Dissecting the Largest National Ecosystem of Public Internet eXchange Points in Brazil

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Abstract. Many efforts are devoted to increase the understanding of the complex and evolving Internet ecosystem. Internet eXchange Points (IXP) are shared infrastructures where Autonomous Systems (AS) implement peering agreements for their traffic exchange. In recent years, IXPs have become an increasing research target since they represent an interesting microcosm of the Internet diversity and a strategic vantage point to deliver end-user services. In this paper, we analyze the largest set of public IXPs in a single country, namely the IX.br project in Brazil. Our in-depth analyses are based on BGP data from all looking glass servers and provide insights into the peering ecosystem per IXP and from a nation-wide perspective. We propose a novel peering affinity metric well-suited to measure the connectivity between different types of ASes. We found lower values of peering density in IX.br compared to more mature ecosystems, such as AMS-IX, DE-CIX, LINX, and MSK-IX. Our final contribution is sharing the 15 GB dataset along all supporting code.

Keywords: IXP, BGP, Autonomous System, Inter-domain Routing

1 Introduction

Internet eXchange Points (IXP) are a relevant approach to promoting the Internet development in terms of connectivity and performance. IXP facilities, located at strategic places throughout nations, allow dozens or hundreds of Autonomous Systems (AS) to interconnect and agree on their traffic exchange. The increased participation of ASes at IXPs is contributing to the critical role of IXPs as tactical infrastructures in the overall Internet ecosystem [3]. The motivation of ASes to peer at IXPs is mainly due to cost savings and performance benefits [13]. With video traffic representing 50% (and growing) of the total Internet traffic, peering at IXPs allows a better distribution of content closer to end users and reducing transit costs. During the 2014 Soccer World Cup[1], Brazilian IXPs played a critical role in delivering the traffic and are expected to be again an important infrastructural piece during the 2016 Olympic Games.

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[1] https://labs.ripe.net/Members/emileaben/internet-traffic-during-the-world-cup-2014

Table 1. Traffic of some of the world's largest public IXPs (August 28, 2015).

IXP	Country	Members	Maximum Throughput (Gbps) Daily	Monthly	Yearly	Average Throughput (Gbps) Daily	Monthly	Yearly
(01) DE-CIX	Germany	600+	3,603.10	3,854.80	3,875.10	2,375.90	2,299.20	1,964.90
(02) AMS-IX	Netherlands	731	3,620.00	-	3,872.00	2,358.00	-	2,013.00
(03) LINX	United Kingdom	630	2,472.00	2,530.00	2,575.00	1,844.00	1,631.00	1,507.00
(04) MSK-IX	Russia	384	1,409.26	1,417.01	1,569.64	924.73	788.26	778.82
(05) NL-ix	Netherlands	527	1,080.00	-	-	871.56	-	-
(06) IX.br	**Brazil**	**715**	**989.90**	**1,070.00**	**653.51**	**656.67**	**610.85**	**451.27**
(07) HKIX	Hong Kong	225	436.43	468.12	485.18	305.02	302.84	245.51
(08) SIX	USA, Canada	200	398.68	411.22	411.22	304.89	288.53	239.61
(09) JPIX	Japan	138	315.54	-	-	200.00	-	-
(10) JINX	South Africa	24	15.90	20.80	11.10	8.60	8.30	6.00

(01) http://www.de-cix.net/about/statistics/
(02) https://ams-ix.net/technical/statistics
(03) https://www.linx.net/pubtools/trafficstats.html
(04) http://www.msk-ix.ru/network/traffic.html
(05) https://www.nl-ix.net/network/traffic/
(06) http://ix.br/cgi-bin/all
(07) http://www.hkix.net/hkix/stat/aggt/hkix-aggregate.html
(08) http://www.seattleix.net/agg.htm
(09) http://www.jpix.ad.jp/en/technical/traffic.html
(10) http://stats.jinx.net.za/showtotal.php

The nature and services of an IXP largely depend on its business and operational model, i.e., the entity owning/operating an IXP may have different vision, incentives, regulatory and commercial considerations. Following the approximate classification of [3], we can distinguish "for-profit" and "non-profit" IXPs, which can be further divided into "cooperative" and "managed" non-profit IXPs (e.g., DE-CIX, AMS-IX, LINX). The latter, mainly found in Europe, are considered among the most vibrant and innovative IXPs [3]. In the US, the predominant business model of IXPs is private, for profit.

