A History of an Internet eXchange Point

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ABSTRACT

In spite of the tremendous amount of measurement efforts on understanding the Internet as a global system, little is known about the 'local' Internet (among ISPs inside a region or a country) due to limitations of the existing measurement tools and scarce data. In this paper, empirical in nature, we characterize the evolution of one such ecosystem of local ISPs by studying the interactions between ISPs happening at the Slovak Internet eXchange (SIX). By crawling the web archive `waybackmachine.org` we collect 158 snapshots (spanning 14 years) of the SIX website, with the relevant data that allows us to study the dynamics of the Slovak ISPs in terms of: the local ISP peering, the traffic distribution, the port capacity/utilization and the local AS-level traffic matrix. Examining our data revealed a number of invariant and dynamic properties of the studied ecosystem that we report in detail.

1. INTRODUCTION

In a rapidly changing system, like the Internet, using a single snapshot of the data for evaluating the algorithm/pro-tocol/model may be risky, as the data on which the results are based may become outdated by the time a solution (protocol, algorithm, etc.) is deployed or model published. Consequently, longitudinal studies of the Internet properties are necessary to reveal both the invariant and the dynamic properties of the Internet.

In this work we study the evolution of a specific biotope of ISPs operating in one region, interacting between each other through an Internet eXchange Point (IXP): the Slovak IX (SIX). Like other IXPs, SIX aggregates most ISPs operating in the country/region and allows accurate characterization of the ecosystem of the local ISPs. The detailed data on the SIX operation has been published on the SIX website since its inception and offers an unique opportunity to understand the dynamics over a long (on the Internet timescale) time horizon of several structures including: the low-tier ISP peering, inter-AS link utilization, port capacity upgrade practices and the local AS-level traffic matrix.

1.1 Related work

Obtaining high-fidelity data for studying the Internet properties is notoriously hard for various reasons ranging from confidentiality concerns to the lack of measurement infrastructure. In addition, analyzing the evolution of the Internet properties requires not only capturing a single snapshot of the data but also the system for continuous data collection and archiving. Consequently, the data that allows such longitudinal studies of the Internet properties is extremely scarce.

Dhamdhere and Dovrolis [10] use available historic data collected by RouteViews and RIPE to study the evolution of the customer-provider links in the AS-level graph, and the stability of such links. As they point out, these datasets have very poor accuracy in inferring the AS-peering links, and our paper complements [10] by offering new insights on the evolution of the AS-level connectivity between the lower tier ISPs.

The data that involves IP traffic measurements is often kept confidential, for obvious business concerns. Several studies have appeared in the literature reporting the properties of traffic evolution in certain vantage points [3, 6, 11], with the caveat that the such longitudinal data is typically collected at a single ISP and not available for public use. The analyzed traffic (and link capacity) data represent the 14-year evolution of the inter-domain traffic of *dozens* of ISPs, and is fully available for *public* use, which allows the analysis of the properties beyond those examined here.

The economics factors are believed to be the dominant force in the link creation (both the fee-based or settlement-free links) process at the AS-level [2, 9]. In this paper we show that in fact a large fraction of peering links is (and has been) virtually valueless. In other words, majority of AS-level links[1] would not be economically viable without IXPs and the link bundling in which high-value peerings are bundled with low-value peering links over the same physical port.

2. THE DATASET

The IXPs as mediators for local traffic exchange, sometimes publish data on its operation. Among IXPs that

[1]The number of peering links in the Internet dominates the number of customer-provider links in the Internet [2].

