IXP traffic: a macroscopic view

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ABSTRACT

Today's public Internet eXchange Points (IXP) are a crucial element in the Internet ecosystem, carrying around $20 - 24Tbps$, i.e. 15-20% of Internet's inter-domain traffic and supporting a large percentage of links among autonomous systems. In spite of their importance, community still lacks empirical data on the nature of the traffic exchanged through IXPs. In this paper, we analyze the traffic data from two medium-size IXPs and draw several important conclusions. We quantify the relationship between the different types (access/content/transit) of ISPs present in the two studied IXPs, both in terms of traffic volumes and peering intensity. We also demonstrate that the peering (AS-level) topology within the IXP is impacted by the pricing model of the IXP. Finally, we shed light on the temporal characteristics of the traffic exchanged at IXPs and list a number of research problems that can benefit from the data studied here. We strongly believe that, in contrast with confidential datasets typically used in studying the Internet traffic characteristics, the IXP data provide rich and publicly available resources crucial for understanding various aspects of the Internet.

Categories and Subject Descriptors

C.2.3 [**Computer-communications networks**]: Network operations; network management

General Terms

Measurement

Keywords

Internet eXchange; Peering; Traffic matrix; Internet traffic

1. INTRODUCTION

Over the previous decade, the Internet eXchange Points (IXPs) have become a vital part of the Internet, carrying a considerable amount of its links and a large fraction of the inter-domain traffic. Globally, there are few hundred IXPs varying in size from small regional IXPs serving single-digit number of members to large international ones containing hundreds of ISPs. Two of the most cited reasons for such expansion of IXPs are the improvement in technical performance and reduction of peering costs for the involved ISPs. Currently, a significant fraction ($\sim$ 20%) of inter-domain traffic is exchanged through IXPs, and this fraction is growing as a result of the increasing number of ISPs that chose to exchange part of their traffic via one or more exchange points [9, 17, 13].

Albeit the significance of IXPs, the research community still lacks a complete understanding of the role of Exchange Points in the Internet ecosystem. One of the main reasons hereof is the absence of sufficient public information from IXPs. Ideally, we would like to have a full ISP-to-ISP traffic matrix for all ISPs that peer at a particular exchange point. However, except for one IXP, we could not identify any IXP that publishes this information. On the other hand, it is common for IXPs to publish their aggregated traffic statistics. When they do it, these stats are of varying granularity, and are usually very crude, typically capturing the stats summed across all ports. Such statistics indeed provide useful high-level information, but are of limited value for understanding the operation of an IXP and the interactions among many involved factors: upstream/downstream traffic, temporal effects, pricing, peering relationships, etc. Nevertheless, several IXPs publish additional information, such as the per-member traffic stats and the peering matrix (who peers with whom). These data can be combined to provide valuable information for estimating the IXP traffic matrix, hence allowing a deeper study of the exchange point. We will elaborate on the data collection and structure later in Section 2.

In this paper our goal is to study the traffic exchanged in IXPs, as well as the interplay between various factors that affect the operation of IXPs. For example, using data from the Milan Internet eXchange (MIX), we underpin with real data the folklore wisdom that the AS-AS traffic matrix is driven by a gravity law (Section 3). We then compare the data from MIX and the Slovakian Internet eXchange (SIX) and demonstrate that the IXP's AS-level topology is strongly correlated with the pricing model the IXP employs for charging its members. Moreover, we use the data of the two IXPs to empirically study the interaction between several ISP parameters such as the ISP type, size, temporal behavior, peering intensity, and report the observed results (Section 4). We conclude the paper with a number of open questions related to the studied subject and point out the importance of publicly available traffic data in studying var-

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ious aspect of the Internet (Section 5).

1.1 Background

An Internet eXchange Points (IXP) is a physical infrastructure used to facilitate the exchange of traffic between Internet Service Providers (ISPs). Two ISPs present at a particular IXP may decide to peer (exchange traffic) between each other or not, depending on their business, social and technological characteristics. While peering between two ISPs can be established outside of IXPs, peering via IXP is often less expensive[1].

Nowadays there are more than 200 IXP around the world [13, 2]. Depending on the number and geographical coverage of their members, IXPs can play different roles in the connectivity of regions. Large IXPs are usually the ideal place for the establishment of peering relationships among companies spanning various countries. Smaller exchange points are usually founded to facilitate the interconnection of national-wide ISPs and enterprises. Many research projects would greatly benefit from the characterization of IXPs (e.g. evaluating the resiliency and security of the Internet). However, although the majority of IXPs are non-profit driven, detailed information on them is scarce.

One of the unresolved questions around IXPs is the amount of Internet links supported by them. Xu et al.[28], He et al.[16] and more recently Augustin et al.[2] have presented different estimations for this value. Out of the 57.6K links detected by [2], around 30K were not found in other large AS-link datasets (CAIDA, DIMEA or PlanetLab), showing how undervalued this type of links were in past Internet measurement projects. The data gathered in [2] is the latest and richest source of IXP's peering links, however, as it is often the case, the methodology is efficient only for interconnections between ASes that possess some kind of "probe" (e.g. Looking Glass or a loose-source record-route router) that can be openly accessed. Since most ISPs do not have these kind of monitoring points available, our knowledge of IXP's links is most probably incomplete [21, 2]. This assumption is certified by comparing the most recent datasets with the peering matrices of some IXPs that publish such information. To give an example, the estimated peering density[2] of MIX and SIX according to [2] is 14% and 10% respectively, while IXP's data shows a peering density of around 58% and 69%. A similar observation was provided in [14] using data of a large European IXP. This is again a proof that our view of the Internet topology is rather limited and many of the missing links are located in IXPs.

