On Correlating ISP Topologies to Their Businesses

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Abstract—Internet Service Providers (ISPs) have different growth or decline patterns in terms of topological and economic characteristics. While some ISPs may have a significant correlation between their topological and business properties, others may not show such strong techno-economic dependence. In this paper, we examine the relationship between the network topology characteristics of the ISPs and their stock market values. We analyze data collected from two different datasets of inter-ISP relationships of various types, i.e., customer, provider and peer. Then, we correlate these topological relationships against the ISPs performance on the stock market. In particular, we examine the correlation between the stock market values as well as revenue of each major ISPs operating in the United States to their degree (i.e., the number of connections they have to other Autonomous Systems) and customer cone size (i.e., the number of customers they are serving).

I. INTRODUCTION

The ever-increasing large demand for the Internet usage and ISP industry growth [13] triggered great interest to understand the nature of its economics and future techno-economical sustainability. In order to dimension and scale the Internet along with the demand growth, it is prudent to understand its hierarchical structure, the critical patterns in its underlying infrastructure, and the dynamics that govern the Internet usage as well as financial and political factors. Due to the complexity of negotiations and dynamics among many entities involved (e.g., more than 4 billion end users and 50 thousand Autonomous Systems (ASes) [9]), efficient pricing of ISP services have attracted attention [25], [27].

ISP business dynamics have significant effects on the emergence of a hierarchical structure in the ISP industry [19] as well as different service types of ISPs such as content, transit, and access as shown in Figure 1. Understanding the dynamics of the ISP industry is also of great importance to develop models for the long-term health of the ISP market. Prior research looked at the techno-economic reasons why ISP businesses fail or succeed [28], developed enhanced revenue sharing [22] and game-theoretic settlement models [10].

Researchers also classify ASes and their relationships into different types. In early studies, it has been presented that the fraction of connections (either peer or customer-provider) derived from AS-Path information of Border Gateway Protocol (BGP) announcements reflect only 60% of the link types which means that any information derived from BGP lacks around 40% of the edges [14], [15], [21]. CAIDA provides a more detailed classification of the inter-AS relationships [2], [18], which we utilize in our study.

Analyzing the interaction between network and business properties of ISPs have received attention as well. One crucial point of the connectivity on the Internet is that every AS establishes and optimizes its own connectivity focusing on its requirements and business goals [17]. The role of topological properties and policies are investigated to maximize the revenue while meeting performance requirements. Agreements between ISPs are not new [12], but based on their business model and analysis, these linkings already have renewed. We try to come up with a model of the newer relationship agreements. However, neither the relationship between the Internet’s topological characteristics and stock market nor dependency and inference of inter-ISP economic relationships have been investigated deeply from the routing and forwarding measurements data.

Mainard et al. [23] studied the relationship between the physical network of ASes and the business performance of the ISPs of the same type. They showed that ISPs providing same service types are positively correlated in terms of stock market performance, and further that geographical proximity increases the correlation – verifying the intuition that the ISPs compete for the same or similar customer pool.

Rather than cross-correlating ISPs in the stock market, in this paper, we correlate the network characteristics of ISPs to their stock market performance and attempt to find out dependency of ISPs’ businesses to their network characteristics, particularly to their relative position in the inter-AS

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topology. To quantify the ISPs’ dependency to their networks, we introduce a new metric, Network Dependency Index (NDI). For about a decade of data, we quantify NDI of various types of ISPs by comparing their stock market value to their AS-level degree and customer cone size. We also compare the kinds of AS relationships (i.e., peering or customer-provider) against the stock market performance of major ISPs. Our study scratches the answers to the key questions of a) how much dependent the ISP market will be on the network structure, b) what will be the network characteristics of a successful ISP, and c) will there be enough incentives for ISPs to invest in their network infrastructure as content is getting increasingly more weight in value.