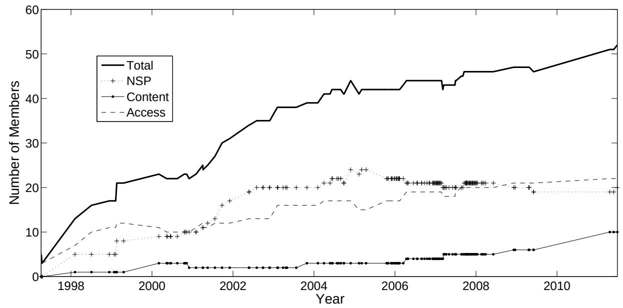

Figure 1: Number of members at SIX since 1997.

publish (or published) the peering matrix[2] and per-member traffic data, we choose to study the one that has done so from its beginning till today: Slovak IX[3]. Currently SIX hosts 52 ISPs which exchange around 50*Gbps* of two-way traffic in the peak hour. At each instance of time from 1997 onwards, SIX has published two sources of data used in our work: (1) peering matrix and (2) Multi Router Traffic Grapher (`mrtg`) [24] data, described in detail below. While the current snapshot of SIX web-page `http://www.six.sk/`, does provide some data on the traffic-stats over previous 12 months, it does not store historic data for public use. In order to study the evolution of the SIX, we take advantage of the *Internet archive* project [15], which stores 155 snapshots of the SIX website since 1997. In what follows we will give more details on the data format and the data collection. Additionally, we continually monitor SIX since 03/2011, by taking a snapshot of the whole SIX website every day. In our analysis we use 3 of these snapshots from the months of March, June and September of 2011. With 155 snapshots obtained from the `waybackmachine.org`, we have in total 158 snapshots covering years from 1997 to 2011. The data used in this paper can be conveniently found at [17].

Peering matrix is a matrix that indicates whether two members (ISPs) of the IXP peer between each other or not. There could be many reasons for peering (or not-peering) between two ISPs, and typically two ISPs would peer if and only if such peering provides (financial) benefits to *both* of the ISPs [2, 8, 12, 13]. At each snapshot[4] of the SIX website, we have the sample of the peering matrix, indicating who peers with whom at that time. Each participating ISP is identified by the name and AS number. In several cases, either name or AS number of an ISP change at some point, and for the purpose of our study we consider that ISP to be the same as the one before the change. However, some ISPs stop peering at SIX and since 1997, we found 32 ISPs that used to peer at SIX that do not peer any more. With 52 ISPs that peer at SIX today, it brings the total number of ISPs that have participated in SIX to 84.

In addition to mapping SIX members to the ISPs (that may change name and AS number), we classified each ISP based on the type of business they are involved with: access, content and network service providers (NSP). We used *peeringDB* service [25] to map ISPs to their type, and in few cases in which no type info was found in *peeringDB*, we manually inspected the ISP type. In Figure 1 we depict the evolution of the number and type of SIX participants.

Per-member traffic demands and port capacity are extracted from the `mrtg` data [24] available for *each* member at the SIX webpage. Figure 2 shows a (partial) snapshot of a webpage generated using the `mrtg` tool. It contains the data from UPC (large access provider), time-stamped on 12/4/2006, with the port capacity[5] of 1*Gbps* (value *Max Speed* in the graph), listing the average, max and current demand for both the inbound and outbound traffic, on daily (shown), weekly, monthly and yearly (not shown in Figure 2) basis. The `mrtg` tool also produces visual images depicting the daily/weekly/monthly/yearly traffic trends, and we designed a script that transforms these visual images into the numeric data. However, for the purpose of this paper, we exclusively work with the numeric data provided directly by `mrtg`: max and average.

Compared to peering matrix data, that is stored each of the 155 times the `waybackmachine.org` crawler hit `http://www.six.sk/`, the `mrtg` data is not archived every time, we believe because of the limitations of the `waybackmachine.org` in terms of bandwidth/storage and perhaps other implementation reasons. However, most ISPs do have at least one `mrtg` sample data point per year, which is enough for (relatively accurate) capturing dynamics on the yearly timescale. In the intervals between the available information, we use simple linear interpolation, to estimate the traffic at any point in time.

3. EVOLUTION OF SIX

In this section we examine various dynamic and invariant properties of the Slovak IXP. We want to stress that several properties observed here (the exponential traffic growth, the rise of the content providers and log-normality of the traffic matrix entry distribution) have been observed in other vantage points before using confidential data [6, 18, 22]. However, we establish them in the IXP context using public-domain data, and report them here for the sake of completeness.