Other important parameter to quantify is the percentage of Intra-domain traffic routed through Exchange Points. A large fraction of existing IXPs publish aggregate traffic statistics, which indicate a steady exponential growth of IXP traffic during the last decade. Worldwide, the current IXP traffic is in the range of 10-12Tbps of two way traffic (thus 20-24Tbps overall) [13]. Using the findings from [17], one can derive an estimate of the total Internet inter-domain traffic (sum of all entries in the global AS-AS traffic matrix) in the mid of 2012 at around 120Tbps[3]. Thus we estimate the fraction of total Internet inter-domain traffic exchanged via IXPs, to be in the range of 15-20%. For some ISPs the fraction of IXP traffic is even higher; e.g. in some European academic networks that openly publish their traffic stats, IXP traffic corresponds to 40-50% of their totals [23, 4]. In some other heavily localized Internet markets such as Japan this fraction can be as high as 70%[6].

1.2 Related Work

Despite its critical importance in the Internet ecosystem, the empirical studies of existing IXPs are only starting to appear. Augustin et al. [2] presented a measurement study of the peering relationships at IXPs worldwide, in which they report around 200 operational IXPs, and rich topological data on the peering relationships happening at these IXPs. The authors of [1, 15] use data from [2] and other datasets, to study implications of IXPs on the AS-level topology of the Internet. More recently, Feldmand et al. [14] analyze a large European IXP, exploring the traffic exchanged among its members and their characteristics. The two IXPs examined here are of mid-size and regional scope, therefore, our study is complementary to [14].

The inter-domain traffic matrix (TM) has many implications on the design of existing networks (e.g. for traffic engineering, transit/peering link creation, etc.) and has crucial effect on the operation of the Internet [5, 9, 10]. Estimation of TM entries from link measurements in an ISP has been widely studied [12, 29, 30] and similar tools can be applied in studying TM in the IXP setting in case no full TM is known. The TM estimation from the ISP link-level data is normally not at the AS granularity [17]. In contrast with confidential data that is typically used for TM estimation, the IXP traffic data is often public and can be used to derive the full information about the traffic exchanged between most of the pairs[4] of ASes that peer at the IXP.

1.3 Contributions

The main contributions of this paper are:

- We study basic characteristics of the traffic exchanged at IXPs. In particular we demonstrate that the IXP-member demand distribution is very skewed and that the traffic is dominated by the few heavy peering pairs (Sec. 4.2). We do not observe significant correlation between the peering intensity (the number of peerings) of a member with respect to its type, nor its traffic volume (Sec 4.3 and 4.4).
- We demonstrate strong correlation between the pricing model employed by the IXP and the peering density among the heavy peers: an IXP with a flat-fee pricing is significantly more likely to see heavy pairs peering, compared to an IXP with usage-based pricing (Sec. 4.1).
- Researching the Internet traffic, normally involves confidential datasets that are usually non-accessible to third parties. We bring attention to the community of a valuable set of public data, and discuss a number of research challenges

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[1] Indeed, the cost of creating N direct (non-IXP) peerings, essentially grows as $O(N)$, while the cost of peering via IXP is virtually independent of the number of peering links established via IXP [8].

[2] The peering density is calculated as the ratio between the actual number of peerings and the number of possible peerings inside the IXP

[3] The estimate of total inter-domain traffic given in [17] was 40Tbps in the mid of 2009, while adjusted for yearly growth of 45%[17, 7], provides this estimate of around 120Tbps of current traffic (June of 2012).

[4] Though, some AS pairs may peer at several IXPs, and in that case the traffic seen at one of the IXPs may not capture all the traffic between these ASes.

	SIX	MIX
Members	46	61
avg throughput (daily)	$5Gbps$	$10Gbps$
peering density	69%	58%

Table 1: Basic stats on MIX and SIX in February 2008.

```
$\textbf{\textit{SolveGravity}}(\mathbf{u}, \mathbf{d}, Peering\_Matrix)$
  for $k = 1 : N$
    $A_k(0) = \sqrt{d_k}$
    $R_k(0) = \sqrt{u_k}$
  endfor
  t = 0
  until convergence
    for $k = 1 : N$
      $\hat{A}_k(t+1) = \frac{d_k}{\sum_{s \text{ peer with } k} R_s(t)}$
      $\hat{R}_k(t+1) = \frac{u_k}{\sum_{s \text{ peer with } k} A_s(t)}$
    endfor
    $\eta = \sqrt{\frac{\sum_{k=1}^{N} \hat{A}_k(t+1)}{\sum_{k=1}^{N} \hat{R}_k(t+1)}}$
    $\mathbf{A}(t+1) = \frac{\hat{\mathbf{A}}(t+1)}{\eta}$
    $\mathbf{R}(t+1) = \eta \hat{\mathbf{R}}(t+1)$
    $t = t + 1$
  repeat
```

Figure 1: The pseudocode for solving gravity.

that these public data can be used for (Sec. 5).

