

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

Kenjiro Cho   Cristel Pelsser   Randy Bush   Youngjoon Won  
Internet Initiative Japan, Inc.

## ABSTRACT

The Great East Japan Earthquake and Tsunami on March 11, 2011, disrupted a significant part of communications infrastructure 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 this time, 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

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

ACM CoNEXT 2010, November 30 - December 3, 2010, Philadelphia, USA.

Copyright 2009 ACM X-X-X-X/XX/XX ...\$5.00.

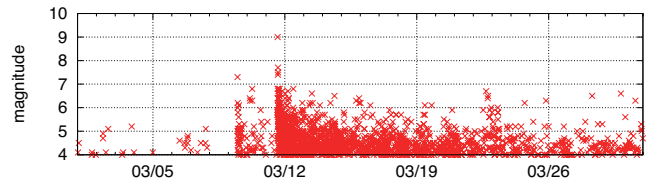


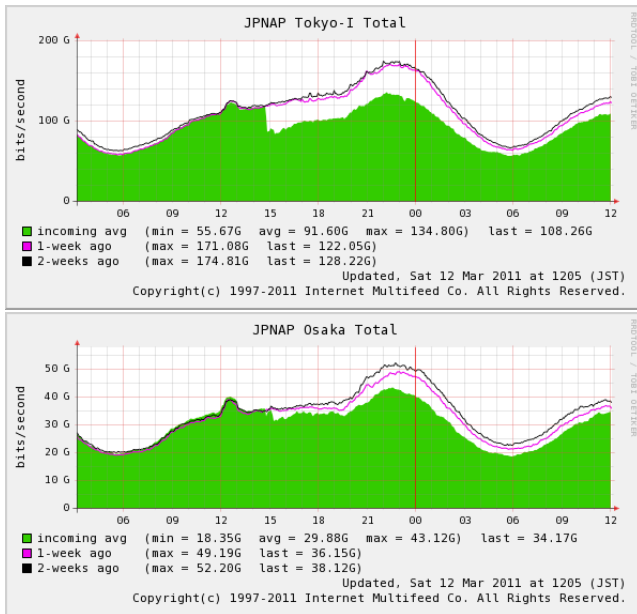
Figure 1: Earthquakes larger than Magnitude 4 in Japan for March 2011

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.

Tokyo only received limited physical damages. However, immediately after the main earthquake, all 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[9]). 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



**Figure 2: Traffic at JPNAP Tokyo1 (top) and Osaka (bottom) on 3.11**

Fukushima Nuclear Power Plant. Its radiation release caused large evacuation, 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 by 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 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.[12] NTT East reported 90 routes in transmission lines were damaged and, in the coastal areas, 65,000 telephone poles were flooded or collapsed and 6,300km of aerial cables was lost.

In the Tokyo area, while voice networks did not work, the Internet did. 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[6], 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. 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)[5], founded in 1992, is one of Japan’s leading Internet-access and network solutions providers. IIJ and its group of companies provide total network solutions that mainly cater to high-end corporate customers. The company’s services include high-quality systems integration and security services, Internet access, hosting/housing, and content design. The company has built one of the largest Internet backbone networks in Japan, and between Japan and the United States.

In this paper, we analyse 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 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 that is 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.
- Sendai Datacenter 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 Sendai Datacenter were down, and connectivity was lost to 6

prefectures in the Tohoku area.

- From around 23:00, undersea cables landing in the north of Tokyo started failing. Some of the US links were down, and the links to Asian countries were also down.

#### March 12, Saturday:

- One backbone link to 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 Sendai Datacenter at around 11:30.
- Two of the damaged US-links are recovered around 21:00. One of these links is rerouted and brought up.

#### March 13, Sunday:

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

#### March 14, Monday:

- Business started. Service restoration and rescue activities started.

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

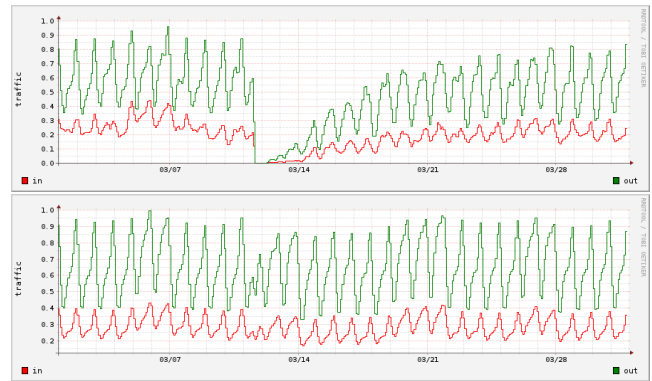
### 3. TRAFFIC

To observe the impact on traffic, we first look at residential broadband traffic, one for a 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 IJ 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 IJ'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.