3.1 Peering matrix

[2]Boolean matrix indicating who peers with whom.

[3]We study SIX in depth because it offers complete data in terms of peering and traffic since its inception to the present day. Studying incomplete data from few other IXPs leads to very similar qualitative findings, omitted here for brevity.

[4]155 historic snapshots from the `waybackmachine.org` and daily snapshots from 03/2011.

[5]Some members lease more than one port, in which case the sum of all port capacities is shown as the port capacity.

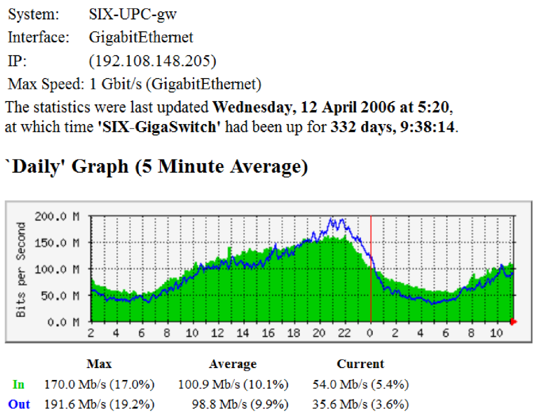

Figure 2: Snapshot of mrtg data.

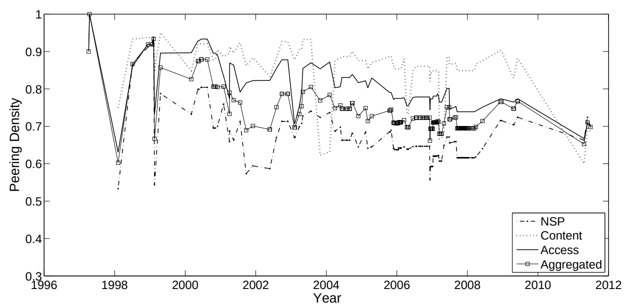

Figure 3: The evolution of peering density of SIX (aggregate) and per ISP type.

Due to its importance, the AS-level topology of the Internet has been one of the most comprehensively studied object in the networks research community. In spite of a tremendous amount of work on this topic, the existing measurement tools have very low accuracy in measuring (inferring) the AS-level topology in the lower tiers of the AS ecosystem [2, 14, 13]. For example, the most complete IXP-peering dataset [2] infers only 30% of the SIX peering links. The IXP data we use here, offer unique opportunity to accurately examine not only the current state AS-level topology among a subset of low-tier ISPs, but also to evaluate its dynamics.

Peering density dynamics. A major difference between the AS-level topology at the IXP level and the global AS-level graph is in the density of interconnections. Namely an 'average' ISP typically peers with a large fraction of other ISPs from the IXP. To quantify how likely the two IXP members are to peer, we use the *peering density*, a common metric defined as the ratio between the number of peering links and the number of all possible pairs of ISPs participating at the IXP [2]. In Figure 3 we plot the density of SIX across the 14 years of operation and observe that this quantity has been fairly stable over the time and is in the range around 70% which is 'normal' for European standards. The peering densities in the US-based IXPs are reportedly

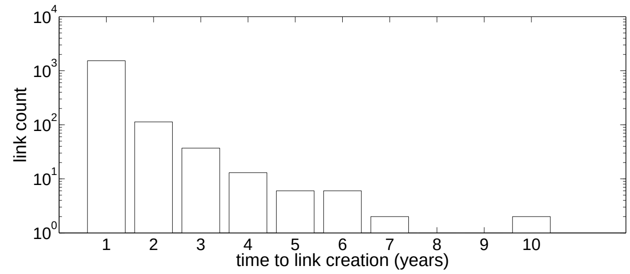

Figure 4: The histogram of link creation times for 1711 peering pairs in the history of SIX.

lower than of the European IXPs, while the IXPs in Australia, New Zealand and far-east are slightly denser in terms of peering [2]. In the same figure we also plot, per-type peering density of content, access and network service providers, and observe no significant dependance between the type of an ISP and the peering density.

