The Japan Earthquake: the impact on traffic and routing observed by a local ISP

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ABSTRACT

The Great East Japan Earthquake and Tsunami on March 11, 2011, disrupted a significant part of communications infrastructures both within the country and in connectivity to the rest of the world. Nonetheless, many users, especially in the Tokyo area, reported experiences that voice networks did not work yet the Internet did. At a macro level, the Internet was impressively resilient to the disaster, aside from the areas directly hit by the quake and ensuing tsunami. However, little is known about how the Internet was running during this period. We investigate the impact of the disaster to one major Japanese Internet Service Provider (ISP) by looking at measurements of traffic volumes and routing data from within the ISP, as well as routing data from an external neighbor ISP. Although we can clearly see circuit failures and subsequent repairs within the ISP, surprisingly little disruption was observed from outside.

Categories and Subject Descriptors

C.2.3 [**Computer-Communication Networks**]: Network Operations—*Network monitoring*

General Terms

Measurement, Management

Keywords

Internet, traffic, routing, measurement, network management, ISP, disaster

1. INTRODUCTION

The Great East Japan Earthquake and Tsunami on March 11, 2011 struck off the northeast coast of the country, leaving more than 15,000 people dead and more than 4,000 still missing even 6 months after the disaster. Although major facilities in Japan are designed as earthquake-resistant, and thus, the direct damage by the earthquakes was limited, the tsunami was devastating to the coastal areas and is reported to account for 90% of the deaths. On that day, around 4.4 million households, almost 10% of the country's households, were left without electricity.

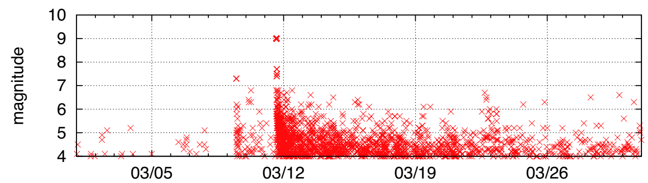

Figure 1: Earthquakes larger than Magnitude 4 in Japan for March 2011

Tokyo only received limited physical damages. However, immediately after the main earthquake, all public transportation, including trains and subways, was stopped. Highways and airports were closed. By evening, roads were filled with people walking home, and cars were completely stuck on the roads. It was only after midnight that a small part of the transportation systems resumed operation. Many people had to spend the night at the office.

The main earthquake of Magnitude 9.0 was preceded by a number of large foreshocks starting two days earlier, and hundreds of aftershocks continuing for months. Just after the main earthquake at 14:46, a series of aftershocks followed, including ones with more than M7, an M7.4 at 15:09, an M7.7 at 15:16, and an M7.5 at 15:26. Figure 1 shows earthquakes larger than Magnitude 4 in Japan for March 2011 (the original data comes from the JMA earthquake catalog[6]). Note that a difference in magnitude of 1.0 is equivalent to a factor of 31.6 in the energy released by earthquakes so that a difference in magnitude of 2.0 is equivalent to a factor of 1,000.

The earthquake and tsunami lead to the failure of the

ACM SWID 2011, December 6, 2011, Tokyo, Japan.

Fukushima Nuclear Power Plant. Its radiation release caused large evacuations, and concerns about food and water supplies, as well as concerns about exposure to radiation especially for children. Subsequently, other nuclear power plants were taken offline upon a request of the government, which lead to a serious power shortage. Scheduled power outages began on March 14 and lasted until March 28, which significantly affected lives in the wide area of eastern Japan including the Tokyo area.

The earthquake and tsunami also disrupted significant part of communications infrastructure both within the country and in connectivity to the rest of the world. The NTT Group reported[9] that damaged facilities and disrupted power supplies at exchange offices impacted 1.5 million circuits for fixed-line services, 6,700 pieces of base station equipment and 15,000 circuits for corporate data communication services. NTT East reported that 90 routes or paths in transmission lines were damaged and, in the coastal areas, 65,000 telephone poles were flooded or collapsed and 6,300km of aerial cables were lost.