2. DATASETS DESCRIPTION

In this paper we use data from two medium-sized IXPs: Milan-IX (MIX) and Slovak-IX (SIX). The datasets are described below.

MIX data. The dataset consists of traffic exchanged between 61 members, present at MIX. For *each* pair of members, the total traffic in both directions is reported for forty eight 30-minute time slots during one day in 2008.

SIX data. Slovak IX publishes the peering matrix with info on which member pairs do peer and which do not. Additionally, SIX publishes `mrtg` [20] statistics, reporting the traffic volumes in both directions aggregated per each member [25]. We have collected the information from SIX since 2010 and used Internet archives to find the data for previous years [3]. In order to compare both IXPs in the best possible way, we use the data for SIX that corresponds to February of 2008. Table 1 summarizes the basic stats of these two IXPs.

Even when the data utilized for the analysis of SIX and MIX is not current, there are reasons to value the comparison of these two IXPs using this data-set. Foremost, despite of the changes experienced by the two exchange points in the last few years, some of the characteristics of IXPs remain invariant for large periods of time [3], thus maintaining the validity of this comparison. Moreover, the different features highlighted here can later be used to compare the state of the IXPs at this time with other regional exchange points around the globe.

3. GRAVITY LAW AT IXP

Before proceeding with the comparison of SIX and MIX, we introduce in this section an algorithm that allow us to obtain an estimation of the distribution of exchanged traffic on an IXP when only the peering matrix and the total traffic per member is known. For this purpose, we quantify up to which extent the so called gravity law applies to IXP traffic. The gravity law states that the amount of traffic T_{ij} flowing from network i to network j can be approximated as:

$$T_{ij} = \frac{R_i \cdot A_j}{F_{ij}}, \tag{1}$$

where R_i is the repulsion factor of i; A_j is the attraction factor of j and F_{ij} is a friction parameter. The attraction and repulsion are related to the tendency of the network to, respectively, receive and send traffic. The friction parameter is typically inversely proportional to the 'distance' (in some metric space) between i and j. Since the two studied IXPs cover relatively small geographic area (a country), the friction parameter is unlikely to depend on the geographic distance, and in this paper we take it to be constant: $F_{ij} = (Mbps)^{-1}$.

In the case where the peering graph G is a full mesh (everyone peers with everyone) computing the repulsion and attraction factors from the upstream/downstream traffic stats is trivial: they are equal (up to a multiplicative constant) to the corresponding upstream and downstream traffic volume, respectively. Unfortunately, the peering graph is normally not a full mesh and the computation of repulsion and attraction is not straightforward. Namely in that case

$$A_j \sum_{(i,j)\text{peer}} R_i = d_j, \text{ for all } j, \tag{2}$$

$$R_i \sum_{(i,j)\text{peer}} A_j = u_i, \text{ for all } i, \tag{3}$$

where u_k and d_k is the upstream and downstream traffic volume of network k, respectively. It is not hard to see that the system (2)-(3) is under-determined: if $(A_1, \ldots, A_N, R_1, \ldots, R_N)$ is a solution to (2)-(3), then for any positive scalar α the vector $(\alpha A_1, \ldots, \alpha A_N, R_1/\alpha, \ldots, R_N/\alpha)$ solves (2)-(3) as well. To enforce the uniqueness of repulsion and attraction parameters we require the following normalization constraint to be met:

$$\sum_{k=1}^{N} A_k = \sum_{k=1}^{N} R_k, \tag{4}$$

Thus, the attraction and repulsion factors are the solution of the nonlinear system: (2)-(4). Pseudocode in Figure 1 provides a simple iterative method for solving it. We compare the estimated TM, obtained by solving the system (1)-(4), with the real TM in Figures 2 and 3. In Figure 2, we plot the estimated average throughput against the real throughput for all pairs of members that peer at MIX. The estimation is reasonably accurate for 'heavy' pairs, but does not deliver precise results for the pairs exchanging lows amounts of traffic. Figure 3 compares the cumulative distribution of both TM for the number of pairs with less than a certain amount of traffic. From both figures, it can be stated that even if the system does not provide a highly accurate estimation on the individual member pairs, it approximates adequately well with the general distribution of traffic among them. It is likely that more precise TM estimation methods could be developed, probably by optimizing existing techniques[12, 29, 30], however, accurate estimation of TM is out of the scope of our work. We rather seek for

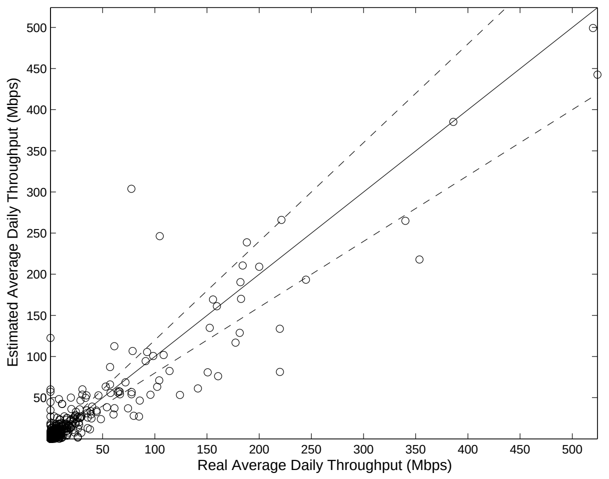

Figure 2: Real throughput compared to throughput estimated using the gravity model.