Peering link creation. Throughout the history of SIX, there have been 1711 pairs of ISPs peering between each other. For those pairs of ISPs that eventually start peering, how long does it take from the moment the newer of them appears at SIX until they engage into the peering (we call this value the *link creation time* - LCT)? In Figure 4 we depict the distribution of LCT for the 1711 peering pairs. We can observe that when the peering happens, it is usually created within a year from the appearance of the newer ISP, yet there is a dozen of pairs, that required more than 5 years of simultaneous existence to start peering.

Peering link removal. Dhamdhere and Dovrolis [10], analyzed AS-level customer-provider (CP) links over a 10-year period, and showed that these links appear and disappear frequently, citing as a major reason the cost optimization process customers perform during the search for the most cost-effective provider. The peering links, on the other hand, have a different business objective and, thus, one may guess that peering links are less likely to be broken once they are created. Our data shows that this is indeed the case. Out of 1711 links, existing in SIX, only 20 link pairs de-peered. The other reason for the peering link removal is the disappearance of one of the ISPs from the IXP. As we mentioned earlier, 32 ISPs[6] that participated in SIX do not participate anymore and indeed peering links they were engaged with are not longer present.

3.2 Traffic dynamics

Traffic growth. The growth of the Internet traffic, has been shown to follow an exponential pattern at many vantage points: the residential broadband networks [6], the transpacific traffic [3], the global interdomain [18], etc. We observe a similar pattern in SIX as can be seen in Figure 5 that depicts the traffic growth

[6]Most of these ISPs either do not exist anymore, or were merged/purchased with some of the existing SIX members.

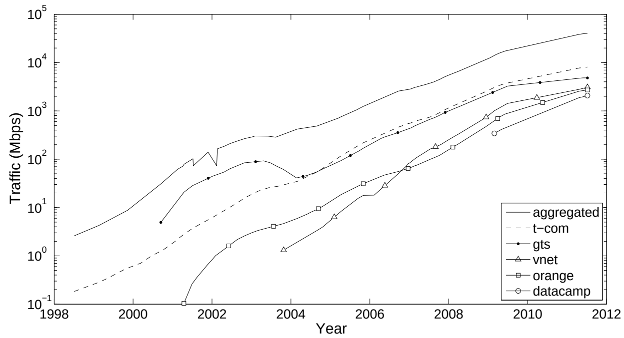

Figure 5: The SIX traffic and the traffic of top-5 current members.

ISP Name (ASN)	Type	AGR
aggregated	N/A	103.2%
t-com (AS6855)	Access	137.2%
gts (AS5578)	NSP	77.88%
vnet (AS29405)	Content	189.8%
orange (AS15962)	Access	143.4%
datacamp (AS39392)	Content	99.26%

Table 1: Type and Annualized Growth Rate (AGR) for aggregated traffic and current Top-5 ISPs.

for SIX and top-5 (in terms of traffic volume) ISPs that are currently active in SIX. In contrast to residential and global inter-domain traffic that grow with *annual growth rate* (AGR) of around 40-50% [6, 7, 18], the AGR of the SIX traffic both in aggregate and individual ISP terms is much higher: around 100% or even more for some ISPs. This hints the growth of the relative fraction of the inter-domain traffic that is exchanged via peering at the IXP, and therefore a decay of the relative fraction of the inter-domain traffic that reaches end-customers via transit, a phenomenon consistent with the widely observed flattening-of-the-Internet trend [18].

Another interesting property of the growth is that it is not uniform among involved ISPs: the traffic of some ISPs grows quicker than for the others. Table 1 contains the AGR for top-5 active ISPs and the total SIX aggregate. Relatively wide range of AGR reveals significant differences in the growth of different ISPs.

Remark: The annualized growth rates are obtained using the linear least-square fitting of the traffic growth curves in log scale.