Immediately after the earthquake, the major carriers for mobile and fixed-line voice services were forced to impose restrictions on up to 95% of voice calls nationwide, because of capacity overloads due to a surge in calls[15]. In the Tokyo area, while it was difficult to place a phone call, people were still able to access Internet-based services. Despite many failures, the Internet was impressively resilient to the disaster, aside from the areas directly hit by the quake and ensuing tsunami. However, little is known on how the Internet was running during this period.

Figure 2 shows traffic at JPNAP[3], a major IX in Japan, on March 11, 2011. JPNAP has 2 exchange points in Tokyo and one in Osaka. The traffic dropped after the earthquake, and Osaka had a smaller impact. This reflects the situation; while Tokyo was hit by the quake and transportation was completely stopped, Osaka was not directly affected by the quake.

In this paper, we investigate the impact of the disaster on a major Japanese Internet Service Provider (ISP), IIJ[2]. We look at traffic measurements and routing data from within the ISP, as well as routing data from an external neighbor ISP. IIJ provides a large variety of Internet related services but our focus in this paper is on Internet services. Although we can clearly see circuit failures and subsequent repairs within the ISP, surprisingly little disruption was observed from outside.

2. OVERVIEW

Internet Initiative Japan Inc. (IIJ)[2] is one of Japan's leading Internet service providers. IIJ's backbone network connects domestic PoPs and datacenters, as well as ones in the US through multiple trans-Pacific links.

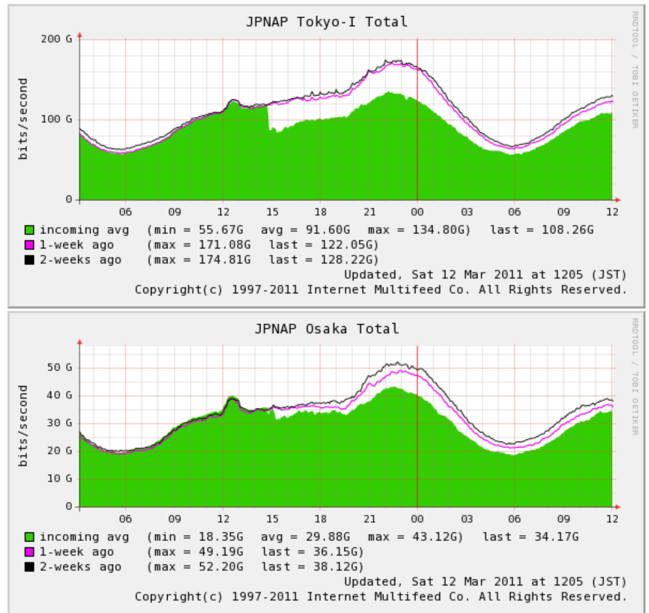

Figure 2: Traffic at JPNAP Tokyo1 (top) and Osaka (bottom) on 3.11. Courtesy of Internet Multifeed Co.

The backbone topology is fully redundant and overprovisioned to ensure automatic failover.

In this paper, we analyze data from IIJ's service networks. The traffic data is based on interface counter values collected through SNMP. For the routing analysis, we used OSPF and iBGP data. The OSPF data is collected in the backbone area, and our focus is on significant events on the links to Sendai (the major city nearest the epicenter) as well as trans-Pacific links. The iBGP data is both RIB dumps and full traces of all iBGP updates using Quagga MRT. Furthermore, we obtained a similar iBGP data from a major peer of IIJ ('neighbor provider').

Most events of interest happened during the 3 days starting from March 11 but we analyze the entire month of March in order to observe the impact of the disaster. All times in the paper is in Japanese Standard Time (UTC+9).

First, we look at a summary of the events in chronological order.

March 11, Friday:

- The earthquake of Magnitude 9.0 hit at 14:46 in the western Pacific Ocean, about 130km east of Sendai city. The tsunami of 15m, or higher in some places, first reached the coastline about 20 minutes later.
- The Sendai datacenter, the main facility in the Tohoku area, lost external power supply, and switched to in-house power generator within 2 minutes after

the main earthquake. The operation was sustained by UPS during this period.

