Impact of Tohoku Earthquake on R&E Network in Japan

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ABSTRACT

The Internet is one of the important infrastructures in our daily life, and its highly distributed and autonomous natures have been said to be robust against failures. This paper reports an impact of an unexpectedly large earthquake (M9.0) hit to the northern part of Japan at 14:46:18 on 11th March (UTC+9), 2011(the East Japan Earthquake) [2] on a nation-wide research and education network (SINET4 [10, 12, 13]) in Japan. We show that the network managed to run even after the earthquake thanks to two different levels of redundancies, though some physical links were damaged; consequently, the impact on the routing (both BGP and OSPF) was insignificant. At the epicenter area, some network nodes (i.e., universities) were disconnected from the network by the blackout upto 70 hours. In the view of long-term traffic trend, it took 5-6 weeks for recovery of the traffic volume there. On the other hand, in the backbone network, the rapid decrease (40-50%) in the traffic volume only lasted for a few hours due to the blackout near the epicenter, and the impact of the traffic decrease in the epicenter area on the backbone traffic is estimated to 15-25%. Furthermore, we confirmed the increases of the traffic generated by users who rushed to access to the network for obtaining up-to-date information and videostreams.

1. INTRODUCTION

The Internet is one of the most important infrastructures in our daily life, and it has been said to be robust because of the highly distributed and autonomous properties of the network. Indeed, for example, IP-level routing enables us to maintain network connectivity from a simple link failure.

At 14:46 on 11th March (UTC+9), 2011, we faced an unexpectedly huge earthquake (M9.0) called the East Japan Earthquake whose damages have been widely spread in the eastern and northern part of Japan. Over 15,000 were missed and lifelines have been hugely damaged in the epicenter areas. Even in greater Tokyo area, most transportation systems had stopped for a day, forcing over 24,000 people to stay at office or campus during the night. In terms of ICT (information-communication technology) infrastructure, we experienced that voice and messaging of mobile phone were highly congested, but the wired Internet services were relatively stable.

The purpose of this short article is to show the impact of the huge disaster on a nation-wide research and education network called SINET4 (Science and Information Network) connecting to over 700 universities and research institutes in Japan. Specifically, we focus on network connectivity and change of edge-level and backbone-level traffic volumes in SINET4. The design, implementation and traffic characteristics of academic networks are likely largely different from those in nation-wide commercial ISPs. However, we expect that this paper will be a part of the contribution to characterize the huge impact of the disaster on the Internet.

The main findings of the paper are as follows; (1) The network connectivity was maintained thanks to two levels of network redundancy though some physical links were damaged. However some network nodes (i.e., universities) lost network connectivity to the backbone network for 1-2 days due to the power blackout. (2) Recovery of the traffic volume took 5-6 weeks in the epicenter area. (3) The rapid decrease (40-50%) in backbone traffic volume was observed for only 1-2 hours (the average impact on the traffic volume after the first drop is estimated as 15-25%). On the other hand, we found an increase in the traffic volume in one of the backbone links because of users accessing to realtime streaming sites to obtain the emergency information.

2. SINET OVERVIEW

SINET4 is a nation-wide research and education network in Japan, covering over 700 organizations (e.g.,

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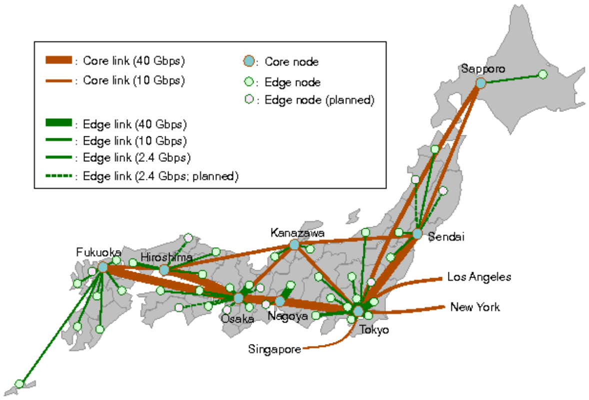

