which escaped damage because the building is located on a hill. Another one of these COs is in Ishinomaki, which although received some flood waters from the tsunami, its building was not seriously damaged because it is located behind a hill that shielded this CO from most of the damaging energy of the tsunami waves.

Other failure mode of 4 out of the 55 PSTN COs without service on 28 March was isolation due to severed transmission links. These links were severed due to fiber optic cables collocated with bridges that were destroyed by the tsunami. Tsunami also damaged repeater station like the one in Saichi. Service restoration involved physically repairing these fiber optic links and deploying mobile microwave transmission repeaters, such as those found in Otsuchi. Finally, of the 55 buildings still experiencing issues on 28 March, 9 of them were located in the forced evacuation area around the Fukushima Daiichi nuclear power plant where access was prohibited due to health issues associated to radiation exposure. Additional extensive outages were caused by tsunami damage to outside plant infrastructure, 6,300 km of aerial cables and 65,000 poles. However, this damage occurred where dwellings and most of other buildings were also destroyed by the tsunami so there was no immediate need for service restoration to such an extensive outside plant damage.

The landline network was in a better shape as a result of lessons learned from Kobe earthquake in 1995. Underground cables were installed in an earthquake protected/proof design, such as using flexible conduits with sliding joints, and flexible joints at manhole connections and tunnels. This is a good topic for further study with the help of NTT. The concept can be applied to other lifeline underground facilities.

Wireless (Cellular) Network

Extensive outages were also observed in wireless communication networks (aka Cellular Network). Although an appreciable number of base stations were destroyed by the tsunami, power outages were the causes of base station failures. Majority of wireless base stations do not have power generators, they all depend of battery reserve power that usually last up to 8 hours. Two observations support this conclusion:

1. Base stations out of service peaked at 6,720 24 hours after the earthquake, whereas the number of outage base stations on the day of the earthquake was 2,200.
2. An important coverage drop inland away from the tsunami affected area, where there was no co-located PSTN infrastructure that failed, and where there was no particularly excessive damage affecting wireless networks infrastructures.

On 13 March, 4,300 base stations of the NTT DoCoMo network were still out of service can be described as follows:

- Iwate Prefecture: 50 % of normal coverage inland with no network coverage along the coast.
- Miyagi Prefecture: almost no coverage except for the city of Sendai, which was mostly covered.
- Fukushima Prefecture: no coverage along the coast. Network coverage inland was about 10 % in the eastern half, and 100% in the western half.

By 22 March, 788 cell sites containing base stations that were out of service on 12 March remained out of service. By 28 March, 307 cell sites were still out of service; 224 had severed transmission links, 62 were destroyed by the tsunami, and 21 were still needed to be inspected. By late April 59 cell sites were still not back on line. In addition to this number of cell sites that were out of service on 22 March, on 28 March, and late April 68 more cell sites (177 base stations) were out of services in the vacated area around the Fukushima Daiichi nuclear power plant.

TCLEE's reconnaissance team was able to document 59 cell sites destroyed by the tsunami, but did not find any damaged sites inland, nor received reports listing damaged base stations inland. Since base stations are located at ground level, it is reasonable to expect damage by tsunami. The TCLEE reconnaissance team found the following failure modes:

1. Base station destroyed by large debris carried by the tsunami,
2. Tsunami lifted up the base station and relocated it,
3. Towers collapsed by debris, and
4. Fires that occurred in the surrounding area.

Causes identified that led to failure mode #3 include failed (twisted and fractured) braces in lattice-type towers, and foundation failures and bucked poles of sites using monopole towers.

Service restoration to damaged base station involved some limited use of COW[6]s, micro-cells, equipment repaired, equipment replaced, or shifted coverage to neighboring cell sites that were not damaged and are located on higher ground with increased capacity. Another cause of wireless communication outages was tsunami-caused damage to switching equipment co-located with PSTN equipment at a destroyed or affected CO. In these cases, switching functions were assigned to other COs. Severed transmission links in between switching nodes and base stations also affected wireless networks coverage. Restoration of these transmission links involved the same strategies used in the PSTN and also adding satellite links. In some key locations up to 870 satellite phones were used to provisionally restore wireless services.