- The 2 redundant backbone links to the Sendai datacenter were down, and connectivity was lost to 6 prefectures in the Tohoku area.
- From around 22:00, undersea cables landing in the north of Tokyo started failing. Some of the US links were down, and a link to Asian countries was also down.

March 12, Saturday:

- One backbone link to the Sendai datacenter was restored at about 6:00. At this time, 30% of the customers served by Sendai datacenter were not reachable.
- External power supply was restored to the Sendai datacenter at around 11:30.
- Two of the damaged US-links were recovered around 21:00. These links were rerouted and brought up.

March 13, Sunday:

- The second backbone link to Sendai came up at around 21:30.
- Most of the backbone connectivity was restored by then.

March 14, Monday:

- Business started. Service restoration activities as well as customer service and support work started.

In the following sections, we will look at these events in terms of traffic and routing.

3. TRAFFIC

To observe the impact on traffic, we first look at residential broadband traffic, one for the disaster area and another for the entire country, in order to compare the impact within a disaster area with the impact to the total traffic in Japan. Then, we examine traffic on trans-Pacific links and show how traffic was rerouted after some of the trans-Pacific cables were damaged.

3.1 Residential Broadband Traffic

Figure 3 shows traffic of the broadband access service operated by IIJ for the month of March 2011 for Miyagi prefecture and also for the entire country. Traffic volumes are normalized by the peak value, so as not to disclose the absolute values.

There was very little damage to equipment at IIJ's Sendai datacenter providing services to the Tohoku area, but two backbone links between Tokyo and Sendai with redundant configuration were both severed. However, one of the backbone links was restored to service by the early morning of March 12th, the day after the quake. At this point, most areas in Miyagi prefecture were

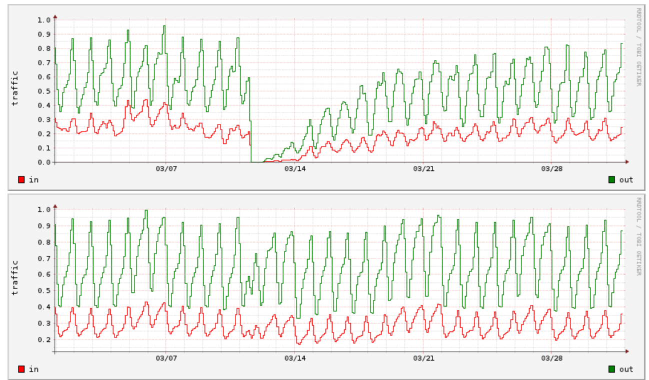

Figure 3: Residential traffic for March 2011, Miyagi prefecture (top) and nationwide (bottom)

without power, and although the Sendai datacenter was operating using in-house power generation, there was almost no traffic. Traffic slowly began to return to normal as power and communication lines were repaired, recovering up to 85% in ten days after the earthquake struck, after which the recovery slowed down. The transmission of power from Tohoku Electric Power Co., Inc. and communications services by NTT East also quickly recovered to 90% of normal in ten days after the quake, with service restored to all but a few areas by the end of April.

Looking at traffic on a nationwide level, it fell by about 20% immediately after the earthquake. Traffic was affected by power outages on the day of the quake, and a quite large number of people being stranded in the Tokyo area without a means to return home. It slowly recovered overnight. On the following day, a Saturday, traffic had recovered to about 85% of the previous Saturday. For a period of about a week following this, the impact of scheduled power outages caused traffic to drop by a few percent, but afterwards it recovered to levels similar to those before the quake. We heard that other ISPs' experience was similar, so these circumstances were not specific to IIJ's broadband access service.

There are several reasons that the impact on traffic was limited. Because there were no major facilities in the areas hit most hard by the earthquake and tsunami, critical services escaped mostly unscathed. This refers to the impact when examined on a macro level, of course. At the time of writing, now six months after the earthquake, service has still not been restored to many of the affected areas. Although many lines have been severed in the frequent aftershocks since March 11th, none has caused major disruption thanks to prompt on-site restoration work. The impact of the earthquake was kept to a minimum through painstaking efforts by many organizations and individuals involved in restoration work.