Figure 1: SINET4 network topology

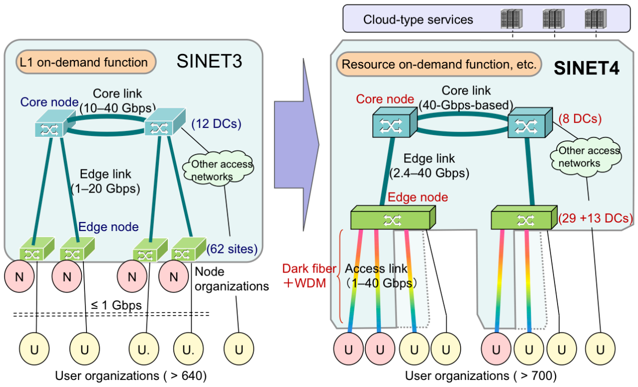

Figure 2: Upgraded from SINET3 to SINET4

universities, colleges, national laboratories), and providing Internet connection for more than 2 million academic users as well as special service (i.e., VPN/VPLS services, and L1 bandwidth on demand service) for big science users (e.g., high-energy physics, and astrophysics). The backbone of SINET4 consists 40Gbps/10Gbps links that forms multiple loops to increase the redundancy of the network as shown in Figure 1. Each backbone link is a protected link composed of two physical links whose geographical routes are different. Core routers are installed at commercial datacenters in eight cities in Japan (core nodes). Additionally, L2 switches and L1 switches are located at commercial datacenters in each prefecture (edge nodes) to provide network connection to the organizations and regional academic networks. The use of L1 and L2 switches enables us to reduce the number of high-end routers in the network. For external links, SINET4 has direct links to commercial IXes in Tokyo and Osaka, and to international R&E networks (Asia and US). From the view of BGP, some regional R&E networks and organizations are connected to SINET4 as customer peers. However, most of the organizations do not use dynamic routing, and route reflectors statically generate appropriate routes and distribute them to other networks.

Note that in March 2011, the network was being upgraded from SINET3 to SINET4 (see also Figure 2). In SINET3, edge nodes were located at 62 national universities ("node organizations" in the figure) that regional universities/institutions ("user organizations") connected to. Only SINET3 edge nodes (universities) connected to SINET4 core and edge nodes (datacenters), though the SINET4 backbone network had already been available. Thus, regional universities lost Internet connectivity if SINET3 edge nodes disconnected from the backbone.

2.1 Redundancy of network

SINET4 provides two different levels of network redundancy in order to maintain its network connectivity; (1) physical link level and (2) network topology level. Physical link level robustness is realized by dual physical links (i.e., protected links) that route along different geographical paths between two core nodes. This guarantees robust peer-level connectivity. The network topology level one is provided by redundant multiple loops in the network topology. Also, each core and edge node are located in commercial data centers supported by private electric generator systems. Thus, the links and nodes have enough redundancy for providing network connectivity to users.

3. IMPACT OF EARTHQUAKE

3.1 Link-level network connectivity

First of all, we focus on the network link-level and node-level failures by the earthquake. Figure 3 illustrates the physical damage to the SINET4 backbone network. The core nodes are located in Tokyo, Sendai, Sapporo and Kanazawa on the map. Also, the edge nodes are placed in Hirosaki, Yamagata, and Koriyama. The difference of colors in links represents the level of the damage due to the earthquake; Red corresponds to the disruption of a protected link (i.e, link down), Gray for a switched link from a primary physical link to a secondary one (i.e., connectivity still remained), black for non-damaged links. Damage from the earthquake concentrated mainly in the Sendai area near the epicenter, marked as "x" on the map. The Sendai node lost direct connectivity to Tokyo and to Kanazawa, but the node was not isolated; the links between Sendai and Sapporo and between Sapporo and Tokyo were still available though one of the physical links was damaged. All edge links from Sendai remained thanks to protected links. Similarly, the Sapporo node located in the fourth largest city in Japan was not disconnected from the backbone. Orange circles and hours at nodes represent the duration that private electric generators worked at each datacenter during the blackout after the earthquake. The blackout lasted for 96 hours at the Sendai node, but due to the backup power supply, the backbone network was not disrupted and managed to provide connectivity. Most of the damaged links shown in red and gray were recovered within 40-60 hours after the earthquake. On the other hand, one of the international links to the US was damaged for 4 months.