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

At this point most areas in Miyagi prefecture were 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. It recovered slightly overnight, but 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. 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 afterward 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 IJ's broadband access service.

There are several reasons that the impact on traffic was limited. First, 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 have caused major disruption thanks to swift on-site restoration work. The impact of the earthquake

was kept to a minimum through the tireless efforts of those working to restore services.

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 users cut back on their use of the Internet for power savings in the first place. 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 deal with clients and customers. Furthermore, due to the earthquake and introduction of scheduled power outages, there was an increase in the migration of work and home servers to cloud services and backup 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, international circuits started to fail.

Most of the undersea cables connecting the U.S. and Asian countries are through Japan. There are a number of undersea cable landing stations in Japan but many cables go through off the Pacific coast in the northeast of Tokyo and were damaged. However, most cable operators have redundant paths to the southern coast of Japan so that they did not suffer from a complete outage.

At the time of the disaster, IJ had 8 links to the U.S. 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 link 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.

Here, we show only 3 links but in reality traffic load



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

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

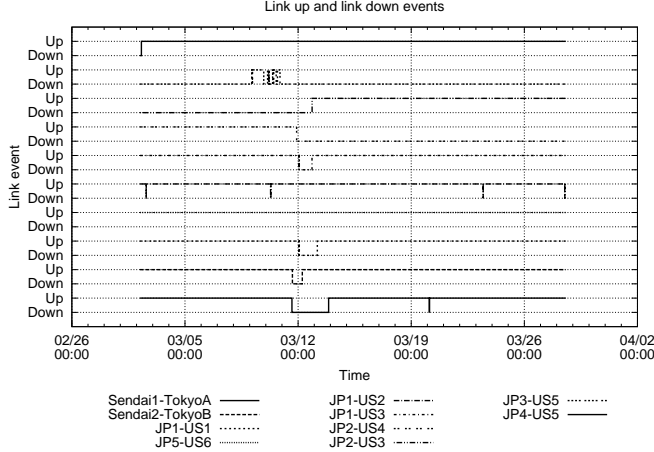
### 4.1 Internal Routing

What story does internal routing data tell us? We look at changes in reachability of internal prefixes, analysing how the earthquake and after-shocks influenced routing within and toward IJ. All times for routing analyses are adjusted to JST.

IJ uses OSPF as its IGP, and collects it in the backbone area using Packet Design’s Route Explorer. 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 IJ’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 during and 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



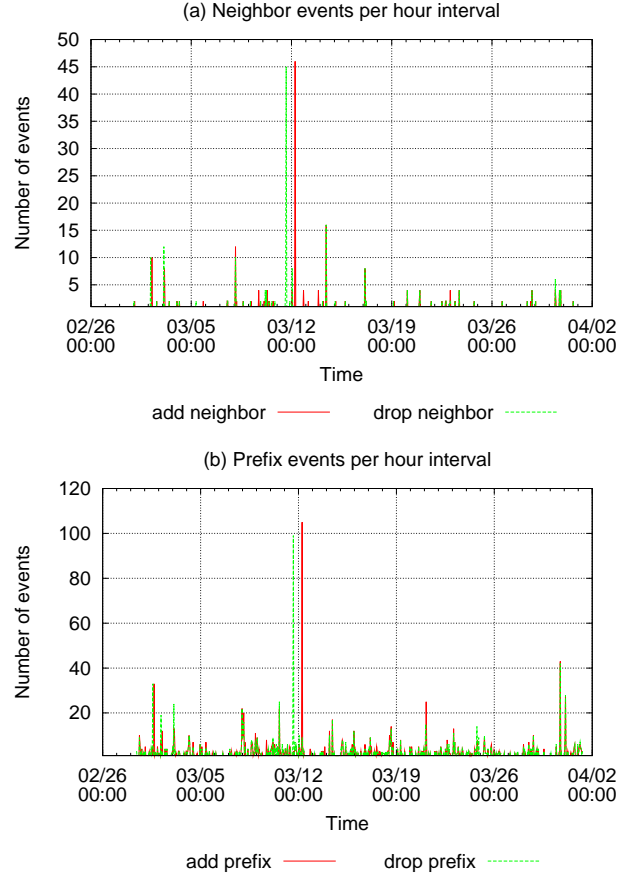
**Figure 5: Quake related link failure and restoration times**

Sendai failed within the next 47 minutes (See the two curves at the bottom of Figure 5). The first link failed immediately while the other was likely broken by the tsunami. 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* is the first Pacific link to seriously fail, doing so at 21:50 March 11th. This is almost eight hours after the earthquake. Then, both *JP1-US1* and *JP1-US3* failed at exactly 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 min later. Recovery time was 19 hours 29 min for *JP1-US3*.