The rest of the paper is as follows: Section II discusses the collected topological and stock market data of ISPs. Section III presents the correlations and NDI of ISPs and extracts insights from the results. The paper is finalized with a summary and potential future work in Section IV.

II. METHODOLOGY

The heterogeneity of AS relationships and the types of ISP businesses bring up different perspectives of understanding the ISP market. We, therefore, consider three prominent AS relationships (i.e., Peering, Customer, Provider) and six types of ISPs (i.e., Content, Access, Transit, Transit and Access, Content Delivery Network (CDN), and Internet Exchange Provider (IXP)) in our study. Figure 1 shows the current logical architecture of the ISP types in the Internet. Note that real ISPs may perform some of these logical services at the same time. We considered each ISP as a single node consisting of multiple ASes. Though, AS and ISP have their distinguished meaning in network studies, RFC 1930 [20] states that multiple ASes (with individual AS number) can act together as a single ISP. To highlight more on business strategy and to keep aligned with what we observe from our data, from here onwards, AS and ISP infers the same entity. We used CAIDA’s classification of ASes and their major business areas to identify which type an AS belongs to and clustered them accordingly. We chose six ISP types based on the terminology used in discussions on NANOG mailing list and in Norton’s white papers [24].

Figure 2 shows the types of AS relationships: peering (between AS 2 and AS 3), customer (AS 4 is a customer of AS 2), and provider (AS 1 is a provider of both AS 2 and 3). AS relationships determine the importance of the ISPs owning them. In particular, we consider two AS-level network properties. First, the degree of an ISP is the number of relationships it has with other ASes. Second, the customer cone of an ISP X is the sum of the number of users in X’s AS, and all the downstream customer ASes of X. We calculate the number of users in a particular AS by counting the number of IP addresses in the subnets provided by CAIDA [1].

A. Dataset

We used three datasets to collect topological and economic metrics of ISPs. The AS list for each ISP is obtained from CAIDA’s AS Rank dataset [1]. In total, we investigated 32 major ISPs operating in the United States and providing 6 different types of services as listed in Table I. Even though ISPs offer a variety of services such as wired access, wireless access, transit and wireless access together, our selection was based on the main service they offer. For instance, Alphabet Inc. owns both Google and Youtube. Similarly, Equinix has dedicated businesses in Asia Pacific, USA, France and so on. Each of these franchises maintains its separate set of ASes. For our study, we consider only one to resolve these cases and select the top-ranked AS from that service provider as a sample for showing its information in the table.

We also collected a second dataset from CAIDA on AS relationships [2] containing relationships of all ASes visible in BGP announcements derived via the methodologies described in [18]. In particular, the dataset lists inter-AS relationships and their types. In our approach, we fetched the data from January 2007 to May 2017. We extracted the number of peers and providers of an ISP from the dataset by accumulating the number of customer-provider and peer-to-peer links. In Table I, continuing with Google example, we mark AS-15169 as the top AS and put its global ranking 1704 since it is the highest among the 5 ASes Google owns. 3-9-192-1 in the last column represents the number of Providers, Customers, Peers and Sibling ISPs Google is connected with.

Stock market performance tends to be volatile over time. In our analysis, stock market data is harvested from End of Day US Stock Prices from Quandl [7] for the dates of the AS relationship data recorded. CAIDA dataset includes data from 1/1/2007 to 5/1/2017 (mostly one per month). We queried Quandl to get the financial data for every available date between that period. If data was provided on weekend, we queried the stock price for the Friday before that weekend. There were some gaps in the AS relationships provided by CAIDA that we could not obtain data for. In total, we queried about 120 timestamps for each ISP.