The case of Brazil, which leads Latin America by operating more than half of the IXPs in the region, follows an interesting approach that may inspire other countries, especially developing regions. Brazilian IXPs are part of an overarching project called IX.br (also known as PTTMetro) and adopt a non-profit business model managed and fully funded by NIC.br, the Brazilian Internet Steering Committee that takes care of DNS registry services, IP allocation, in addition to government-funded Internet development activities. Since 2006, Brazil has grown from 4 IXPs to the current 25 in operation –with 16 new locations under evaluation[2], especially in the north, west and central regions where there is a concerning deficit of rich Internet connectivity compared to the south, southeast, and northeast. The IX.br expansion plan aims at attracting ISPs (access providers) to those isolated areas with poor connectivity by offering IXP incentives (fee free usage). As shown in Table 1, IX.br is among the world's top ten IXPs in terms of traffic. PTT-SP (in Sao Paulo) alone is among the top five largest in terms of number of members (700+)[3].

In this paper, we present the first empirical analysis of the Brazilian IXP ecosystem and bring out an extensive data collection and analysis work considering all public IXPs operating in Brazil. After classifying all AS participants, we generate AS-level connectivity graphs (per IXP and nation-wide) to sustain the analytic studies on the observed topologies, shedding light on the peering density, advertised routes (AS-PATH), average vertices' degree, path depth, and traffic engineering practices based on AS-Prepend.

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[2] According to NIC.br, there are currently 45 candidates interested in hosting the new IXPs. Interested entities, be it commercial or not, are only requested to operate neutrally and free of fees to IXP participants. [3] http://ix.br/particip/sp

Another contribution is proposing *peering affinity* as a metric to evaluate the peering density between different types of ASes. Our publicly available[4] dataset –currently the largest one in the context of the Latin America IXPs– has more than 15 GB of data and the information from all 25 Brazilian public IXPs, including the member classification, IPv4/v6 BGP tables, supporting spreadsheets, connectivity matrices, as well as all coding and supporting tools (e.g. scripts, gnuplot, Neo4j, NetworkX) we use.

2 Methodology: Data In, Knowledge Out

Our workflow to gather data and generate outputs (knowledge) is as follows. The first step is to access every Brazilian IXP via telnet to its publicly accessible LG (`lg.<code>.ptt.br`) that mirrors the route server. Once connected by telnet at each IXP LG, the second step is to query BGP to collect the following data: (*i*) BGP tables (both IPv4 and IPv6), (*ii*) list of BGP AS-PATH, and (*iii*) community codes. The raw dataset with the output of these BGP queries is first stored locally as simple text files (step 3), and then parsed/pre-processed (step 4). Finally, the datasets go through a set of analytic functions (steps 5 and 6) implemented with two different graph-oriented tools. The manual and time-consuming task described in steps 1, 2 and 3 were automated through the developed framework consisting of a set of scripts to automatically access every Brazilian IXP by telnet and save the outputs from the different BGP queries in the corresponding text files.

Our analytic framework uses two different tools for the job of generating and dissecting the AS-level graphs based on the input BGP data: (1) NetworkX[5] software for complex networks, and (2) Neo4j[6] graph-oriented database. As inputs to both tools we used the adjacency matrices generated from the files extracted from each IXP LG. We generated an AS-level connectivity graph for each IXP and a nation-wide graph based on interconnecting all IXPs through their common AS members. In all graphs, nodes (vertices) are ASes as observed in the BGP AS-PATH attribute and edges represent the BGP connectivity.