Internet Network

Due to decades of building the 'dense-mesh' network in responding to the increasing demand of Internet services, this network held up very well among all the service outages of landlines and wireless network. The network was able to cope with an estimated increase of about 200 times normal traffic after the earthquake/tsunami. The down side was that cyber criminals took advantage of that to exploit the victims.

With a self-healing quad peering point-based dense mesh, the network performed well. The four peering points are BBIX[7], JPIX[8], JPNAP[9], and NSPIXP-6[10].

There are three submarine cable landing sites (Kitaibaraki, Aligaura, and Tokyo) within 200 km of the epicenter. Unlike the earthquake off the southern tip of Taiwan in 2006, which knocked out millions of users due to submarine cables damage. Although there was damage to the submarine cables, only 100 out of 6,000 Japanese Internet routing prefixes were temporarily withdrawn from service. This is quite an achievement considering the magnitude of the event. The damage was likely to be caused by submarine landslide. With the 'dense-mesh' and the dense web of international connectivity, this network allows the Japanese internet to route around the damage area and keeps the data packets flowing. Japan telecommunication, a critical gateway of Internet traffic in and out of Asia, has performed well.

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[6] COW = Cellular On Wheels
[7] BBIX = Broad Band Internet Exchange
[8] JPIX = Japan Internet Exchange
[9] JPNAP = Japan Network Access Protection
[10] NSPIXP-6 = Network Service Provider Internet Exchange Point - 6

DAMAGED SITES

During the reconnaissance trip, many photos were taken, a selected few are presented here in this section to provide a better perspective of the situation of the damage. The photos show both failure mode and good performance.

Landlines Network (PSTN)

The COs at Miyako, and Ofunato all experienced power outage and mobile power generators were brought in to maintain service. It is possible that both of these COs have backup power generators, which might be inundated. Figures 1 to 2 shows the condition of the buildings and the mobile power equipment.

Fig. 1 Miyako CO on the left and the mobile power generator on the right

Fig. 2 Ofunato CO with more than one mobile power generators

The COs at Yamada, Otsuchi, and Kamaishi were serviced by portable generators. Figures 3 to 5 shows the portable genset on site to provide power. At Kamaishi, a fuel truck nearby was to provide fuel, indicating the expectation of a very long duration of power outage in the area.

In addition to power outage, which had the biggest impact to the PSTN network, total destruction of COs by tsunami were also observed. It was hard to separate any earthquake damage from the water damage after the tsunami. In order to effectively utilizing the resources to provide service, many of these destroyed COs were left unattended. Nobiru CO building (Fig. 6) had all the upper third portion of its outer walls destroyed by the tsunami. Shichigahama 2-floors concrete CO building (Fig. 7) was entirely uprooted from its foundations and carried 500 m inland by the tsunami.

Figure 3. Yamada CO, genset on the left

Figure 4. Otsuchi CO

Figure 5. Left: A portable genset at Kamaishi CO with a truck of additional diesel storage expecting very long autonomies. Right: Watertight door at Kamaishi CO.

However, in Sanriku (Fig. 8), Shizugawa (Fig. 9), Onagawa (Fig. 10), and Rikuzentakata (Fig. 11), the CO buildings show relatively little external damage and are one of the few remaining standing buildings in the town, which suggest an adequate CO building performance considering the tremendous magnitude of the tsunami—notice that the CO building in Onagawa has the remains of a home on its roof. In Unosumai (Fig. 12) the CO building walls and roof were destroyed but the foundations and inner supporting structure, such as metal beams and columns, remained in place.

Figure 6. Noburi CO was gutted by the tsunami

Figure 7. Shichigahama CO. Left: The original location of the building with the temporary huts used to restore service. In the front are the remains from the original building. Right: Foundations of the original building carried 500 m. inland by the tsunami.

Figure 8 Sanriku CO, left is the side view, right is the back view

Figure 9 Shizugawa CO

Figure 10. Onagawa CO with a roof of another house on its roof.