Traffic per ISP type. As the Internet ecosystem matures, we are likely to expect the emergence of the specialized ISPs that target specific customer group. By looking in our data, we can see the emergence of one such class: content ISPs. Namely, until 2006, the content ISPs carried a very small fraction of the SIX traffic: under 10% in both directions. Since mid-2006, the number of specialized content ISPs doubled from 5 to today's 10; see Figure 1. The relative outbound traffic of those members, however, grew for an order of magnitude, from under 5% to over 40%.

Traffic imbalance. From Figure 6 one can notice

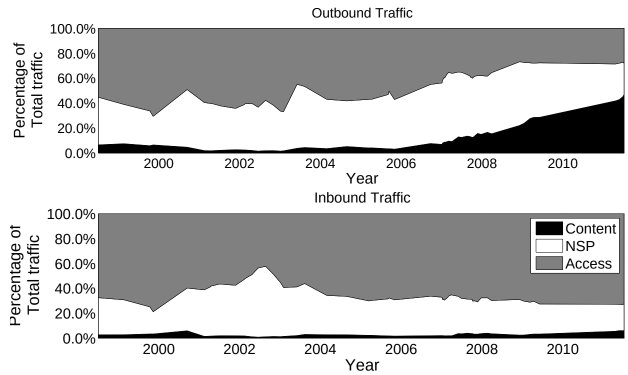

Figure 6: The percentage of total inbound/outbound traffic per ISP type.

that inbound to outbound traffic ratios vary significantly for different ISP types. For example a fully residential ISP traffic is likely to be heavily inbound, while the traffic of an ISP serving only content is likely to be heavily outbound. Additionally, balanced traffic is explicitly required in many peering contracts between tier-1 or tier-2 ISPs and the traffic imbalance has been cited as the main reason for de-peering in a number of recent de-peering incidents [4]. Here we look at the evolution over time of the traffic imbalance which we define for ISP X at time t as:

$$IB(X,t) = \max\left(\frac{T_{inbound}(X,t)}{T_{outbound}(X,t)}, \frac{T_{outbound}(X,t)}{T_{inbound}(X,t)}\right)$$

Where $T_{inbound}(X,t)$ and $T_{outbound}(X,t)$ is the inbound and outbound traffic of the ISP X at time t, respectively. In Figure 7 we depict the evolution of the median ISP IB, as well as the 10th and the 90th percentile. We also plot the (traffic) weighted average of the imbalance across all ISPs present in SIX at time t:

$$WA\_IB(t) = \frac{\sum_{X \in Active_t} T(X,t) \cdot IB(X,t)}{\sum_{X \in Active_t} T(X,t)}, \qquad (1)$$

where $T(X,t) = T_{inbound}(X,t) + T_{outbound}(X,t)$ is the total traffic of ISP X at time t. From Figure 7 we can see a growing trend in the traffic imbalance, indicating the increasing focus of the ISPs in particular end-customer groups. The fact that the weighted average is close to the 90th-percentile indicates that the large ISPs are more pronounced in such traffic imbalance, compared to the small and medium ISPs.

3.3 Capacity and utilization dynamics

In order to exchange traffic at SIX and most other IXPs, each member needs to pay a monthly fee for each port it uses for traffic exchange. The prices of ports increase with the port capacity, but however are subadditive, with price per $Mbps$ going down as the higher port capacity is purchased. The reasons for upgrading from lower port capacity to a higher one can be different, but roughly speaking most of the upgrades happen

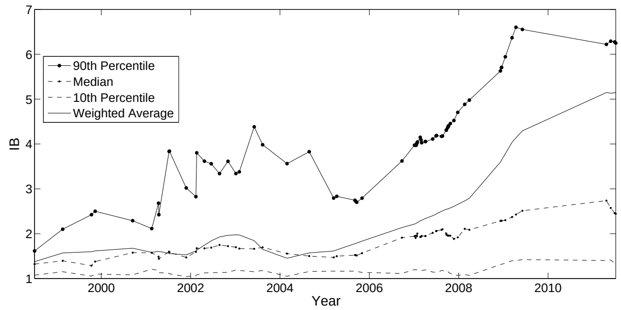

Figure 7: The evolution of ISP traffic imbalance (IB), median, 10th-, 90-th percentile and the weighted average.