B. Network Dependency Index (NDI)

We introduce Network Dependency Index (NDI) as the correlation of the inter-AS network structure, size and/or position of an ISP to its economic status. NDI is computed as the correlation coefficient of the underlying network to the economic aspects of an ISP business by comparing its stock market price and value to its AS-level degree or customer cone size. In other words, NDI of an ISP quantifies the

![Fig. 2: AS Relationships [2]](image-url)
TABLE I: ISPs grouped by service types (sorted by Market Capital)

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Stock Name</th>
<th>AS Count</th>
<th>AS Degree</th>
<th>Top AS Number</th>
<th>AS Rank</th>
<th>Provider-Customer-Peer-Sibling Count</th>
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<tbody>
<tr>
<td>Transit &amp; Access</td>
<td>AT&amp;T</td>
<td>T*</td>
<td>12</td>
<td>255,273,728</td>
<td>7018</td>
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<td>Time Warner Cable</td>
<td>TWC*</td>
<td>24</td>
<td>45,897,216</td>
<td>7843</td>
<td>47</td>
<td>4-22-30-10</td>
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<td>Sprint</td>
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<td>32</td>
<td>330,382,848</td>
<td>1239</td>
<td>19</td>
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<td>Internet Initiative Japan Inc.</td>
<td>IJJ</td>
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<td>36,473,856</td>
<td>2497</td>
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<td>CDN</td>
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<td>AKAM</td>
<td>17</td>
<td>13,843,200</td>
<td>32787</td>
<td>141</td>
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<td>Rackspace Hosting Inc.</td>
<td>RAX*</td>
<td>7</td>
<td>1,853,952</td>
<td>12200</td>
<td>2781</td>
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<td>Limelight Networks Inc.</td>
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<td>22822</td>
<td>302</td>
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<td>Content</td>
<td>Google Inc.(Alphabet Inc.)</td>
<td>GOOGL</td>
<td>5</td>
<td>1,529,088</td>
<td>15169</td>
<td>1704</td>
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<td>FB</td>
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<td>3919</td>
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<td>IBM Corp</td>
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<td>33445</td>
<td>5903</td>
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<td>CMCSA</td>
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<td>CHTR</td>
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<td>Cablevision Systems</td>
<td>CVC*</td>
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<td>6128</td>
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<td>Frontier Communications</td>
<td>FTR</td>
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<td>GNCMA</td>
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<td>Qwest Comm. (CenturyLink)</td>
<td>CTW*</td>
<td>13</td>
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<td>WOW*</td>
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<td>ZAYO*</td>
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<td>CCOI</td>
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<td>GTT*</td>
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<td>CONE</td>
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<td>649</td>
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<td></td>
<td>Any2 (CoreSite Realty Corp.)</td>
<td>COR*</td>
<td>5</td>
<td>104,704</td>
<td>2734</td>
<td>1740</td>
<td>9-9-20-0</td>
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</table>

dependency of that ISP’s economic status to its underlying network properties. We use the ISP’s stock market value to express its economic status and its AS-level degree or customer cone size to express its network’s status.

We calculate NDI of an ISP as the correlation coefficient [11] between two time series: i) the stock market value of the ISP over time, and ii) AS-level degree (NDI-d) or customer cone size (NDI-c) of the ISP. For simplicity and initial observations, we choose to use AS-level network properties of the ISP. It is worthy to note that NDI could be calculated in other ways with more temporal and spatial granularity. For instance, router-level topologies of the ISPs could be used to attain a more accurate NDI with better spatial granularity.

A negative NDI for an ISP means that this ISP’s small network does not seem to play a role in its profitability while a positive NDI indicates larger network seems to benefit ISP. Zero NDI means that ISP’s business is ambivalent to its network size and properties. Note that NDI does not express causation of why an ISP’s business is (un)successful, but merely indicates one of potentially several arguments for why.

III. Results

We used Pearson’s correlation coefficient [11] to correlate ISP’s network and economic fluctuations. Using both Quandl and Yahoo Finance dataset, market capacity (i.e., the total market value of the shares outstanding of a publicly traded company) and adjusted closing stock value are used to compare the companies and the prices. We also used the market capacity as sorting criteria for the ISPs.