Figure 11 Rikuzentakata CO. Right: Disposed water damaged batteries.

Figure 12 Unosomai CO, side and roof were replaced on the back half of the building

Wireless Network

In addition to power outages many base stations near the coastal areas that were hit by the tsunami were destroyed. Figures 13 to 17 show the conditions of the base stations after the tsunami. There was at least one case of fire at a base station in Yamada, Figure 17. COWs and microcell were quickly installed to provide coverage and new equipment was installed to restore service in the heavily damaged areas, Figures 18 to 20. Small gensets were also in place where mircocells were set up, as most locations were still out of electricity. A temporary microwave dish was constructed to provide long distance link, Figure 21.

Many newer antenna towers such as those shown in Figures 13 and 14, stood up to impact of debris from the tsunami. However, many unanchored equipment enclosures expectedly performed poorly. As many base stations also act as repeater stations, the impact on the network was substantial. With dense mesh network, redundancy, satellite phones, and fast emergency response, the duration of inconvenience to subscribers was much less in a disaster of this scale.

Figure 13. Destroyed cell site at Sanriku

Figure 14. Destroyed cell site at Ishinomaki

Figure 15. Cell site destroyed by the tsunami in Rikuzentaka

Figure 16. A collapsed tower of a base station located in the Karakuwa Peninsula.

Figure 17. This base station in Yamada was also damaged by fire in addition to tsunami damage

Figure 18. COW in place to restore coverage

Figure 19. Microcell install beside a damaged bridge near Rikuzentakata

Figure 20. New base station equipment was being installed in Heita.

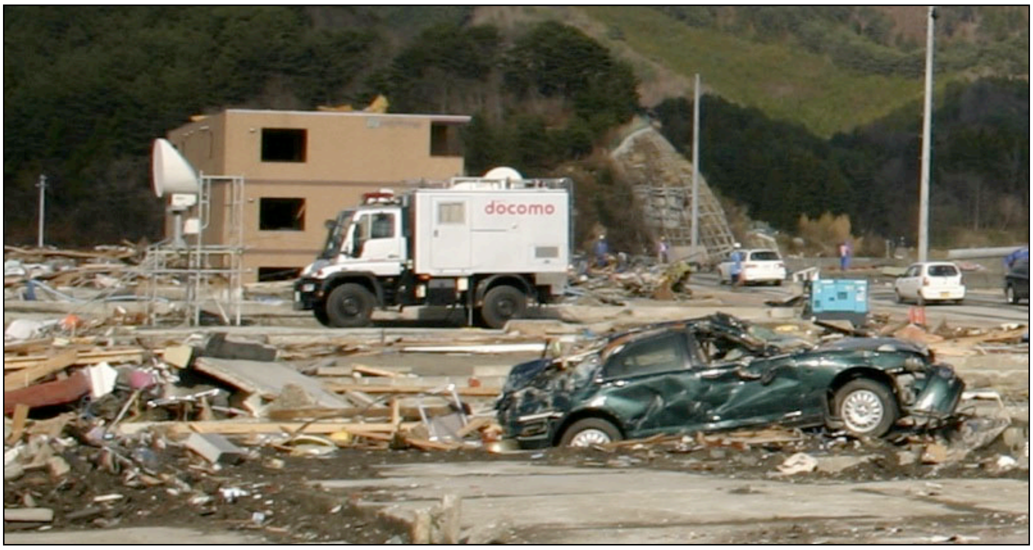

Figure 21. A temporary microwave repeater in the town of Otsuchi

CONCLUSIONS

There are many new lessons as well as validation of upgrades based on past lessons. The overall performance of the telecom network/system within Tohoku area was good. There are rooms for improvements. We urge the service providers to work with researchers on understanding the failure modes to improve designs and emergency response planning to develop a more resilient system.

With the deployment of fiber optics network to meet the demand of speed and volume of data packet delivery, the end users will now be in the boat as the telecom service providers – power outage. The recent announcement of NTT entering into the power business market may hold hope for the future of power interdependence issues.

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