There was also little impact on traffic due to power shortages or energy saving measures after the earthquake. Initially it was thought that power shortages would be limited to the service areas of Tohoku Electric Power Company and Tokyo Electric Power Company. That said, these areas account for over half of total broadband traffic. However, in reality the reduced usage due to power saving measures was offset by increased use of the Internet in search for information.

It is likely that few end users cut back on their use of the Internet for power savings in the first place, because there is no intuitive way for users to know the power consumption of network equipment. Many organizations took steps such as shutting down as many in-house servers and PCs as possible. However, even if internal traffic dropped significantly in this case, it is difficult to cut back on the inter-organization traffic seen by ISPs due to the need to negotiate with other parties such as clients and customers. Furthermore, due to the earthquake and introduction of scheduled power outages, there was an increase in migration of work and servers to cloud services and in backing up data to remote locations, and this may have boosted traffic levels.

3.2 Trans-Pacific Traffic

The earthquake and tsunami also caused a widespread damage to undersea cables. Initially, it was reported that the damage to the undersea cables was limited. It was only after several hours that international circuits started to fail.

Japan is a major hub for trans-Pasific and intra-Asia submarine cable networks, with a number of undersea-cable landing-stations. Many cables were laid out off the Pacific coast in the northeast of Tokyo and were damaged. However, most cable operators have redundant paths from the southern coast of Japan so that they did not suffer from a complete outage.

At the time of the disaster, IIJ had 8 links to the US in a redundant and over-provisioned configuration. Figure 4 shows traffic on 3 of them to illustrate how traffic was rerouted under the outage. The traffic volumes in the plots are normalized to the link capacity.

The top plot shows traffic on a damaged link that dropped to zero at about midnight on March 11. The traffic was automatically rerouted to another link shown in the middle plot but, as a result, the peak volume on the next day was almost tripled, leaving little headroom in the link capacity. In the evening on the same day, one of the damaged links was restored using an alternate undersea cable. Then, part of the traffic on the middle link was rerouted to the restored link in the bottom plot, and the traffic level on the middle link went back to the normal level.

Figure 4: Traffic on 3 JP-US links for March 2011, damaged (top) not-damaged (middle) and rerouted (bottom)

Here, we show only 3 links but in reality traffic load was balanced among all the available links. In the next section, we will look into the routing information to better understand the situation.

4. ROUTING

4.1 Internal Routing

What story does internal routing data tell us? We look at changes in reachability of internal prefixes, analyzing how the earthquake and after-shocks influenced routing within IIJ.

IIJ uses OSPF as its IGP, and collects it in the backbone area using Packet Design's Route Explorer[11]. With the generous help of Packet Design's staff, we were able to extract all OSPF events and then focus on significant events on the links to Sendai as well as IIJ's trans-Pacific links.

Figure 5 shows that the March 11th earthquake impacted connectivity to Sendai while the after-shocks cut a few links over the Pacific. The links to Sendai failed immediately after the earthquake itself, while the few Pacific links failed some hours later, around midnight on March 11th. It is believed that undersea landslides subsequent to aftershocks are the cause of the trans-Pacific cuts. In addition, after the failure of link *JP2-US4*, another link ending at a different router on the US side is turned on. It thus appeared as a new link in the figure (link *JP2-US3*), although this link was already present in February.