3 Analyses and Discussion of the Results

Due to space limitations, we focus our analysis mainly on the nation-wide graph (column called “Brazil”) and four representative IXPs: (*i*) small IXP (PTT-DF) located in the capital Brasilia, (*ii*) medium (PTT-MG), (*iii*) medium-to-large (PTT-RJ), and (*iv*) large (PTT-RS). However, raw data and results for every IXP are available in the public repository.

One noteworthy observation is the validity of the results of two IXPs, namely PTT-SP and PTT-PR. BGP data collected from both IXP LGs revealed that filters are being applied to the exported routing tables, a fact confirmed by IX.br representatives due to performance and scalability issues of the LG servers in operation. For this reason, most of the analyses do not include these IXPs.

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[4] **https://github.com/intrig-unicamp/ixp-ptt-br**

[5] https://networkx.github.io/ [6] http://neo4j.com/

Table 2. Profile of ASes at Brazilian IXPs as of March 25, 2015. The Brazil column includes absolute numbers whereas individual IXPs reflect only percentiles.

Classification	**Brazil (*)**	**DF**	**MG**	**RJ**	**RS**	**SP**
1. Internet Provider	743 (65.1% ± 20%)	37.5%	55.9%	51.9%	68.0%	73.1%
1.1 Transit Provider	98 (8.6% ± 09%)	20.8%	14.7%	19.2%	5.0%	5.6%
1.2 Access Provider	645 (56.5% ± 21%)	16.7%	41.2%	32.7%	63.0%	67.5%
2. Services Provider	115 (10.1% ± 07%)	8.3%	8.8%	17.3%	5.0%	12.5%
2.1 Content Provider	37 (3.2% ± 06%)	0.0%	2.9%	5.8%	3.0%	4.7%
2.2 Hosting Provider	78 (6.8% ± 05%)	8.3%	5.9%	11.5%	2.0%	7.8%
3. Public Organization	140 (12.3% ± 21%)	37.5%	20.6%	15.4%	11.0%	4.4%
3.1 Public University	20 (1.8% ± 19%)	0.0%	0.0%	0.0%	2.0%	1.1%
3.2 Government	100 (8.8% ± 13%)	33.3%	17.6%	13.5%	8.0%	2.2%
3.3 Other	20 (1.8% ± 03%)	4.2%	2.9%	1.9%	1.0%	1.1%
4. Private Organization	144 (12.6% ± 09%)	16.7%	14.7%	15.4%	16.0%	10.0%
4.1 Private University	8 (0.7% ± 03%)	0.0%	2.9%	0.0%	4.0%	0.0%
4.2 Private Company	119 (10.4% ± 09%)	16.7%	8.8%	15.4%	10.0%	8.9%
4.3 Other	17 (1.5% ± 09%)	0.0%	2.9%	0.0%	2.0%	1.1%

(*) Average of ALL 25 Brazilian IXPs.

3.1 Members Classification: Who is who?

A first effort to organize our dissection was manually classifying all 1,142 ASes at IX.br. Actually there are 715 unique members registered at IX.br, but there are 1,142 ASes considering the overlap of members peered at multiple IXPs[7]. Our "ground truth" attempt to classify the type of ASes present at IXPs is relevant for an accurate view on the current profile of the members interested in peering in every region of Brazil. The classification task was executed following a manual approach by members of our research group and included individual cross-validation actions. In addition to *whois* services of both NIC.br (Brazil) and LACNIC (Latin America), content from the AS Web sites was used to sort each AS into the categories presented in Table 2. Again, the complete dataset with the individual classification of all ASes can be found in our public repository.

The tables ahead include a column called "Brazil" with the average and confidence intervals of the results considering all IX.br IXPs. The high values of the Brazil-wide standard deviation confirm the heterogeneity of IXPs, as their sizes end up being a relevant factor for many of the observed metrics.