Throughout this main event, a minimum of three trans-Pacific links out of eight were always available. This situation lasted for 19.5 hours. Then, recovery of the lost links began. The two links ending on US3 came back at the same time, 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 part (a). In Figure 6, we see the number of events of a given type that happen in an hour. The green curve is the number of “drop neighbor” events while the red 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.



**Figure 6: OSPF add and drop events**

The peak of 45 “drop neighbor” events that we see shortly after the earthquake, Figure 6 (a), is caused by the loss of adjacency 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 redundant bi-directional adjacency, it results in only 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 time-frame. 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* and *JP2-US3* ending at *US3* and line *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 of 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 see this in the March 31st 01:08 and 02:08 bins.

On March 14th in the 10:08 bin, we see a similar number of neighbor and prefix events. Failures in the Fukuoka PoP occurred and were resolved within the hour.

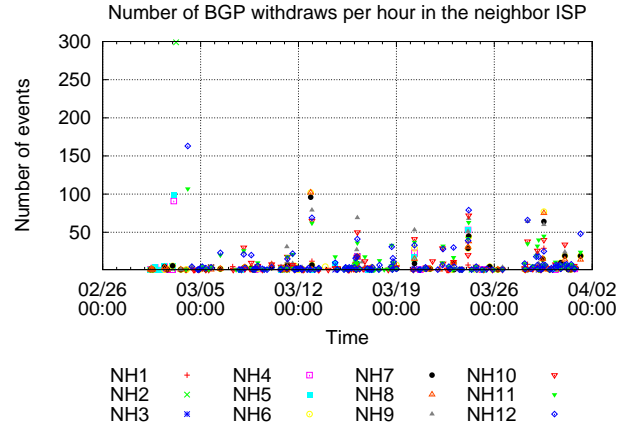
Summarizing the OSPF measurements, depending on the role of the routers, the number of prefixes affected by an event on an adjacency varies greatly. It may be very large if one of the routers is an ABR.

## 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 analyse how IIJ saw the world as well as how IIJ appeared from the ‘outside.’ From the update traces, we were able to extract the announcements and withdrawals from March 2011. This gives us a limited but never the less interesting view of how failures local to our ISP affect routing in the neighboring AS (and vice versa).

To focus on IIJ announcements as seen by the other provider, we use the neighboring ISP’s iBGP data. We first collected the prefixes that have IIJ’s AS as the first AS in the path. These are the prefixes originated 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 first position in the AS path. We established that list of nodes. Then, we extracted the updates and withdrawals sent by these nodes and for the prefixes originated by IIJ. That is, we removed all BGP messages from BGP nodes that do not peer with IIJ and we focus on IIJ’s prefixes.

Similarly, to study how IIJ sees the neighbor ISP dur-

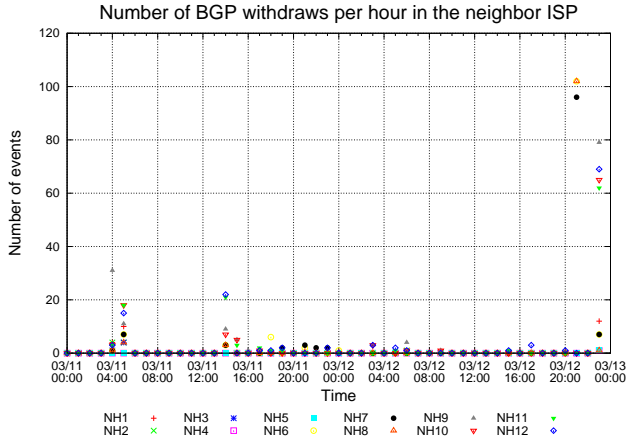


**Figure 7: BGP withdrawals for our ISP in a neighboring ISP**

ing the earthquake, we extracted from the iBGP data collected in IIJ, all the advertisements and withdrawals for prefixes originated 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 originated and 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 (JST time), where *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 withdrawals. We only see five withdrawals 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 withdrawals 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 of withdrawals. This may be due to a slight path explo-



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

ration in the iBGP of the neighboring ISP. Lastly, only one withdraw and 20 updates are seen by the monitor at 20:00 March 12th, when the two Pacific links ending at router US3 are 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 an interest for network researchers. Despite tragedy, it is an opportunity to test robustness of the Internet architecture. Due to a lack of systematic studies on measuring the Internet aftermath, we often rely on unconfirmed media/industry reports to get a glimpse at the situation.