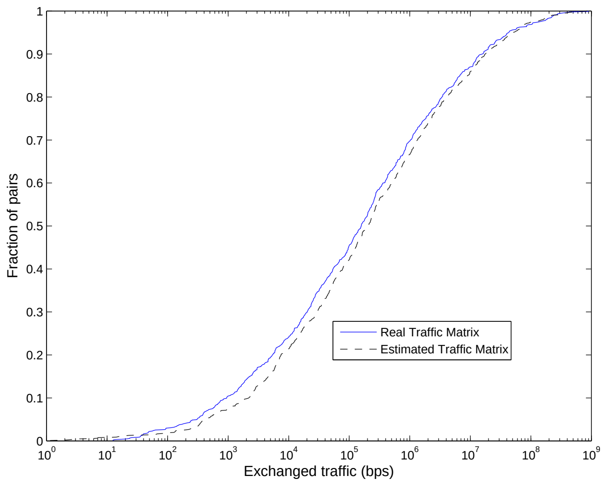

Figure 3: Cumulative distribution of exchanged traffic for peering pairs in both the real and estimated traffic matrix of MIX.

a simple method allowing us to explicitly estimate the IXP TM with reasonable accuracy, which is indeed achieved by the gravity method tailored for the IXP case.

3.1 Attraction and repulsion

As we mentioned, even though closely correlated, the repulsion/attraction parameters of an ISP, are not directly derivable from the upstream/downstream traffic measurements. For example a heavy attractor/repulser may peer with a low number of peers, which can result in low amount of traffic exchanged. Therefore we use the repulsion and attraction parameters as indicators of the ISP demand (size) rather than the observed traffic itself.

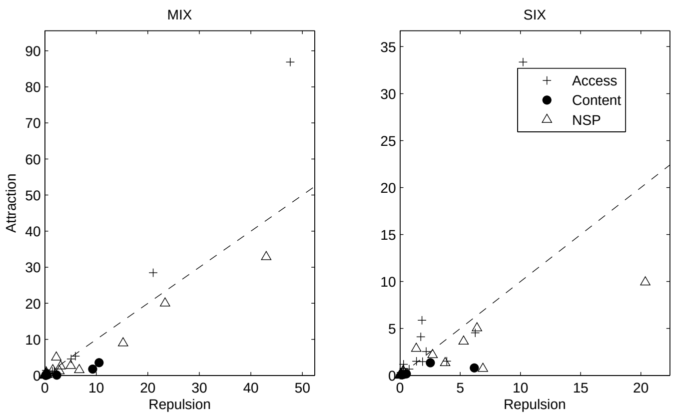

Figure 4: Attraction vs Repulsion for members of SIX and MIX.

In Figure 4 we plot attraction against repulsion for each member of MIX and SIX. We used the *type* classification from PeeringDB [22] to distinguish between access, content and network service providers (NSP). We stress that there is no sharp line between these three categories, since often each network may provide multiple services (e.g. a NSP offering access services). From Figure 4 we can deduce two important observations. First, not surprisingly, the access networks typically have larger attraction/repulsion ratio while the content providers have the opposite property. And second, the distributions of repulsion and attraction parameters are very skewed, with a few members dominating the others in terms of size.

4. COMPARING SIX AND MIX

4.1 Pricing model matters!

The two studied IXPs are similar in many ways: they host similar number of members, with similar traffic levels, and similar peering density (see Table 1). Besides, both of them are the dominant national IXP, with virtually all their members operating in Italy or Slovakia respectively. Nevertheless, there is one striking difference between them in terms of peering between 'heavy' pairs. In order to define the weight of the pair of members, we use the repulsion and attraction parameters to obtain a first-order approximation of the traffic flowing between the pairs of members in an IXP (for those that peer and also those that do not peer). We define the weight or *potential* of a pair of members (i, j) as

$$P_{ij} = (A_i \cdot R_j + R_i \cdot A_j)(Mbps). \tag{5}$$

As we showed in Section 3, the gravity model provides a fairly accurate approximation for the traffic of peering pairs. We extrapolate such reasoning for the pairs that do not peer, and use (5) as an estimate of traffic flowing between any pair of peers. In Figure 5 we depict the values of potential, for top-100 pairs (ranked by the potential). As we can observe from this figure, most of the pairs with high potential at MIX do not peer, while this is not the case at SIX. There can be many factors that impact the decision on whether a member should exchange traffic with another member at the IXP or not. However, we believe that the critical factor that influences the peering decision between the heavy pairs is the financial one. Namely, the pricing model of the two IXPs is fundamentally different: while SIX used flat fee [25] (traffic-volume independent pricing), MIX employed usage