Access Providers dominate. Looking at the AS type profiling in Table 2, despite some variations in the percentile values, we observe that the majority of IXPs members are access providers of local coverage. This is an expected result given the economic incentives of access providers to exchange the maximum amount of traffic as possible through multilateral agreements at IXPs, thereby reducing the transit costs of upstream links. The increasing presence of smaller access providers at IXPs has a positive impact on the prices ISPs apply to their downstream customers, contributing to a scenario of local competition between

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[7] Although IX.br is a national project, we highlight that a member peered at one IXP of IX.br is not connected to the members of other IXPs.

multiple access providers. Like in most developing countries, the average quality of Internet connectivity in Brazil is still low compared to developed nations. The public IXP initiative is contributing to revert this situation by keeping traffic regionalized and reducing the distance between endpoints, and may be more importantly providing an incentive-rich environment for innovation and healthy IP connectivity market practices. These seem to be the factor behind ISPs, mostly access providers, extending their reach to include locations with poor connectivity options. Without the cost-attractive infrastructure of the IXPs, access providers would need to rely on transit providers, resulting in higher costs and fewer competition in the access provider arena –arguably the most interested type of AS in open peering.

In the capital things are different. The only exception to the dominance of access providers happens at PTT-DF IXP where the presence of government and public organizations is high, a regional particularity at the federal capital of Brazil. Among the PTT-DF members we can highlight the Federal Senate, Federal Police, Serpro, Dataprev, Telebras, and others.

Few but heavy Content Providers. A relative low participation of content providers was observed at IXPs of different Brazilian regions, such as newspapers, magazines, radio and television stations, etc. The majority of content providers are companies that operate Content Delivery Networks (CDN) responsible for a large fraction of the traffic. This result highlights the fact that few Brazilian content providers are exploring the benefits of IXP peering due to cost savings and reduced hop distance to eyeball ISPs. We recognize as a plausible reason the common practice of content providers relying on CDN providers to deliver their content closer to the users of a wider geographical span (including internationally), as opposed to IXPs that bring more localized benefits.

Low presence of private companies. This fact can be explained by the main motivation of private companies to increase their redundancy through multihomed connections with larger ASes (telcos). These telcos can reach the whole Internet in contrast to IXPs with more restricted reachability towards their local region. While the amount of private companies at IXPs is low, the observed peering density (amount of open peering with all types of ASes) is relatively high, according to the results to be presented in Sec. 3.2.

Majority incentives lead to the predominance of open peering. Based on the IX.br records, currently, 97.72% of ASes opt for open peering through multilateral agreement –a high fraction in harmony with the spirit and efforts on public, open policies conducted by NIC.br. Only 2.28%, mainly transit providers, choose private peering based on bilateral agreements, once large telcos sell transit to local access providers and hence lack economic incentives to openly exchange traffic except with ASes of similar size and nature. Small, regional ISPs are mostly customers that already buy transit somewhere else, recalling that one requirement of IX.br free usage of their IXPs is that ASes are not allowed to rely on the IXP connectivity as the only Internet access. Despite 97.72% of members opted for multilateral peering in IX.br official records, this high percentage reflects just a contractual term. In practice this does not mean that an AS will effectively exchange traffic with all other members of an IXP, which explains the low peering density we found in our analyses. Considering the experiences from more mature IXPs in Europe, we may conjecture that the current high fraction of open peering is due to IX.br ASes still being in a "learning" phase seeking peering relationships with a very open approach.

Low AS presence at multiple IXPs. The broad majority (83.68%) of ASes (759 of 907) are peered to only one IXP. This result can be expected because ASes choose to peer at IXPs mostly to benefit only from local traffic, so they are commonly multi-homed through at least one transit or access ISP to reach the entire Internet. The set of ASes peering at more than one IXP is mostly composed of access providers that sell services in more than one region. Again, the access providers motivation in exploiting open peering as much as possible is clear: cost savings by avoiding transit links sold by big telecommunication operators. Large ASes can be identified by their simultaneously peering practices in over half of all IXPs (14 to 23) and are predominantly two big telecom operators that we consider transit providers in the national landscape, namely NET and GVT, in addition to public organizations managing the DNS root servers (ICANN), a national Internet performance measurement service (NIC.br), and RNP.