Figure 3 shows the market capacity of the ISPs in June 2017 (using Yahoo! Finance except for Rackspace (acquired by Apollo Global Management in Nov 2016 [5]), Time Warner Cable (merged with the parent in May 2016 [6]) and Cablevision (acquired in June 2016 [3]). The list of ISPs are clustered based on their types and sorted within each group by the market capacities.

A. NDI Based on Degree (NDI-d)

Figure 4 shows NDI-d, the correlation between the degree and the stock market price of each ISP sorted by market capacity of the ISP along with circle points representing
the peering policies these ISPs implement are more open compared to the policies of the access and transit providers. Open interactions with other players allow more exposure and easier access to their content – a business benefit to the content provider, as we can observe from our data. Google, Facebook, and Amazon have high positive NDI-d while the other content ISPs are also on the positive side. As an example of large AS degree (due to more peering) benefiting ISP business, Facebook operates only three ASes while their peer count has increased from 79 to 180 between 2012 to 2017 (the number of providers increased from 11 to 19).

CDNs show smaller NDI-d and Rackspace is on the negative side. CDNs are well-connected multi-homed ASes and rely on transit providers to carry the content to end users. Although it is not significant, the average NDI-d of CDNs is lower than content provider’s average NDI-d indicating that content providers take extra steps to increase their degrees to attain lower delays to end users.

Access and transit providers with smaller revenues may naturally act more biased on peering due to their interest in the mainline business of provisioning a higher quality network rather than mere exposure and trade of content. Time Warner shows positive NDI-d, this is not surprising because of its earlier nature of being a content provider, now entered into the transit and access business.

IXPs showing higher NDI-d is self-explanatory as they act as the common point for exchanging traffic among other ISPs. As a matter of fact, Equinix has 22 exchange points around the globe supporting more than 1,000 networks globally [8].

Comparing the average NDI-ds of transit and access providers, ISPs involved in more transit business yield a higher NDI-d, which verifies the intuition that transit ISPs’ stock market price is highly dependent on the number of connections they have with other ISPs. Higher degree ASes are crucial for a successful transit as this enables shorter paths to end users and easier reach to other potential customer ISPs needing transit services. Even though same can be said for the access providers, the existence of some access ISPs with lower NDI-ds suggests that the performance of access network has more weight than transit network performance, e.g., transit ASes being well connected to the rest of the ASes. For instance, AT&T, Sprint, and Verizon are known to have strong wireless access networks while having large transit networks. Yet, we observe that their NDI-d is negative suggesting that transit networking is less important in determining their business success, which is in alignment with the recent trends of weakening transit services as a profitable business. Another reason could be that these access ISPs serve a certain region and do not establish a lot of AS neighboring relationships, which explains Frontier and General.

B. NDI Based on Customer Cone (NDI-c)

Figure 5 displays NDI-c, the correlation of the customer cone and the stock market price of the ISPs along with circle points representing the average NDI-c for that particular group of ISPs. Most of the NDI-c values are on positive side since
the performance of an ISP business positively correlate with the total number of end users it serves.

Low positive NDI-c between the customer cone and the stock market prices verifies the intuition that when the number of customers increases, the demand for ISP’s stock increases. Even so, the NDI-cs of content providers and CDNs, here, are on the low positive side. This can be because content providers don’t really manage the delivery, rather just providing them to the users. Yelp! shows negative for both NDI-d and NDI-c. From our dataset, they seem to have very small connectivity compared to others. They only have 20 peers and 7 providers. They also recently increased their number of owned ASes from 2 to 3, which means as the number of customers is increasing, they are expanding their networks too. Furthermore, Limeligt has a noticeably lower NDI-c among the CDNs, which is likely caused by its focus on data center management.

Comparing the average NDI-c for all types, we observe, only Access ISPs have all positive, while NDI-c value appearing very close to 0 for IXPs means, they don’t have enough impact of customer cone size, as they deal with other ISPs directly.