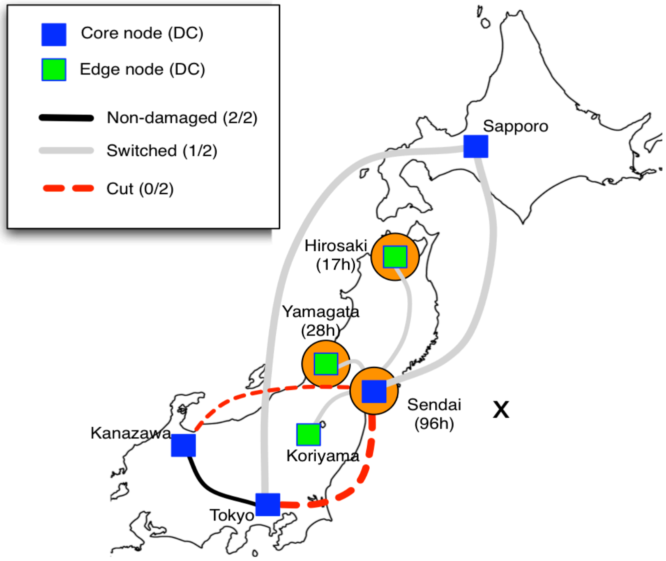

Figure 3: Link and node level damage of the network

On the other hand, the universities and research institutions were directly impacted by the effect of the earthquake. Table 1 lists the disconnected time of the universities/institutions (ex-edge nodes in SINET3) from the backbone network due to the blackout. The most impacted nodes were located near the epicenter; Hirosaki, Sendai, and Tsukuba areas. Only Keio U. is far from the epicenter, in Yokohama 300km away from the epicenter. The difference of the disconnected time from the time the earthquake occurred is mainly caused by (1) multiple cuts of the power lines and (2) the time for exhaustion of backup battery (i.e., UPS) at universities. The procurement for our UPS system in SINET3 required at least 10 minutes of power for network equipment. The uptimes are also largely different among nodes; it took over 2 days in the worst case. These universities provided connectivity to other regional universities/institutions as SINET3 edge nodes or different regional ASes. Thus, such connected ones were also isolated from the network though we do not know the total number of the suffered users.

Table 1: Disconnected time of the universities/institutions (ex-edge nodes in SINET3)

Node	Time	Duration
Hirosaki U.	3/11 14:51 - 3/12 16:45	25h54m
Tohoku U.	3/11 15:16 - 3/13 13:54	46h38m
KEK	3/11 15:29 - 3/14 11:44	68h14m
Tsukuba U.	3/11 16:07 - 3/11 17:43	1h35m
Keio U.	3/11 16:09 - 3/12 00:06	7h57m

In summary, link-level connectivity in the backbone remained though some fibers were cut and some data center suffered from the blackout. However, the customers (i.e., universities and research institutes) were in any event disconnected from the Internet due to the blackout.

3.2 IP-level network connectivity

Next, we investigate the effect to the routing dynamics. IP level network connectivity in SINET4 relies on BGP and OSPF.

For BGP, we have been collecting all BGP messages at route reflectors for research purposes. By manual inspection of these messages, not surprisingly, we confirmed that there were only three of our customer ASes disconnected from SINET4 out of over 400 peers. Also, one of the two international links to the US was damaged, however, the impact on BGP was limited because the routes were simply switched to the non-damaged one.

For OSPF, we only logged the event messages generated by routers and switches. So, it is impossible to reconstruct the sequence of events precisely. However, the type of messages still might be useful in understanding the routing behavior. We found that 6 OSPF nodes temporally disappeared due to the blackout in total. This small impact is mainly because L3 routers are located in only eight cities, and most universities do not use dynamic routing.

As expected, the impact on the routing system was less for both BGP and OSPF thanks to the robustness of link level connectivity, though some leaf nodes disappeared in the blackout area.

3.3 Traffic volumes near epicenter area

Now, we turn into the impact on the traffic volumes near the epicenter area. Figure 4 displays the long-term aggregated traffic volumes in two edge links near the epicenter area. The original data was 1-minute granu-

Figure 4: Edge-level traffic

larity byte counter data passing through interfaces at L2 switches taken by SNMP. In and Out indicate the direction of the traffic from the SINET backbone view. Clearly, we can confirm a sudden drop of the traffic volume on 11th March due to the blackout. In general, the variation of traffic volume in our network is highly affected by the activities of students on campuses. Different from the traffic variation in the residential broadband users [1], the peak time of traffic volume in SINET4 is 1-2 PM on weekdays and less traffic during weekend. Also, different from other countries, the academic fiscal year starts in April in Japan. Thus, usually, the traffic volume in March (i.e., in spring break) is relatively smaller than other months. After the blackout, traffic volumes increased gradually, and reached roughly the same level before the earthquake by the end of April. One plausible reason for such a gradual recovery is that (1) some universities in Tohoku area postponed the start of the new semester from early April to May, and (2) students gradually came back to campus. We could not check the actual connectivity of all regional universities, but the gradual recovery of volume suggest that the damage to physical links seems relatively small and it was recovered earlier.