3.2 Peering Density: How much peering?

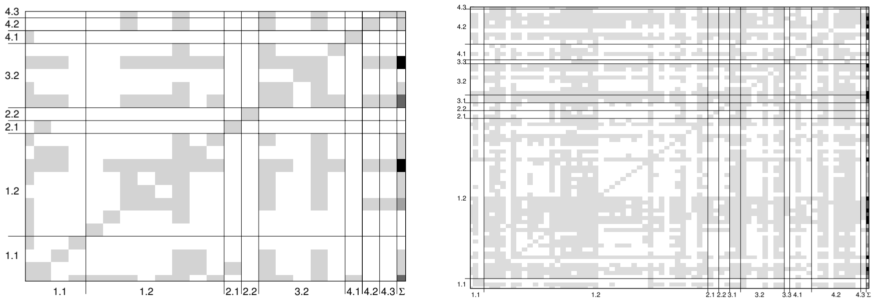
We consider density of peering as the ratio between the quantity of active BGP connections (peering links) of the n ASes at an IXP and the sum of all possible peers ($n*(n-1)/2$). The observed peering density (Tab. 3) shows wide dispersion in different regions and peering density below 50% points to the potential to expand direct traffic exchange between current IXP members.

Table 3. Peering density at IX.br (Brazil) and European more mature IXPs.

Description	**Brazil (*)**	**DF**	**MG**	**RJ**	**RS**	**DE-CIX**	**MSK-IX**
Peering Links	126	57	79	271	1,952	-	-
Density (%)	44.2% ± 23%	20.7%	34.2%	21.3%	63.4%	79%	95%

(*) Average of 23 Brazilian IXPs without filters, that is, excluding PTT-PR and PTT-SP.

We find lower values of peering density in IX.br compared to those presented in previous works regarding other more mature ecosystem of IXPs, such as AMS-IX, DE-CIX, LINX and MSK-IX. While the average percentage of peering density in IX.br is around 40%, more mature IXPs exhibit an average peering density between 79%-95% [6]. This study confirms our observation that there is a relevant empty space for peering between ASes exchanging traffic at IX.br. One possible explanation to the lower peering density is that IX.br is still young compared to more mature IXPs such as the above-mentioned European IXPs. While IX.br started its first IXP (PTT-SP) in 2004, the peering initiative in Europe started in the early 90s –the oldest IXP of IX.br has only half the lifetime of the largest European IXPs. Another fact could be the relatively limited



(a) PTT-MG (b) PTT-RS

Fig. 1. Peering Matrices indicating the level of connectivity between ASes sorted by category: (a) PTT-MG is a medium size IXP and (b) PTT-RS is a large size IXP.

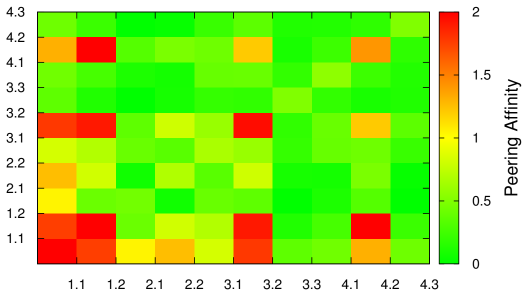


Fig. 2. Peering Affinity (PA): matrix of all Brazilian IXPs, where the amount of peering follows a color scale and both axes are grouped in a symmetrical fashion by AS type.

market that national ASes get through IX.br given that the traffic patterns in Brazil show strong international components.

Who peers with whom? Tell me your AS type... To analyze the inter-AS connectivity, we generated a peering matrix for every IXP in the spirit of an adjacency matrix, where x and y axis contain all IXP members (ASes) in a symmetrical fashion. We also considered a unified matrix with all the IXPs to provide a wider view on the nature of peering in the national landscape, i.e., integrating all individual IXPs.