ISPs of similar types are closer to each other but the distribution of the ISPs across NDI-c is less skewed. Moreover, the values are less scattered in NDI-c compared to NDI-d. Overlapping confidence intervals prevent us from judging whether these ISPs operations are statistically different or not. Nonetheless, based on NDI-d values, we can say that IXPs business model (in network connectivity) significantly differs from that of CDN or Transit & Access providers.

C. Providers’ Stock Value Analysis

Another dimension to explore is the effect of the number of providers on the stock value of an ISP. As indicated in Section I, the results for peer-to-peer links we show in this study should be considered as lower bounds on the actual number of peer-to-peer links since the dataset consists of only a portion of the actual links [15].

The NDI we calculated based on ISPs provider were somewhat unclear and difficult to interpret. We assume that the reason for having intricate values for ISPs is due to the fact of having fewer providers in our data than they normally have. In further analysis of the data, we have faced an interesting representation of the provider-stock value relationship for the ISP groups. When we plot the number of providers versus stock values for each ISP group, plots present a power-law-like heavy-tailed distribution. In Figure 6, different from Figures 4 and 5, we present data points of provider and stock value pairs for each date we have.

Figure 6 presents the relationship between the number of providers and the stock prices of ISPs. The data points for higher stock value on this graph are later in time. Inside figure presents the same data in log-log scale. It shows that there is an exponential decrease in the number of providers for all ISP types as the stock value is increasing. When the number of providers is high, the market value is small; but when the number of providers decreases, the market value increases exponentially.

Since these data points are sorted by earlier date to later date, we see that all ISPs are trying to reduce the number of providers from which they are getting service. As a result, they end up with an exponential increase in their stock values. Interestingly, the number of providers for content provider ISPs does not diminish with the same speed compared to other ISP groups. Earlier, the number of providers in content provider network is similar to the Transit and Access Provider ISPs; however, they reduce the number of providers in a slower trend. This might be due to the speed of growth in their infrastructure as they target much wider areas (i.e., the distance around the globe) for their infrastructure expansion.

These results show that the stock value of an ISP is highly dependent on the number of providers the ISP has. The trend of ISPs shows that they are trying to have fewer providers over the time; and fewer providers they have, they get better in stock market performance. This follows the intuition that an ISP with more providers is a smaller ISP in terms of market
performance and needs more help from others. As an ISP gets stronger in business value, it needs less of help from others and thus reduces the number of its providers.

D. NDI using ISP Revenue

We extend our work by calculating $NDI$ using revenue of ISPs as another economic status metric instead of stock market price as revenue values may provide a more stable look while stock prices may fluctuate depending on investors' sentiments and expectations that sometimes gets biased by various incidents like announcement of launching a new product, merging with other company, employee layoffs or even company scandals [29].

We primarily gathered revenue data for our concerned ISPs from Ycharts during the period of 2007 to 2017 June. Similar to the stock market data, we matched quarterly revenue dates with the closest date for network information and calculated $NDI_d$ and $NDI_c$ values.

Figure 7a and Figure 7b show revenue-based $NDI_d$ and $NDI_c$ values consecutively. A couple of interesting observations can be made from these analyses. For example, most of the ISPs show strong correlation compared to the stock price-based $NDI_c$ in Figure 5. This is because, with more customers being served, ISP revenue is increased but it may not reflect the stock price. Some ISPs have switched their place from being on the negative side in earlier discussion to positive $NDI$ side in the revenue-based analysis and vice-versa (i.e., Qwest and Cablevision).

As expected, transit and exchange ISPs show higher positive $NDI_d$ and $NDI_c$ values. Due to their business model of carrying traffic on behalf of other ISPs or acting as a common point of interest, the more these ISPs are connected to others, the higher their profit margins are. This is more true for the North American region where organizations are least interested in peering than charging for transit [26]. Since revenue is a better representation of the profitability of a company than its stock market prices, this outcome is validating our intuitions.