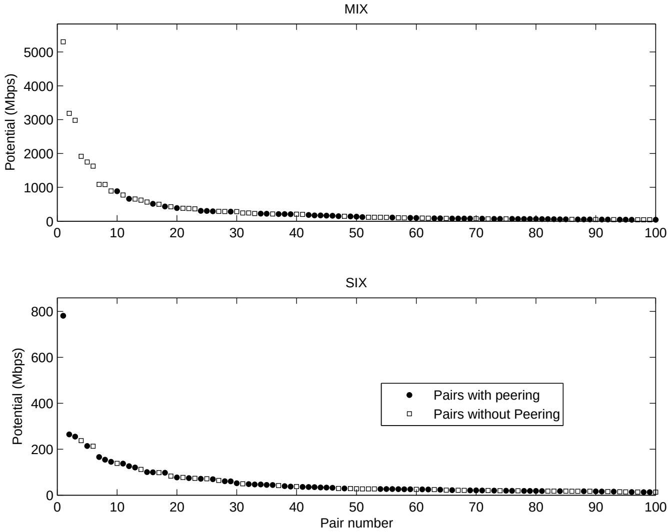

Figure 5: The potential between pairs at SIX and MIX (Top 100 pairs shown).

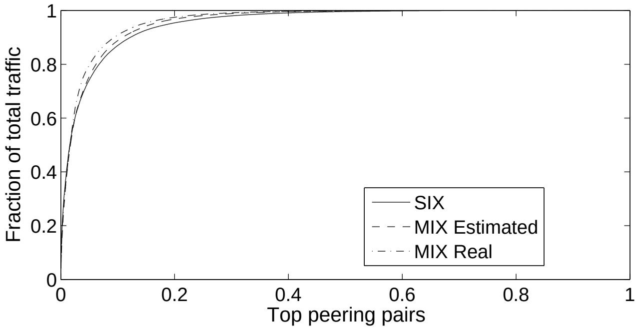

Figure 6: Fraction of total traffic generated by heaviest peering pairs at SIX and MIX.

based, 90th-percentile pricing [19]. Additionally, the price per $Mbps$ in MIX case was prohibitively expensive, calling for non-IXP peering between heavy pairs (willing to peer).

Remark. After our MIX-traffic data was collected, the pricing model in MIX changed from usage-based to flat-fee. However, we did not see significant increase in the peering density between heavy pairs, which is probably due to the fact that once a non-IXP peering is created, there is virtually zero-cost for maintaining such peering.

4.2 Traffic distribution

Another important property of the IXP traffic is the heterogeneity of the traffic volumes among the peering pairs. In other words, the IXP traffic is dominated by a few heavy peering pairs. In Figure 6 we depict the fraction of the IXP traffic generated by the top-x% peering pairs. For MIX, both the direct measurement and the gravity estimates are shown, while for SIX only the estimated values (from gravity model) are shown. We can observe that top-10% of peering pairs generate 85-90% of traffic and top-1% of peering pairs generate 30-40% of the IXP traffic. A different perspective of the distribution of traffic among peering pairs is depicted in Figure 7, which shows a histogram of the traffic exchanged by peering pairs in both MIX and SIX. The traffic distribution of both IXPs is quite similar and in both cases half of the peering pairs exchanged less than $300Kbps$, a very low amount of traffic which most probably would only make sense to exchange inside an IXP.

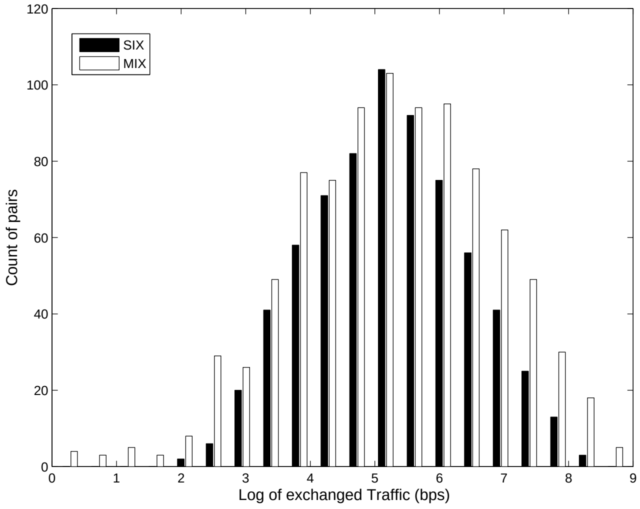

Figure 7: Traffic distribution for SIX and MIX in 2008.

4.3 ISP-type

Different types of networks peer through IXPs. We use the Peering DB[5] [22] to classify the members of SIX and MIX into three categories: access, content and network service providers (NSP). We stress that this classification is relatively crude as some members (particularly at MIX) offer multiple services and cannot be clearly classified in one of these three types. Table 2 lists the fraction of the total IXP traffic flowing between different member types. Not surprisingly, we observe that access networks are sinks of more than 50% of total traffic (65% in SIX case) and that content traffic is dominated by download. Inconsistencies between SIX and MIX, are mainly result of the fact that several large Italian access and content providers are represented at MIX by the parent AS which is an NSP.

One may wonder whether peering density varies between different types of members (i.e. whether access ISP is more likely to peer with content ISP than NSP). We summarize our findings in Table 3, which shows no evidence for significant difference of peering density between different member types.