Figure 1 depicts the individual peering matrices of two IXPs. A gray pixel (bit 1) indicates the existence of peering between two ASes while a white pixel (bit 0) indicates the absence of peering. The last column illustrates a scale of the amount of connections between an individual AS with other ASes of each respective category previously presented in Table 2, where darker shades mean more connections. The horizontal and vertical lines traversing the graphics are the boundaries between AS categories. We can visually identify through the long vertical and horizontal lines that some ASes (mostly from access ISP 1.2 cat.) tend to peer more with all types of ASes.

In order to quantify (and not just visualize) the amount of peering between different types of ASes, we propose **Peering Affinity (PA)** as a cross-AS-type peering metric defined as follows. Let P and Q be sets of ASes such that each set represents a single profile, including the case in which both sets are the same. Let $c(AS_i, AS_j)$, such that $AS_i \in P$ and $AS_j \in Q$, be the *connection function*:

$$c(AS_i, AS_j) = \begin{cases} 1 & \text{if } AS_i \text{ and } AS_j \text{ are peers} \\ 0 & \text{otherwise} \end{cases}$$

Then, the *peering affinity* function in respect to P and Q, $\mathbb{PA}(P, Q)$, is:

$$\mathbb{PA}(P, Q) = \frac{\sum_{AS_i \in P} \sum_{AS_j \in Q} c(AS_i, AS_j)}{|P| + |Q|}$$

We opt to divide by the sum of vertices resulting in a scale from 0 to 2 instead of dividing by their product because it returns a more convenient scale to highlight the differences in peering degree. Taking as example the peering affinity between members of categories 1.2 (Access Providers) and 2.1 (Content Providers), the amount of connections between all peered ASes of categories 1.2 and 2.1 totals 98, divided by the number of vertices of both categories (236), returns 0.42 as the cross-AS-type peering affinity metric.

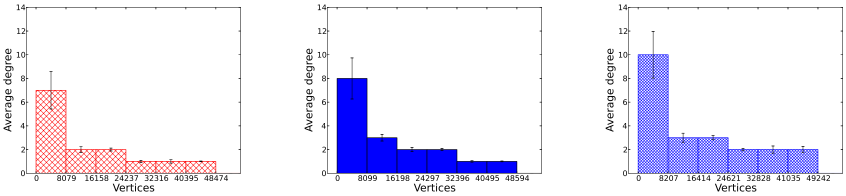
Figure 2 presents the result of the nation-wide analysis regarding peering affinity with the color scale being a function of the ratio between the sum of connections (peering between ASes) and the number of vertices of both crossed categories. We can observe a relatively high density of peering between ISPs, either transit or access providers. We also observe high density between public organizations, more specifically from the government. The availability of PTT-DF in the federal capital is certainly an enabler to the increased connectivity between many government agencies.

To the best of our knowledge, our peering density analysis is the first one that considers a set of peering matrices where ASes are grouped together by their type. When crossing the peering matrices in Figure 1 with the numbers of Table 3, we find coherent results that reinforce our methodology.

3.3 Vertice Degree: How many peers?

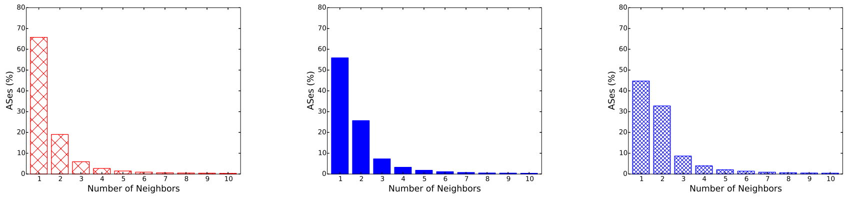
We now turn our attention to the vertices' degree (both distribution and average values) in each IXP graph. By doing so, we aim at revealing and understanding the behavior of the ASes in terms of the amount of neighboring peers.