Most of the access ISPs are grouped together by showing higher positive values except for Qwest and Cablevision, which is opposite to what we’ve seen from the stock-based $NDI$ values. Similar can be said for content ISPs with Yahoo and IBM being on the negative side. This is not quite surprising if we consider the fact that Yahoo is going through an economic hardship as they are on the verge of getting out of business and acquired by Verizon. While this merger had a positive effect on Yahoo’s stock market value to give it positive $NDI$ in Figure 4 and Figure 5, but it suffered from fewer revenue earnings and thus show negative values for revenue-based $NDI$. For IBM, more than one-third of its revenue comes from technology service and cloud platform [4]. Strategic outsourcing, integrated technology services or even selling software adds up the revenue for them, and thus explain why they have negative $NDI$ value as its business has become less dependent on its network. However, during 2015, Cablevision lost about 6000 subscribers but still managed to increase their profit [16]. This hints, losing a good chunk of customers sometimes have less impact on revenue for some of the ISPs.

CDNs show an almost identical sparse behavior in both revenue-based and stock-based analysis with Rackspace having negative $NDI$ values. As CDNs sit in the middle to deliver contents from content ISPs to end users using transit & access ISPs network infrastructure, they are less interested to manage their own network delivery system and may have already come up with a business agreement with their carriers. This explains why sometimes CDNs revenue growth may not directly correlate with the number of connections or end customers they have.

AT&T, Verizon, and TimeWarner from transit & access ISP...
group show negative revenue-based \( NDI_c \) which is similar to what we observed from their stock-based values. This justifies our assumption about them of having diversified business beyond just acting as an ISP.

IV. SUMMARY AND FUTURE WORK

In this paper, we investigated whether there is a correlation between ISP characteristics at the AS-level (such as the number of providers and the number of customers) and the stock market prices of these ISPs. We introduced Network Dependency Index (NDI), a metric to quantify the correlation of the topological structure of an ISP to its economic value. We believe our novel approach will open new horizons on understanding the relationship between the ISP networks and the stock market, and provide valuable insights into the dynamics of operating an ISP.

For this analysis, we harvested data of 32 major United States ISPs. By utilizing four different datasets (i.e., CAIDA AS Relationships, AS Rank, Quandl, and Yahoo Finance), we pointed a high correlation between ISPs’ stock values and their network characteristics such as customer cone size and AS degree. Even though there is a correlation between stock market values and ISP network characteristics, the correlation strongly depends on the type of the ISP (i.e., content, carrier, or access).

We observed that degree based NDI illustrates that transit businesses are the most dependent on AS degrees. Furthermore, content providers not the content delivery networks are performing much better in the stock market when they have higher AS degrees, i.e., customer-provider relationships. On the other side, NDI based on customer cone size demonstrates that by having a positive correlation, transit providers are the most dependent on the number of the customers.

We restricted our research only among such ISPs who are public company trading on the NASDAQ and NYSE. We found other companies who own more ASes with bigger customer cones than those ISPs we discussed here, but they were either subsidiary from other countries organization (NTT America, Inc. has an AS with rank 4 or Telia Company AB) or yet to be declared as the public company (Hurricane Electric, Inc.). We also found that some of the top-ranked ASes are owned by same companies (i.e., Level 3 owns 2 ASes among the top 15).

In future, we would like to expand our study to larger datasets including ISPs from other countries. One of the biggest limitations of our research was the availability of historical financial data. In particular, we would like to look in depth at the correlation between ISP characteristics and the stock values for the dataset starting from as early as late 90’s. We would like to analyze time periods where there were a financial crisis and/or Internet-related global activities such as the recession in early 2000, the recession in 2008, and the dot-com boom between 1995 and 2001. Moreover, we would like to spread our work with analyzing transit degrees of ISPs to see whether being highly connected (i.e., ingress points of the ASes which belong to these ISPs) is beneficial or not.

REFERENCES