4.4 Peering intensity vs. member size

Another question that arises in the analysis of IXP is whether the member's traffic volume affects the number of peerings it engages at the IXP, or not. We do not observe such dependence at neither MIX nor SIX. In Figure 8 we plot the number of peerings for each member of the IXPs, against its size. Apparently, the peering intensity (the number of peering relationship the member engages) of a mem-

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[5] Peering DB is an online data-base that stores the basic info on most ASes involved in peering. For the few ASes without an entry in PeeringDB, we manually inspected their type.

	From \ To	Access	Content	NSP
SIX	**Access**	22.3%	1.4%	12.5%
	Content	10.7%	0.2%	4.4%
	NSP	35.1%	2%	11%
MIX	**Access**	24.6%	1.6%	12.9%
	Content	7.7%	0.7%	6.3%
	NSP	18.1%	2.3%	25.4%

Table 2: Relative traffic exchanged between the different types of members for SIX and MIX.

	From \ To	Access	Content	NSP
SIX	**Access**	77.8%	92%	65.9%
	Content	92%	100%	75.2%
	NSP	65.9%	75.2%	53.8%
MIX	**Access**	52.4%	67.4%	44%
	Content	67.4%	80.9%	52%
	NSP	44%	52%	43.3%

Table 3: Density of peering between types of members for SIX and MIX.

ber does not appear to depend on its size, in spite of large differences in the member traffic volumes (multiple orders of magnitude).

4.5 Temporal effects

Different networks have different diurnal cycles, some peak in early afternoon, others in late evening [18]. The ratio between the peak-hour traffic (say 95th-percentile) and the off-peak-hour traffic (say 5th-percentile), is another parameter heavily influenced by the user base, their behavioral pattern and also the application mix they are running. However when two ISPs with different temporal patterns peer, the traffic exchanged between them follows the temporal pattern influenced by both ISPs. In Figures 9 we visualize the empirically observed peak-hour ratio for the MIX's top-20 attractors, top-20 repulsers and the peering pairs that exchange at least $10Mbps$[6]. The checkerboard plot in Figure 9 illustrates the peak-hour value for the exchanged traffic, while the external bars (parallel to the axes) show the peak-hour for the total traffic of each ISP. As the external bars show, the ISPs are sorted based on their peak hour.

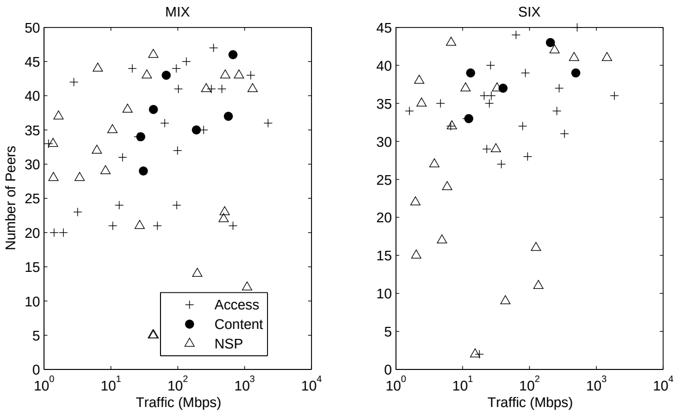

Figure 8: Peering intensity vs. traffic of ISPs peering at MIX and SIX.

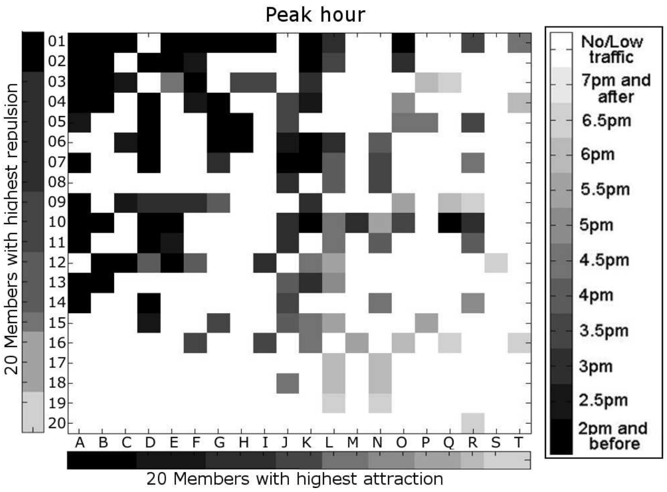

Figure 9: Peak hour for the MIX's top-20 repulsers (upstream), the top-20 attractors (downstream) and the pairs that exchange $> 10Mbps$.

To provide an example of the interpretation of Figure 9, we examine here the traffic exchanged between ISPs 01 and R (ISPs names are anonymized). From the adjacent bars, we can observe that the total traffic of ISP R peaks at 6pm, while the total traffic of ISP 01 peaks at 2pm or before. The total exchanged traffic (sum of the traffic flowing in both directions) peaks at 3.5pm, a value that is depicted in cell (01, R) of the Figure.

Figure 10 has the same interpretation than Figure 9, but it shows the peak-to-valley ratio instead of the peak-hour. From the two Figures, one can observe that the temporal parameters (peak hour and peak-to-valley ratio) of each pair of ISPs can be roughly approximated with a weighted average of the corresponding parameters of the two involved ISPs.