The earthquake occurred at 14:46 JST. The links to

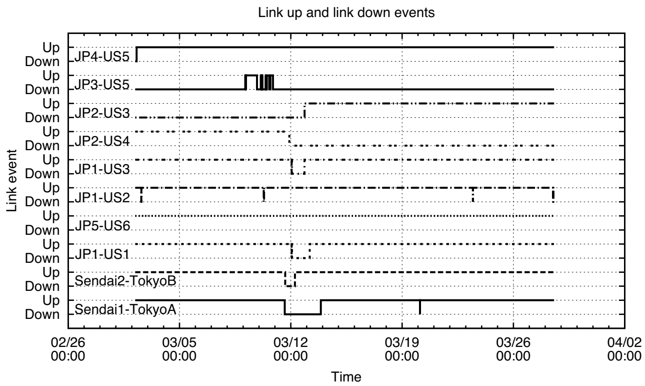

Figure 5: Quake related link failure and restoration times

Sendai failed within the next 3 minutes (See the two curves at the bottom of Figure 5). At 14:48:13, the first link was lost. The second link was lost at 14:48:56, leading to the disconnection of Sendai. For the second link, at 14:48:56, only the failure of the Tokyo-to-Sendai direction was advertised in OSPF. The other direction was considered down 45 minutes later, when the LSA expired because its age was longer than an hour. One link between Tokyo and Sendai was restored in 15 hours and the second was brought back online within 55 hours.

In February, there were nine trans-Pacific links. One of these links only appeared for four days at the end of the month and then disappeared in March. The other eight links are shown in Figure 5. Two of the Pacific links, *JP3-US5* and *JP2-US3*, were already down before the earthquake. We observed a few events for *JP1-US2* but these failures lasted only a few seconds. *JP2-US4* was the first Pacific link to seriously fail, at 21:50 on March 11th. This is almost eight hours after the earthquake. Then, both *JP1-US1* and *JP1-US3* failed exactly at the same time (March 12th, 01:12:51). They came back up less than a minute later only to fail again. *JP1-US1* was recovered 27 hours 24 minutes later. Recovery time was 19 hours 29 minutes for *JP1-US3*.

In short, three trans-Pacific links out of eight were damaged by the earthquakes. From a routing perspective, a minimum of three trans-Pacific links were always available. This situation lasted for 19.5 hours. Then, recovery of the lost links began. The two links ending on US3 came up at the same time, at around 21:00, March 12th.

We now look at total OSPF add/drop events per hour. The failures highlighted previously appear clearly in Figure 6 (a). In Figure 6, we see the number of events of a given type that happen in an hour. The green/dotted curve is the number of "drop neighbor" events while the red/plain curve measures reestablishment of OSPF adjacencies ("add neighbor" events). At time x, we show the number of events that occur within the $[x, x+1)$ time interval. We call this interval a time bin. Each time bin starts at 8 minutes after the hour. The first time bin starts at the first event observed in March.