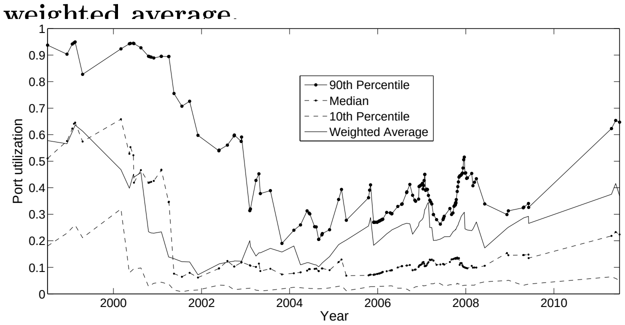

Figure 8: Per member port(s) utilization of SIX since 1998: median, 10th, 90th-percentile and weighted average.

because the member's traffic reaches port-utilization that is above some threshold.

Information on network utilization and upgrades by commercial ISPs are notoriously hard to obtain. Literature often cites 50% rule-of-thumb for net upgrades [21, 27], but we are not aware on any empiric study across a set of diverse ISPs that evaluates such statements. The data we study here offers an unique opportunity to shed light on the upgrade practice and the port utilization in dozens of operational ISPs.

Port utilization. In Figure 8 we depict the median, the 10th and the 90th-percentile of peak utilization among all members of SIX at each time instance for which we have a SIX snapshot. We used the peak utilization as the maximum monthly utilization averaged in 2-hour slots, available in mrtg data. In the first couple of years, the SIX ports were very highly utilized with median members' peak utilization being greater than 50%. In the early 2000's, a significant increase in the port capacities occurred and brought the utilization of many members down. From mid-2000's until today we observe the increase in the utilization levels, yet still 90% of the members currently have the peak utilization of their port(s) under 65%. We also depict the evolution of the weighted average of the utilization, weighted with the traffic of the ISP, similarly to Eq. (1). We can see that, since 2004, most of the heavy ISPs are running their ports at a higher utilization than the median.

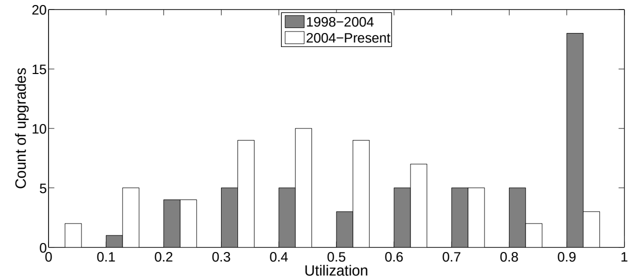

Figure 9: The estimated utilization at the time of port upgrade.

Port upgrades. In any ISP, increasing capacity of its networks is the most important mechanism for ensuring the high level of quality of service. Typically, the capacity upgrades in operational networks require a lot of planning and serious implementation efforts. In contrast, upgrading the port capacity at the IXP level is rather straightforward and can be done almost instantaneously. Hence, the data from SIX can offer insights on the operational practices of the involved ISPs. Figure 9 contains two histograms on the peak utilization at the moments of capacity-upgrades, one for the period from 1997-2004, and another for the period since 2004. In the earlier period, majority of upgrades happened because of the port overload, however since 2004, most ISPs upgrade their capacity early to avoid congestion of their SIX port. While most of the upgrades happen when the utilization reaches the range [30%-60%], there is still a non-negligible fraction of upgrades that happen outside of this range.

Comment. We analyzed the impact that port upgrades have on the traffic growth, and observed no statistically significant difference on the growth of the traffic before and after the upgrades.