Temporal dynamics of SIX is somewhat different as its members peak a couple of hours later than MIX in average. This is probably due to differences in the predominant type of final customers served by the members of each IXP. Though, the variation in peak-hour periods and peak-to-valley ratio among different members of SIX is similar to that observed in MIX.

5. DISCUSSION AND OPEN PROBLEMS

We believe that the public traffic data available at many IXPs is an under-utilized resource for understanding the Internet properties. In this work we present some initial results and quantify basic properties of two medium-sized IXPs. The data studied here opens many opportunities, beyond those investigated in this paper, including several listed below.

Correlation of inter-domain traffic with measurable parameters. Each AS has a number of globally mea-

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[6] Those pairs that exchange less than $10Mbps$, often lack the regularity of the daily pattern to draw meaningful conclusions on the temporal effects.

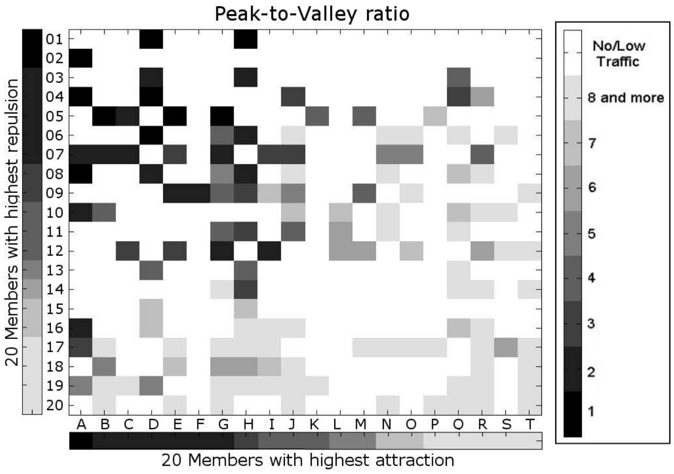

Figure 10: Peak-to-valley ratio for the MIX's top-20 repulsers (upstream), the top-20 attractors (downstream) and the pairs that exchange $> 10Mbps$.

surable parameters that can characterize its position in the Internet ecosystem such as IP address space size, AS neighbors, number of bittorrent clients, etc. Our initial analysis shows strong correlation between the repulsion / attraction of an ISP and some of those parameters, and suggests that some very simple methods can be used for estimating repulsion / attraction of an arbitrary AS. We acknowledge that more subtle methods would be needed on top of such first-order approximation for an accurate estimation of the AS-AS traffic.

Using traffic info to do IXP topology mapping. There are a dozen of IXPs that publish per-member traffic statistics but no peering matrix, limiting the accuracy of the TM estimation. Mapping of the IXP topologies is far from complete [2, 26, 24]. The most recent of these projects [2] identifies only around one third of the existing peering pairs in the two IXPs studied here. Can we infer IXP's AS-level topology using traffic statistics and some signal processing tools?

IXP traffic dynamics. Traffic dynamic on various time scales is an important aspect of any network. For example, monthly or yearly growth is essential for infrastructure dimensioning and traffic engineering. The network's daily and seasonal trends provide interesting social information regarding its user base. The peak-to-valley ratio in a given network is closely related to the application mix used in the network; i.e. a residential ISP with heavy P2P usage would have a low peak-to-value ratio, while an enterprize network would typically have very high peak-to-valley ratio [11, 27]. Understanding the evolution of such temporal properties is in the focus of our current research. While IXPs often provide data for the past 12-24 months, web-archives can be used for digging into historical data.

Comparing Large (international) and Regional Exchange Points. In terms of the member composition IXPs can be: (1) regional/national IXPs with similar user base and (2) international IXPs that host globally present ISPs and large ISPs from a number of different countries. Most of the IXPs, including the two analyzed here, belong to the first category. However, several largest IXPs are of the second type. We believe that the traffic in those international IXPs differs in some important aspects (e.g. gravity law with constant friction may not apply) and further research and measurement data is needed to reveal the similarities and differences between these two types of IXPs.

Economics of IXP. Qualitatively, the positive impact that IXPs have on the involved ISPs have been widely acknowledged. On the quantitative level however, very little is known on the economic impact of IXPs on their members and the Internet in general. This is partly due to the lack of empirical data on the IXP usage. As part of our future work, we plan to deepen the quantitative understanding of the IXP's economics, using the data studied here.

Using IXP traffic to estimate non-IXP traffic. IXPs see/publish only part of the members' traffic. Can we use the IXP traffic to estimate the non-IXP/transit traffic of an ISP in terms of volume, daily/seasonal peaks, peak-to-valley ratio, up/downstream ratio, etc.?

6. SUMMARY

Thanks to their economical and technical benefits, IXPs have become an significant part of the Internet infrastructure and a key element for the connectivity of regions. Although their importance is evident, the research community is still striving to acquire a better understanding of IXPs.