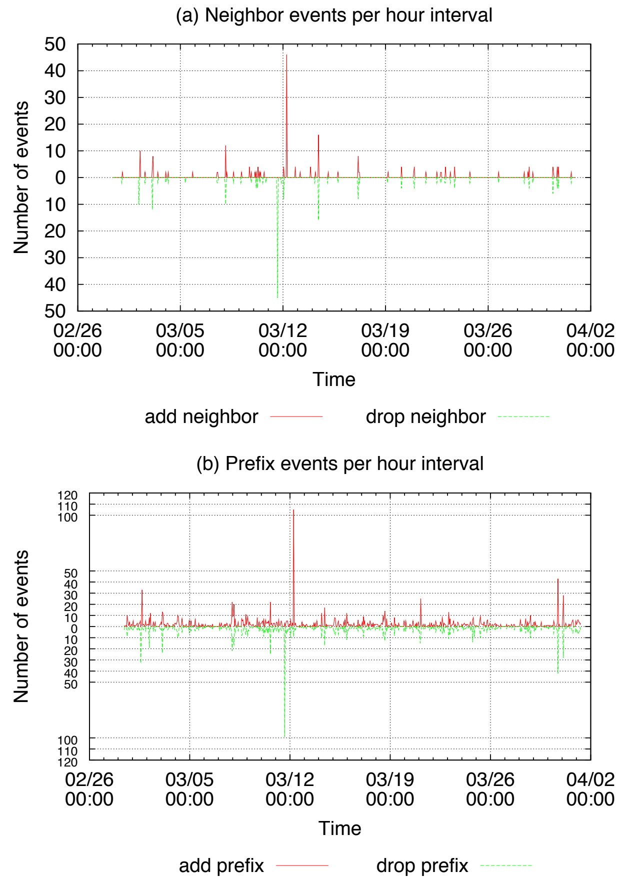

Figure 6: OSPF add and drop events

The peak of 45 "drop neighbor" events that we see shortly after the earthquake in Figure 6 (a) was caused by the loss of adjacencies between Sendai and Tokyo routers, and the "sympathetic" events of the OSPF monitor's loss of view of the links within Sendai. Then, a few hours later, in the 21:08 time bin, we lost one of the Pacific links. As this is the loss of a bi-directional adjacency, it results in two "drop neighbor" events. We can barely see this in the figure.

Thus, on March 11th, we observe mostly the loss of links in and to Sendai. Then, March 12th, connectivity in/to Sendai was recovered within the 06:08-07:07 timeframe. This corresponds to the peak of 46 events on the red curve. The other "add neighbor" events on March 12th involve the recovery of three lines over the Pacific, lines *JP1-US3*, *JP2-US3* and *JP1-US1*.

Finally, we note that an adjacency between Tokyo and Sapporo failed at the same time as the first link from Tokyo to Sendai broke, in the March 11, 14:08 time bin. These two adjacencies were restored at the same time (in the March 12, 21:08 time bin). We believe that the two lines used the same physical path going North from Tokyo to Sendai. Lacking physical diversity, they shared the same fate.

While Figure 6 (a) counts link-state neighbor events, Figure 6 (b) plots the number of "add prefix" and "drop prefix" events. As in Figure 6 (a), we also observe a high "drop" peak on March 11th, in the 15:08 bin. 99 prefixes were dropped between 15:08 and 16:08. Again, a high "add" peak (105 events) appears in the 06:08 time bin on March 12th. The "add" peak is higher than the previous "drop" peak as it gathers events which occurred in Sendai (96 events) and in the US (9 events). We note that roughly half of the "drop prefix" and "add prefix" events concern prefixes external to the backbone area.

In addition to these two main spikes, we observe peaks in Figure 6 (b) that are not present in Figure 6 (a). These correspond to prefixes which were injected into the backbone area from a spoke area; i.e. the failure happened outside the backbone area but affected prefix redistribution. We observe such events on March 31st in the 01:08 and 02:08 bins. Moreover, on March 14th in the 10:08 bin, we see a peak in number of neighbor and prefix events due to a failure in the Fukuoka PoP that was resolved within the hour.

Summarizing the OSPF measurements, we can clearly see circuit failures and subsequent repairs within the ISP, although the number of routing events does not necessarily indicate operational significance. Depending on the role of the routers, the number of prefixes affected by an event on an adjacency varies greatly. It may be very large if one of the routers is an area border router.

4.2 External Routing

IIJ and a major peer of IIJ ('neighbor provider') collect iBGP data, both RIB dumps and full traces of all iBGP updates from within their networks using Quagga MRT. This allows us to analyze how IIJ saw the world as well as how IIJ appeared from the 'outside.'

We chose to exploit the rare opportunity to view our ISP's routing data through the eyes of a large neighbor's iBGP. We chose this approach as opposed to just looking at Route Views data for a number of reasons. First, the neighbor's iBGP would be ground truth, the real data on which the neighbor would be routing traffic. Secondly, Route Views data are indirect and must be used with great caution and with understanding of their serious limitations[12]. As we had ground truth, we saw no need to use indirect data.

To focus on IIJ announcements as seen by the other provider, we use the neighboring ISP's iBGP data. From the update traces, we were able to extract the announcements and withdrawals for entire March 2011. This gives us a limited but nevertheless interesting view of how failures local to our ISP affect routing in the neighboring AS (and vice versa).

We first collected the prefixes that have IIJ's AS as the left most AS in the path. These are the prefixes advertised by IIJ. In the neighboring AS, the BGP nodes that peer with IIJ are the nodes that send updates with IIJ's ASN at the left most position in the AS path. We established that list of next-hop nodes. Then, we extracted the updates and withdraws sent by these next-hop nodes and for the prefixes advertised by IIJ. That is, we removed all BGP messages from BGP nodes that do not peer with IIJ and we focus on IIJ's and its customers' prefixes.