3.4 Traffic matrix dynamics

Even though we do not have the exact *traffic matrix* (TM) between the pairs of ISPs peering at any instance of time, we can utilize the standard tools to estimate TM entries with reasonable accuracy. Here we choose to use the *tomogravity* method [28], that has been extensively deployed in operational ISPs and is fairly simple to implement. The expected errors of any TM estimation tool can be relatively large for a single origin-destination (O-D) pair. However, we do not analyze specific O-D pairs, but rather focus on aggregate statistics of the TM entry distribution, to draw the relevant conclusions.

Per-peering traffic distribution is skewed. An invariant property of the SIX traffic matrix is the variability of its entries. Namely the distribution of per-peering traffic appears to be log-normal with the exponentially growing mean (and variance) which is consistent with the previously observed property of intra-domain traffic matrix snapshot [22]. In Figure 10 we

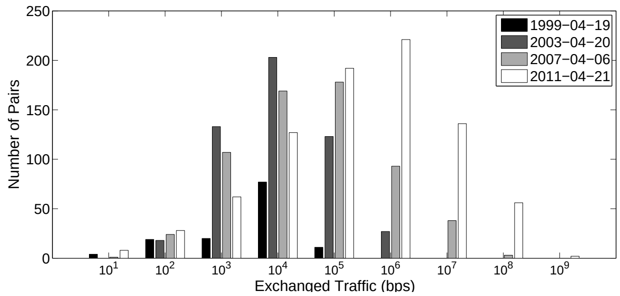

Figure 10: Histograms of traffic per peering pair in 4 points in 1999, 2003, 2007 and 2011.

depict the histogram of per-peering traffic of peering pairs present in the years 1999, 2003, 2007 and 2011. Consequently, several heaviest pairs carry most of the traffic (e.g. top-1% and top-10% of the pairs carry 40% and 85% of the traffic, respectively) and majority of the peering pairs carry very little traffic.

Peering: cost-reduction or performance? The most widely cited reason for creating a peering relationship between two ISPs is cost reduction: if the traffic between ISP A and ISP B is exchanged directly via peering, there is no need to be delivered via transit provider(s), hence the transit cost for both ISPs is expected to reduce. While such reasoning is indeed valid when the traffic volume between ISPs A and B is large, it becomes questionable when the traffic is small, since engaging into a peering relationship has a non-zero monetary cost (for legal agreements, staff, maintenance, etc.) associated with it. In Figure 11 (top) we depict the (estimated) median traffic volume among all peering pairs at SIX present at any instance of time, as well as the corresponding wholesale price of IP transit per $Mbps$ per month[7] [23]. In spite of two-order-of-magnitude change in these two quantities, the value of the median peering (calculated as the product of the median peering volume and the wholesale IP transit price) remains stable and under 10 USD per month; see Figure 11 (bottom). Such low median peering value suggest that majority of the peering links carry very low monetary savings and would not be economically viable outside Internet eXchange Points.

4. DISCUSSION AND FUTURE WORK

Diurnal (daily) traffic dynamics. Most of the analysis we performed in this paper treats the (traffic) dynamics on the yearly time-scale. The diurnal dynamic properties (such as the peak-to-valley ratio, peak-hour, etc.) is critical for the success of several recent proposals [19, 20, 5], and can be derived from the visual `mrtg` images. For example we observe that the peak-hour has shifted from early afternoon (1-2pm) in the late 1990's and early 2000's to late evening (9pm) nowadays. The ratio between the peak hour and off-peak hour from 10:1 in the late 1990's, to 3:1 in the mid 2000's (coinciding with p2p revolution), to 10:1 nowadays. We however omit the detailed discussion of these properties due to space limitation.

[7]The wholesale price used here is for the ports in EU/USA hubs. In other continents, the price per $Mbps$ can be 5 to 10 times greater.

