A first look at the Latin American IXPs

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ABSTRACT

We investigated Internet eXchange Points (IXPs) deployed across Latin America. We discovered that many Latin American states have been actively involved in the development of their IXPs. We further found a correlation between the success of a national IXP and the absence of local monopolistic ASes that concentrate the country's IPv4 address space. In particular, three IXPs have been able to gain local traction: IX.br-SP, CABASE-BUE and PIT Chile-SCL. We further compared these larger IXPs with others outside Latin America. We found that, in developing regions, IXPs have had a similar growth in the last years and are mainly populated by regional ASes. The latter point clearly contrasts with more internationally re-known European IXPs whose members span multiple regions.

CCS CONCEPTS

• **Networks → Public Internet**;

KEYWORDS

Internet eXchange Points, Latin America

1 INTRODUCTION

Latin America covers 20 million km^2 [5] and comprises 20 countries: right after North America, it has the largest urban population rate [6]. Moreover, Latin America (LatAm) is home of 652 million people [52] and has three out of the four largest metropolitan areas in the Americas (Sao Paulo, Mexico City and Buenos Aires with populations of 21.3M, 21.2M and 15.3M habitants respectively) [51]. LatAm also has appealing numbers regarding to Internet: by July 2019, 8661 out of 10171 ASNs delegated to LACNIC currently appear on BGP routing tables. Furthermore, out of 65438 active ASes, 6458 have been delegated by NIC.br (Brazilian NIR) to Brazilian-based organizations. However, few Internet studies have focused on Latin America, let alone their IXPs.

Latin America was on board for the massive irruption of Internet Exchange Points (IXPs) that began in the early 2000s and that contributed to flatten the Internet [17]: it hosts 119 out of 967 IXPs deployed worldwide [29]. Many reasons suggest why IXPs have also widespread in Latin America. First, national IXPs in LatAm are essential to avoid forwarding packets between local end-hosts through thousands-kilometer-long detouring paths [25]. Indeed, the ability to peer locally at IXPs not only shortens paths, but also reduces latency [25]. Second, Latin America has densely populated megalopolis that host a large base of customers of online services and applications. This attracts CDNs that, as an effective way to get to *eyeballs*, use IXPs to peer directly and simultaneously with several ASes [16]. In turn, IXPs are also interested in hosting CDNs, to provide cost-effective access to content to their members [22].

Compared to regions such as North America and Europe, *Latin America is short of resources for Internet measurements.* For instance, Routeviews [53] (RVs) and RIPE RIS [47] only have two and one BGP data collectors in LatAm, respectively. The lack of collectors only allows to draw a fairly incomplete representation of the AS ecosystem in Latin America [35]. On the other hand, little active-measurement-derived analysis can be performed in LatAm (e.g. to unveil paths from/to content providers) due to a limited availability of active vantage points (as of July 2019, RIPE Atlas (311/10,209), Ark CAIDA (12/190)).

In this paper, we take a closer look at the Latin American IXPs. We are interested in the public policies that lead to their creation, their growth and development over time, and the role they play in their own national AS ecosystem. In particular, in Sec. 2, we introduce the dataset we built to carry out our analysis:

◇ We identify multiple BGP collectors of Packet Clearing House (PCH) that provide valuable data of the Latin American AS ecosystem. Moreover, we manually extended the BGP view in Brazil leveraging several Looking Glasses (LGs) that are available and distributed in the network of the Brazilian IXP.
◇ We use AS relationship, RIR delegation, and prefix mapping files to derive metrics that help quantify the growth of IXPs and to better understand the role of transit providers at IXPs.

Our contributions are:

- We provide insights in Sec. 3 about how countries' public policies have encouraged the development of IXPs in Latin America.
- We propose several metrics in Sec. 4 and 5 that allow to account how IXPs have been increasingly gaining importance since their creation and how this phenomena correlates with the presence of a balanced AS ecosystem, i.e., the absence of monopolistic transit/access ASes.
- We compare IXPs deployed across multiple continents and find that IXPs in developing regions share similar properties.
- We release the code that allows both to fetch the publicly available data we used and to replicate our results[1]. In addition, we make publicly available the LGs' dumps we manually collected[2].