Similarly, to study how IIJ sees the neighbor ISP during the earthquake, we extracted from the iBGP data collected in IIJ, all the advertisements and withdraws for prefixes advertised by the neighbor received from internal BGP nodes peering with that neighbor. In this paper, we do not show the results of that study as they enable us to reach the same conclusion.

Over the month of March, IIJ advertised 1412 prefixes to the neighbor ISP. However, at most 299 prefixes are withdrawn by an iBGP peer within a one-hour bin. This happened March 3rd between 6:00 and 7:00 AM, where a next-hop node, *NH2*, lost reachability to 299 prefixes (see Figure 7). This was eight days before the big earthquake. The number of BGP withdrawals is rather low on March 11th. The same is true of BGP update messages. There was not much BGP churn due to the multiple outages related to the earthquake and tsunami. It does not stand out compared to the rest of the month.

During the earthquake, we do not observe much reachability loss in BGP. Figure 8 illustrates two days of BGP withdrawals as seen in the iBGP of the neighboring ISP. At this scale, we are able to relate the BGP events to OSPF and link failures events. First, we see a burst of withdraw messages (68 messages), between 14:40 and 15:28, following the loss of OSPF adjacencies in and to Sendai. The other OSPF events lead to very few BGP withdraws. We only see five withdraws upon the loss of a Pacific link at 21:00 March 11th. Then, when the first link to Sendai was recovered on March 12th in the 06:00 time bin, the iBGP monitor received seven withdraws of four prefixes, and 49 updates for these same prefixes. When reachability is recovered, we may observe withdraw messages. Additionally, the number of update messages is sometimes higher than the number withdraws. This may be due to a slight path exploration in the iBGP of the neighboring ISP. Lastly, only

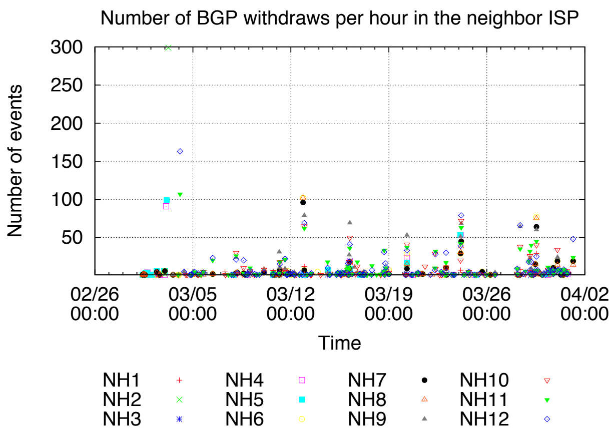

Figure 7: BGP withdrawals for our ISP in a neighboring ISP

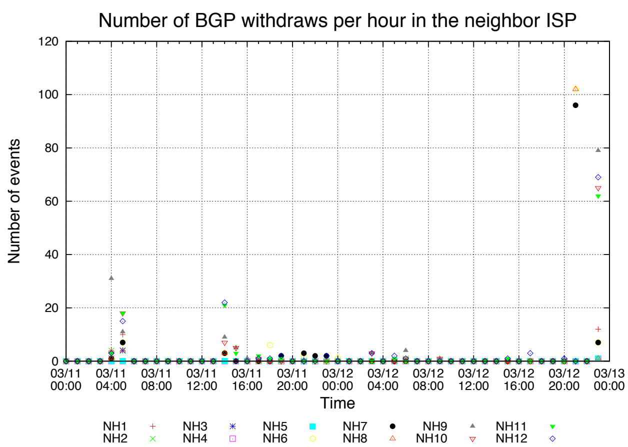

Figure 8: 2 days of BGP withdrawals for our ISP in a neighboring ISP

one withdraw and 20 updates were seen by the monitor at 20:00 March 12th, when the two Pacific links ending at router US3 were restored.

The withdraws observed in the 04:00 and 05:00 bins March 11th are not quake related failures. The same is true for the BGP activity between 21:00 and 24:00 on March 12th.