In this paper, we examine and compare data from two European IXPs to obtain a better characterization of exchange points. Not surprisingly, we encounter that no past project was able to find many of the peerings established inside the two analyzed IXPs and thus, we reassert that the current measured AS-level topology still underestimates the total amount of peering links located in exchange points. We also show that the traffic distribution in both IXPs is similar and observe that it is dominated by a few heavy peering pairs. Furthermore, we look into some of the temporal characteristics of the exchanged traffic. Finally, we discuss some open problems that we plan to address in our future work.

7. REFERENCES

[1] M. Ahmad and R. Guha. "Understanding the impact of Internet exchange points on Internet topology and routing performance". In *Proceedings ACM CoNEXT Student Workshop 2010.*

[2] B. Augustin, B. Krishnamurthy, W. Willinger. "IXPs: Mapped?". In Proceedings of ACM SIGCOMM 2009.

[3] J. C. Cardona Restrepo, R. Stanojevic. "A history of an internet exchange point". ACM CCR, vol. 42(2) 2012.

[4] CESNET, Traffic Stats. `http://www.ces.net/netreport/`.

[5] H. Chang, S. Jamin, Z. Mao, and W. Willinger. "An empirical approach to modeling inter-AS traffic matrices". In *Proceedings IMC 2005.*

[6] K. Cho, K. Fukuda, H. Esaki, A. Kato. "The Impact and Implications of the Growth in Residential User-to-User Traffic". In Proceedings of ACM SIGCOMM 2006.

[7] Cisco Systems. "Cisco Visual Networking Index: Forecast and Methodology". Cisco White Paper, 2008.

[8] CISCO. (2009) "The value of peering". ISP/IXP Workshop. CISCO. [Online]. Available: `http://www.pacnog.net/pacnog6/IXP/IXP-peering.pdf`

[9] A. Dhamdhere, C. Dovrolis. "The Internet is Flat: Modeling the Transition from a Hierarchy to a Peering Mesh". In Proceedings of ACM CoNEXT 2010.

[10] A. Dhamdhere, C. Dovrolis, P. Francois. "A Value-based Framework for Internet Peering Agreements". In

Proceedings of ITC 2010.

[11] X. Dimitropoulos, P. Hurley, A. Kind, M. Stoecklin. "On the 95-Percentile Billing Method". In Proceedings of PAM 2009.

[12] V. Erramilli, M. Crovella, N. Taft. "An independent-connection model for traffic matrices". In Proceedings of ACM IMC 2006.

[13] European Internet Exchange Association, `www.euro-ix.net`.

[14] A. Feldmann et al. "Anatomy of a Large European IXP". In Proc. of ACM SIGCOMM 2012.

[15] E. Gregori, A. Improta, L. Lenzini, and C. Orsini. "The impact of IXPs on the AS-level topology structure of the Internet". *Computer Communications*, 2010.

[16] Y. He, G. Siganos, M. Faloutsos, and S. Krishnamurthy. Lord of the links: a framework for discovering missing links in the internet topology. *IEEE/ACM Transactions on Networking (TON)*, 17(2):391–404, 2009.

[17] C. Labovitz, S. Iekel-Johnson, D. McPherson, J. Oberheide, F. Jahanian. "Internet Inter-domain Traffic". In Proceedings of ACM SIGCOMM 2010.

[18] N. Laoutaris, G. Smaragdakis, P. Rodriguez, R. Sundaram. "Delay Tolerant Bulk Data Transfers on the Internet". In Proceedings of ACM SIGMETRICS 2009.

[19] MIX. Peering prices at MIX, March 2008. [Online]. Available: `http://replay.web.archive.org/20080415151545/http://www.mix-it.net/costi-2007.htm`

[20] T. Oetiker, The Multi Router Traffic Grapher. `http://oss.oetiker.ch/mrtg/`.

[21] Oliveira, R. and Pei, D. and Willinger, W. and Zhang, B. and Zhang, L., The (in) completeness of the observed internet AS-level structure. *IEEE/ACM Transactions on Networking (ToN)*. 2010..

[22] PeeringDB. Website. [Online]. Available: `http://www.peeringdb.com/`

[23] SANET, Traffic Stats. `http://samon.cvt.stuba.sk/`.

[24] Y. Shavitt and E. Shir. "DIMES: Let the internet measure itself". *ACM SIGCOMM Computer Communication Review*, vol. 35, no. 5, pp. 71–74, 2005.

[25] SIX. [Online]. Available: `http://www.six.sk/`

[26] Skitter project. [Online]. Available: `http://www.caida.org/tools/measurement/skitter/`

[27] R. Stanojevic, N. Laoutaris, P. Rodriguez. "On Economic Heavy Hitters: Shapley Value Analysis of the 95th-Percentile Pricing". In Proceedings of ACM IMC 2010.

[28] K. Xu, Z. Duan, Z. Zhang, and J. Chandrashekar. On properties of internet exchange points and their impact on as topology and relationship. *NETWORKING 2004, Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications*, pages 284–295, 2004.

[29] Y. Zhang, M. Roughan, N. Duffield, and A. Greenberg. "Fast accurate computation of large-scale IP traffic matrices from link loads". In *Proceedings of ACM SIGMETRICS 2003.*

[30] Y. Zhang, M. Roughan, C. Lund, and D. Donoho. "An information-theoretic approach to traffic matrix estimation". In *Proceedings of ACM SIGCOMM 2003.*