3.4 Traffic volumes in backbone

Next, we examine traffic volumes in the backbone network to understand the impact of the earthquake. The annual traffic growth rate in the backbone has been approximately 1.5 for the past five years, in spite of the seasonal trend.

Figure 5 indicates the long-term trend of the backbone traffic volume taken at two backbone links with SNMP (the arrows point the time of the earthquake occurred) [1]. As mentioned earlier, the total amount of traffic volume in SINET usually decreases during March because of the spring break. Even considering such seasonal variation, the backbone traffic volume was recovered to the same level 3-4 weeks after the earthquake. On the other hand, it is hard to identify significant decrease in traffic volume at backbone-level except the day of the earthquake (i.e., Out traffic was mostly half immediately after the earthquake), even though the some universities had lost network connectivity for 1-3 days. Also, note that the impact of the earthquake on backbone traffic may be relatively small because it occurred on Friday afternoon; the traffic volume on weekends is much smaller than that of weekdays in academic networks, different from residential user traffic.

Figure 5: Backbone traffic at IXes

Finally, we shed light on the backbone traffic pattern on the day of the earthquake. Figure 6 represents the change of the daily normalized traffic volume to/from commercial Internet exchanges (IXes). The red and blue plots correspond to the traffic volumes on 11th March (the day of the earthquake) and the green and purple are those on 6th March (1 week before the earthquake) as reference. Inbound and outbound indicate the view from the SINET backbone. Clearly, we can confirm a sudden decrease of traffic volume just before 3 PM.

In Figure 6 (a), outbound traffic volume (to IXes) remains low after the earthquake (40-50% of traffic loss).

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[1] The decrease in the traffic volume after 24th Mar in Figure 5 (b) is due to the replacement of the link in the migration, not related to the earthquake.

However, inbound traffic volume (from IXes) resumed within 2 hours from the 30-40% immediately after the earthquake. The ratio between the red (blue) plots and the green (purple) plots on evening (6-9 PM) show the impact of the traffic decrease in the epicenter area on the backbone-level network traffic volume; approximately 15% for inbound volume and 25% for outbound volume.

Figure 6 (b) indicates the backbone traffic variation at a different link. The behavior immediately after the earthquake is similar to the previous figure, however, the inbound traffic volume (red plot) increased more than that of the previous week (green one) in 4-11 PM with some spikes at 5, 6, and 10 PM. Also, the difference between outbound traffic volumes for two days is smaller than that of the previous figure. With sampled netflow data at the backbone, we identified the increase of the traffic volume arrived from two specific ASes (Akamai (AS20940) and Limelight (AS22822)) that are well-known CDN providers. The traffic flows from Akamai used mainly TCP port 1935 (macromedia-fcs) and the TCP port of the traffic volume from Limelight is mainly TCP port 80. The former is a typical port for video streaming used by Ustream [14]. The latter is also likely realtime video-streaming traffic by a popular Japanese video streaming site (NicoNico Douga [9]). Considering the duration of the blackout in the epicenter areas, most users contributing this streaming traffic are those in the non-damaged area.

A plausible reason for this increase is due to redistribution of breaking news on TV to the Internet. Currently, TV companies have not provided simultaneous broadcast of their contents to both TV and the Internet, and also the Japanese law does not allow users to re-broadcast TV programs to the Internet. However, a user of Ustream just started to redistribute captured TV news program to the network in realtime [2]. After a few hours, the official and temporal real-time streaming by the TV companies started collaborating with these streaming sites as an exceptional case.

We also checked the traffic volume from micro blogs and SNSes (e.g., Twitter [11], Facebook [3], and Mixi [8]), since it is thought that they were helpful in obtaining and sharing the emergency information as opposed to cell phones in the earthquake. However, we could not confirm clear rapid increase of the traffic volume from them. These data are mostly text messages, so their contribution to the backbone was hidden in other traffic.

In summary, the traffic volume from the epicenter area rapidly dropped because of the blackout, but the realtime video streaming traffic had non-negligible contribution to the backbone traffic.