From a routing perspective, the internal network was quite resilient and stable. Apart from the area directly affected by the disaster, no region was disconnected from the backbone or the world. Outside connectivity to the prefixes served by IIJ was maintained. BGP did a good job at hiding the internal failure and recovery activities from the outside world.

Having an inside view, even if limited, in a neighboring ISP is very unique and useful in determining failures and configurations that affect routing stability of one's prefixes.

5. RELATED WORK

Routing and traffic impacts by (non)natural disasters have been of interest to network researchers. Despite tragedy, it is an opportunity to study the robustness of the Internet architecture. Due to a lack of systematic studies on measuring the Internet aftermath, we often rely on unconfirmed media and industry reports to get a glimpse of the situation.

The 9/11 attacks in the US have shown immediate loss of reachability to 1% of globally announced prefixes[1]. A partial loss sustained for the next 2-3 days due to power outage and restored within 4–24h. NYC areas, South Africa, and South America networks became globally unreachable from 10 selected peers (e.g., AS 513, 559, 1785) in Europe, US, and Japan. However, these reachability losses did not create severe routing instability in the global Internet.

Hurricane Katrina in 2005 swept out 1.75M telecommunication lines, 1000 cellular towers, 4 large toll switches, and fiber optic path in the Gulf region of the US[5, 10]. Internet2/Abilene links from Houston to Atlanta were out and restored after one week. Again, the global Internet remained unaffected by Katrina; most of initial Internet outages were bound to local regions only. Katrina demonstrated that the public Internet continued to achieve its high reliability and survivability.

Unlike the above two disasters, Taiwan earthquake in 2006 revealed fragility of the global Internet[16, 7]. A series of quakes over 3 days were reported to have destroyed two of nine submarine cables. A sudden peak of network outages, prefix unreachability, was followed by gradual increase in the first 2 days. To estimate impact of an involved AS, PenaltyBox[8] computed a score that is proportional to the amount of flapping prefixes advertised by the AS. Overall, 1667 ASes were impacted (in)directly, and more heavily in China, Hong Kong, India, and Singapore. Incomplete cutoff of communication caused unstable paths, leading frequent path changes and severe packet losses. To remedy the situation, temporal transits were made among non-regional ISPs (e.g., China Netcom AS9929 uses temporarily Sprint AS1239 and DTAG AS3320 as transits) at the time of disaster. It clearly showed how local event can have a broad impact, and vulnerabilities particularly in Asia.

The Egyptian crisis in 2010 is an example of intended disaster. Egypt simply disappeared from the net[17]. Apart from networking technology, others are looking at the good use of the Internet during disasters, such as Twitter behavior analysis[13, 14].

So far, we have heard numerous initial estimates of damage and recovery in Japan[4, 15]. There are some reports on the Internet, but few have analysis combining traffic data with routing data. It is crucial to collect bits and pieces of information to estimate the overall impact. Thus, we highlight the fact that our paper illustrated the collaborative view of routing and traffic from the inside of major ISPs in Japan.

6. CONCLUSION

We have reported the impact of the Great East Japan Earthquake on IIJ, one major ISP in Japan. We observed a severe damage and gradual recovery in the aftermath from residential traffic in Miyagi prefecture. However, it had only a limited impact on the total residential traffic in Japan. We also observed how redundancy and over-provisioning worked for the Internet from traffic on trans-Pacific links. From the routing analysis, we have identified significant internal events within IIJ, but also observed that these events were masked to the rest of the world.

When examined at a macro level, the impact of the disaster was quite small. The fact that there was little impact on Internet traffic even during a disaster which had significant effects on society demonstrates that the Internet is becoming a reliable and indispensable infrastructure in our daily lives.

Our observations illustrate the resilience of the Internet to large scale disasters, and emphasize the importance of redundancy and over-provisioning in the network design. In some sense, however, we were just lucky this time; the damage could have been much worse, if major facilities were impacted, if more cables were cut, or if power generators at datacenters did not last until external power was restored.

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