Figures 3 and 4 show the vertices' degree of the following IXPs graphs: PTT-DF (small size), PTT-MG (medium size), and PTT-RS (large size). Figure 4 plots the degree distribution for all ASes. Since the amount of vertices is large and diverse on an individual AS granularity, Figure 3 sorts ASN in the x axis in a growing fashion and presents the average degree for a group of ASes in bins of



(a) PTT-DF (b) PTT-MG (c) PTT-RS

Fig. 3. Average Degree



(a) PTT-DF (b) PTT-MG (c) PTT-RS

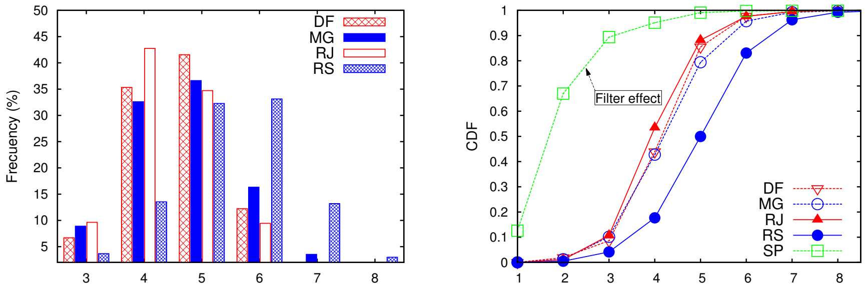
Fig. 4. Degree Distribution

8,000 ASN along the 95% confidence interval. In sought of connectivity patterns, we discovered that nodes with higher degrees tend to correspond to older ASes based on the incremental assignment of AS numbers (ASN). This approach suggests that ASes registered for longer time (smaller ASN) exhibit higher connectivity, a coherent result considering that vertices with higher degrees commonly correspond to telecommunications operators with more adjacencies because of the nature of their transit business and their longer time in operation.

3.4 Depth / Diameter: How far are you?

As advertised prefixes traverse BGP domains, ASNs are added to the list of ASes (AS-PATH) to avoid routing loops. By counting the ASN that exist on every AS-PATH announce we can quantify the amount of AS-level hops to reach an advertised prefix from every IXP.

Figure 5(a) shows the observed depth from routes advertised by IXPs members based on the AS-PATH attribute. Depth values equal to 1 mean the AS-PATH is composed of only one AS, i.e., ASes directly connected to IXPs and advertising their own prefixes. The remaining routes –with depth higher than 1– correspond to those learned by IXP members from other ASes, which means these routes are not directly advertised by adjacent IXP members. The fraction of routes of depth equal to 1 and 2 is very low compared to the remaining route advertisements and are therefore omitted in Figure 5(a) for the sake of visual clarity. To provide an accurate view on the AS-level distances (i.e., real path



(a) Isolated Depth (b) Accumulated Depth

Fig. 5. Depth of AS-PATH

depth), redundant information was removed, for instance, duplicated ASNs due to AS-Prepend practices (further discussed in Sec. 3.5) were filtered.

By observing all IXPs together, we found that average depth of all routes advertised at IXPs varies between 4 and 6, with the higher concentration of routes being of depth equal to 5. We can conclude that 8 is the highest meaningful depth, that is, the most distant sources of AS announcements reaching IXPs are 8 AS hops far away, recalling that each hop means an entire AS –not a single router as `traceroute` would reveal. Prior studies regarding the Internet topology found an almost constant path length of 4 hops [4], while in our analysis we found an average diameter of 4-6 (majority equals to 5). Regarding this difference we recall that many routes have to leave the country toward international content, as already observed to happens in Africa [8].

As mentioned earlier, the results of PTT-SP and PTT-PR shall be carefully considered due to filtering practices. We include PTT-SP in Figure 5(b) precisely to illustrate the effect of route filtering and how the resulting *out of the curve* observations may compromise this kind of Internet measurement research.