The 9/11 attacks in US have shown immediate loss of reachability to 1% of globally announced prefixes [4]. A partial loss was continued for next 2-3 days due to power outage and restored within 4–24h after its discovery. In 9/13, NYC areas, South Africa, and South America networks became globally unreachable from 10 selected peers (e.g., AS 513, 559, 1785) in Europe, USA, 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 fibre optic path in the Gulf region of US [8, 13]. 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 outage 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 [2, 10]. A series of quakes over 3 days destroyed two of nine submarine cables (reported). 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 [3] 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 on 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 broad impacts and a high vulnerability particularly in Asia.

Egyptian crisis in 2010 is an example of intended disaster. It simply disappeared from the net and had no visible impact [1]. Apart from networking technology, others are looking at the good use of Internet during disasters, such as Twitter behavior analysis [14, 15].

For now, we hear numerous initial estimates of damage and recovery in Japan [7, 11]. In traffic-wise, JPIX dropped by about 25 Gbits/sec after the quake and climbed back to normal state at the end of the day. Yet, any routing concern has not been reported. It is crucial to collect bits and pieces of information to estimate the overall impact. Thus, we highlights 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 to 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 IJJ, 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.

## Acknowledgments

We thank Cengiz Alaettinoglu, Kim Dimick and Kris Olander at Packet Design for their help in decoding the OSPF data. We are also grateful to Olaf Maennel for his comments.

## 7. REFERENCES

- [1] Overview of the Egyptian Internet Shutdown. <http://www.pch.net/resources/misc/Egypt-PCH-Overview.pdf>.
- [2] Quaking Tables: The Taiwan Earthquakes and the Internet Routing Table. <http://www.nanog.org/meetings/nanog39/abstracts.php?pt=MjUyJm5hbm9nMzk=&nm=nanog39>.
- [3] Taiwan Earthquake Fiber Cuts: A Service Provider View. <http://www.nanog.org/meetings/nanog39/abstracts.php?pt=MjUxJm5hbm9nMzk=&nm=nanog39>.
- [4] A. Ogielski and J. Cowie. Internet Routing Behavior on 9/11 and in the Following Weeks. <http://www.renesys.com/tech/presentations/pdf/renesys-030502-NRC-911.pdf>.
- [5] IJJ. Internet Initiative Japan, Inc. <http://www.ijj.ad.jp/>.
- [6] Internet Multifeed Co. JPNAP Service. <http://www.jpnap.net/>.
- [7] J. Cowie. Japan Quake. <http://www.renesys.com/blog/2011/03/japan-quake.shtml>.
- [8] J. Cowie, A. Pospescu, and T. Underwood. Impact of Hurricane Katrina on Internet Infrastructure. <http://www.renesys.com/tech/presentations/pdf/Renesys-Katrina-Report-9sep2005.pdf>.
- [9] Japan Meteorological Agency. Japan Meteorological Agency Earthquake Catalog. [http://www.hinet.bosai.go.jp/about\\_data/?page=3](http://www.hinet.bosai.go.jp/about_data/?page=3).
- [10] Y. Kitamura, Y. Lee, R. Sakiyama, and K. Okamura. Experience with Restoration of Asia Pacific Network Failures from Taiwan Earthquake. *IEICE Trans. Commun.*, E90-B:3095–3103, July 2007.
- [11] Nikkei Communications. Lost Two of Three Core Networks by KDDI East (in Japanese). <http://itpro.nikkeibp.co.jp/article/NEWS/20110408/359264/?ST=network>.
- [12] Damage and Restoration Status Regarding the Tohoku-Pacific Ocean Earthquake and Future Prospects. , NTT Group, Mar. 2011.
- [13] P. Rhea. Hurricane Katrina: Telecom Infrastructure Impacts, Solutions, and Opportunities. <http://www.nanog.org/meetings/nanog36/presentations/rhea.pdf>.
- [14] K. Starbird and L. Palen. Pass It On?: Retweeting in Mass Emergency. In *ISCRAM Conf.*, May 2010.
- [15] T. Sakaki, M. Okazaki, and Y. Matsuo. . April 2010.