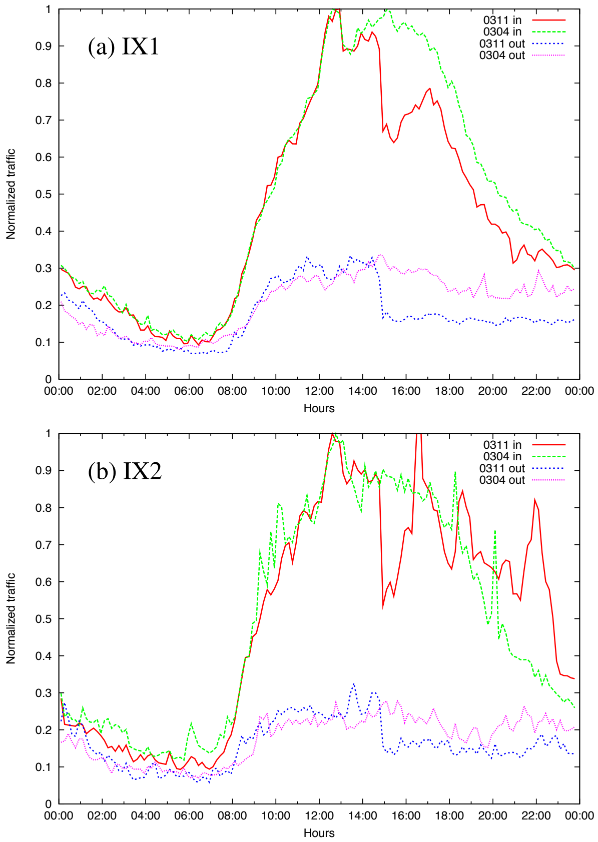

Figure 6: backbone traffic at IXes in the day of the earthquake

4. DISCUSSION

As explained, our backbone network was robust enough because of two redundant mechanisms. The protected link provides connectivity between core nodes, and the loop topology guarantees IP-level connectivity. Depending on the level of damage from the disaster, both mechanisms were essential in continuing the network service in our case. Indeed, we could continue to provide connectivity to the Sapporo node located in the fourth largest city in Japan without disruption. Our mission is to provide network connectivity to universities, and we consider that the design and implementation of our network achieved excellent robustness at acceptable cost. However, we also recognized the importance of the dispersion of the peering points, though there was less impact on connectivity to the commercial IXes and to the international R&E networks.

Furthermore, the rapid increase of the traffic volume in the backbone highlighted the importance of the Internet as a lifeline infrastructure. An integration of TV and Internet worlds has not been realized yet in Japan.

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[2] It is thought that the number of users to watch this program increased via Twitter or SNSes. The total number of viewers are over 900K and the number of tweets related to this site are over 85K.

However, our results demonstrated the high availability and flexibility of the Internet under the disaster situation.

5. RELATED WORK

There are a few studies measuring and characterizing failures in the Internet. Most of them are related to long-term routing dynamics (e.g., IS-IS [6,7], BGP [4]). A study of the Sprint backbone network [6] showed that 30% of the failures are shared by multiple links and can be attributed to router/switch related problems, and the rest of them are related to single link failures. Medem et al. [7] pointed out that the failures related to circuits/fibers in the Internet2 network required 11 hours to be recovered on average. In this sense, the damage to our network is more significant than the usual failures, as expected.

Kitamura et al. [5] discussed the impact of the earthquake that occurred on the coast of Taiwan in 2006 on Asia-Pacific networks (APAN (Asia-Pacific Advanced Network) and national research and education networks (NRENs)). Their focus is mainly on inter-AS collaborative network operations and traffic engineering to reroute BGP paths to calm down the impact of the earthquake, since many international submarine cables between Asia and the US were damaged near the epicenter. In this sense, the impact of the East Japan earthquake on other R&E and commercial networks is not significant from the viewpoint of our network.

6. CONCLUSION

We report the impact of the massive earthquake hit to Japan on the academic network. Two types of network redundancies prevented the network disruption even against multiple cuts of the physical cables. The traffic volume at the epicenter area was recovered 4-5 weeks after the earthquake. On the other hand, the sudden drop (40-50%) of the traffic volume at the backbone level was limited only for 1-2 hours, and the impact after the first dop is estimated as 15-25% of the backbone traffic volume. Furthermore, we confirmed that some backbone traffic volumes increased more than usual because of the rush to real-time video streaming sites to obtain the realtime and emergency information.

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