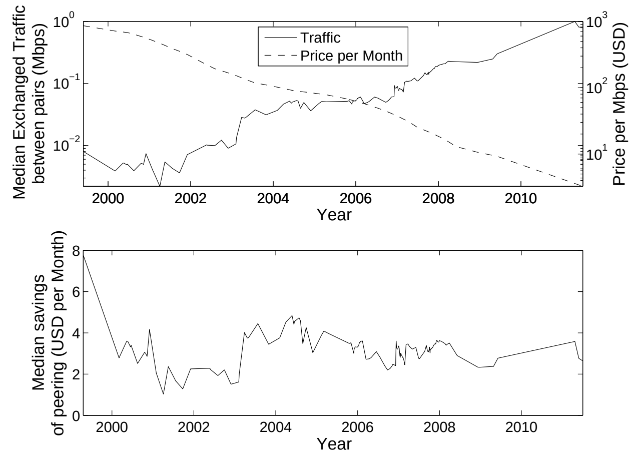

Figure 11: Median per-peering traffic and wholesale IP transit price (top) and peering value (bottom)

Matching large shifts in traffic with some real events. We believe that several important events can be observed from the data, such as large-scale DDOS attacks, capacity upgrades or port blocking/throttling in an ISP. For example in 2003 a significant drop in SANET-AS2607[8] traffic happened (60% reduction in the traffic without any change in the peering) for which we speculate that is caused by sudden p2p port blocking by the SANET.

Effects of private peering. Public peering, via IXPs, offers many benefits to the ISPs interested in peering, by allowing inexpensive and convenient peering with many peers. However, some ISPs may choose to peer privately, in which case such relationships may be invisible to the IXP. In context of Slovak ISPs, it appears that only a small fraction of local peering are private. Namely, the existing AS-level topology datasets [16] reports circa 34 private peering links among Slovak ISPs, which is under 4% of the number of IXP peerings.

Is SIX a representative IXP? Apart from the three largest IXPs (Amsterdam AM-IX, Frankfurt DE-CIX, and London LINX), all other IXPs are dominated by the "local" ISPs, that operate in the close proximity of the IXP, with a mix of access, content and network service providers. Thus we expect (and confirm on a limited data from several other IXPs) that most of qualitative findings we observe in SIX to be applicable to many other IXPs. While we are not aware of any particularity that may affect the applicability of

[8]Slovak academic network, acting as the access ISP to all Slovak universities.

our qualitative results to other IXPs, the quantitative values are largely impacted by the local ISP ecosystem and are expected to differ from IXP to IXP.

Internet-wide properties from the IXP data. IXPs are essentially a local object, mediating the exchange of "local" traffic. A property, observed in [18], that *globally* a large fraction of traffic is moving towards the content ISPs, is reflected in our data from SIX. Are there other properties of the global Internet that can be derived from the IXP data?

5. SUMMARY

Even though being in the periphery of the Internet, IXPs are an important part of the Internet ecosystem, currently mediating the exchange of 15-20% of the inter-domain traffic. With the trend of flattening-the-Internet [9, 18] (i.e. bypassing the transit providers with direct peering), the relative importance of IXPs, and peering in general, is likely to increase. In this paper we study one such IXP, Slovak IX, for which we acquired detailed peering and traffic data for 14 years of its existence. Such data allows us to characterize not only the current state of the IXP, but also the dynamic and invariant properties of the studied IXP.

Examining the evolution of SIX revealed a number of interesting facts in regards to the peering and traffic trends at the IXP. We discovered that once it has been created, a peering between two ISPs is very unlikely to disappear unless one of the members leaves the IXP. From the perspective of traffic dynamics, we observe a growth at SIX that is greater than the growth of the global inter-domain traffic, indicating the potential decay of the relative fraction of the transit (paid) traffic in the inter-domain. The emergence of content ISPs and heavily-unbalanced ISPs are two major factors characterizing the last 5 years of SIX operation. By estimating the SIX traffic matrix, we observe that the distribution of traffic per peering-link has been skewed since the beginning of SIX. This property indicates that the majority of peering links carry very low amounts of traffic (and consequently have very low monetary value), which challenges the folklore wisdom that promotes financial gain as the main cause for peering.

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