3.5 Traffic Engineering with AS-Prepend

The default behavior of BGP is preferring shorter routes, i.e., prefixes advertised with less ASNs in the AS-PATH attribute. A common “traffic engineering” practice referred to as AS-Prepend consists of ASes adding their own ASN multiple times to turn the resulting AS-PATH attribute less attractive (larger depth) regarding the reachability to a given prefix [2]. AS-Prepend is regarded as a BGP “knob” for inbound traffic engineering, often criticized and even considered harmful because it may compromise the integrity of routing information[8].

The results of Table 4 show that AS-Prepend also is commonly used at IXPs as it is used in Internet. Note that while the second set of rows in the table refers to all ASes (be them IXP members or not) observed from IXPs’ graphs, the last set of rows reflects only prepend practices from IXP members. We observe a

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[8] https://www.ripe.net/ripe/meetings/regional-meetings/manama-2006/BGPBCP.pdf

Table 4. Statistics on AS-prepend viewed through IXPs.

Metric Description	**Brazil (*)**	**DF**	**MG**	**RJ**	**RS**
Routes	832,989	559,159	434,264	1,150,905	1,947,453
Routes with AS-Prepend	295,909	127,184	245,129	294,663	1,710,070
AS-Prepend X Routes (%)	30.8% ± 22%	22.7%	56.4%	25.6%	87.8%
ASes at Graph	43,333	47,176	46,939	47,632	48,351
ASes with AS-Prepend	7,305	6,206	8,629	8,890	10,803
AS-Prepend X ASes (%)	16.1% ± 04%	13.2%	18.4%	18.7%	22.3%
Members Advertising	18	24	22	51	79
Members Advertising with AS-Prepend	6	7	6	19	36
AS-Prepend X Members (%)	22.5% ± 19%	29.2%	27.3%	37.3%	45.6%

(*) Average of 23 Brazilian IXPs without filters, that is, excluding PTT-PR and PTT-SP.

larger amount of AS-Prepend practices per AS at IXPs, a fact pointing to the traffic engineering needs of IXP peering links.

When looking at the numbers in Table 4 it is worth to recall the difference between two distinct concepts present in BGP tables: (*i*) number of routes, and (*ii*) number of prefixes. While the full BGP table currently features around 512,000 prefixes, it is usual to find at IXPs BGP tables with millions of entries due to the advertisement of multiple routes towards the same prefix.

4 Related Work

Many efforts have been devoted towards a better understanding of the complex Internet ecosystem and IXPs have become attractive research targets because they represent a relevant microcosm of Internet diversity [1, 9, 10, 12, 5, 11, 14].

Closest to our work is a recent study characterizing the nature of Internet connectivity in Africa [7], specifically focused on JINX (Johannesburg) and KIXP (Nairobi), two major IXPs in Africa. The authors measured the presence of local ISPs in various African IXPs and which of them chose to interconnect at these exchanges. An interesting result was finding that 66.8% of the paths between residential users and Google leave the continent, mainly because local ISPs are not present at these IXPs or because they are not peered between each other. The individual peering matrices for JINX and KIXP inspired our peering density analysis (Sec. 3.2), which lead to our proposed peering affinity metric based on a peering matrix grouped by AS types applied to individual IXPs and to the national-wide public IXP ecosystem.

5 Conclusion and Future Work

This paper presents the first effort to comprehend the peering ecosystem of the largest set of public IXPs in a single country, which happens to be in Brazil. We developed a analytics framework that allows scalable in-depth analyses of all Brazilian IXPs BGP data. Our studies move beyond traditional sets of individual peering matrices to include a single national-wide AS graph. Sorting ASes by their category, we propose a novel metric called *peering affinity* to quantify the amount of peering between different types of ASes.

Equally important to the analysis effort presented in this paper is to recognize some limitations of research work when building AS-level topologies [9]. It is important to highlight that information collected from public servers do not represent the totality of traffic exchange, but only a fraction of everything that can be publicly observed, specifically the multilateral peering at IXPs.

Our ongoing extensions of this work include a temporal analysis based on datasets over a longer period (different snapshots) that will allow a deeper understanding of the dynamic aspects and evolution of the IX.br ecosystem.

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