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[1]Project repository: https://github.com/CoNexDat/latam-ixp-obs
[2]LG dumps: https://cnet.fi.uba.ar/latam-ixp-obs/lg-ribs/

2 DATASET

Our dataset relies primarily on BGP table dumps (BGP-TDs) obtained from collectors deployed across multiple LatAm countries. We also manually gathered BGP-TDs in LGs available in Brazil. In addition, we used RIR delegation, CAIDA's AS relationship and *pfix2as* files, PeeringDB and other digitalized documents. Next, we detail these sources.

BGP-TDs: we use BGP-TDs from the collector of RVs in Sao Paulo, Brazil (BR)[3]. The first snapshots dumped in this collector date from 2011. We also rely on PCH's "IPv4 Daily Snapshot" archive to obtain a long-standing collection of feeds, even dating from 2010 in some cases, from Argentina (AR), Belize (BZ), Chile (CL), Costa Rica (CR), Ecuador (EC), Haiti (HT), Honduras (HN), Mexico (MX), Paraguay (PY) and Trinidad and Tobago (TT)[4]. Indeed, with 15 monitors co-located at IXPs in multiple countries of LatAm, PCH is, by July 2019, the route collecting project with the largest footprint in the region.

In addition, to put our results in context, we also downloaded BGP-TDs from PCH collectors in other regions: France-IX (Paris), DE-CIX (Frankfurt, Germany), JINX (Johannesburg, South Africa) and BKNIX (Bangkok, Thailand). We chose these IXPs because either themselves, or the countries where they are deployed, share properties with those deployed in LatAm: largest populations in their region (e.g. France, Germany and Brazil), similar age (e.g. BKNIX and the Chilean IXP are recently created IXPs, while DE-CIX and the Argentinian IXP have been both operating for more than two decades) and comparable current values of GDP per capita (e.g. South-east Asia, South Africa and Latin America) [7].

All BGP-TDs of RVs and PCH were collected the first day of each month. We observed that some ASes share full tables, and we believe that this not what actually gets advertised in the IXPs, i.e., following Gao-Rexford principles [36], no AS would offer cost-free transit via its upstream providers. Consequently, when analyzing each IXP, we relied only on entries provided by their route server: in these cases, the revealed routes are usually from ASes advertising their customers, at least partially. Finally, all BGP-TDs were sanitized removing AS-path prepending and dropping entries with AS sets (less than 1%). While BGP-TDs may not able be to capture the entire AS topology, overcoming this incompletenesses requires traceroute-derived data [27], a limited resource in LatAm (see the introduction).

Finally, we enlarged the BGP data collected in Brazil using the LGs publicly accessible via telnet in IX.br [9], the network interconnecting the Brazilian IXPs. Unfortunately, IX.br does not keep historical LGs' BGP-TDs. By running "`show ip bgp paths`", we gathered BGP-TDs in the 31 regional IXPs of IX.br in July 2019. Despite only partial-BGP-TDs can be obtained in Sao Paulo and Curitiba [9], this does not affect our analysis, as explained in Sec. 4.2.

RIR delegation files[5]: we queried LACNIC delegation files to determine the set of ASes delegated to each country. However, it must be noted that nationality in RIR delegation files does not actually indicate that an AS only or mainly operates in the country to which the ASN was delegated to, but it does show that the organization that holds the ASN has economical activities in that country. Further, our goal is not to precisely determine ASes location, but rather from where the companies that join the IXPs come from.

CAIDA's AS relationship and prefix2AS files[6]: while the former were used to pinpoint *active* ASes each month, i.e., with at least one inferred AS relationship, the latter were used to compute the address space originated by each AS.

PeeringDB [42]: we used PeeringDB to retrieve IXP's Route Server ASNs and to validate inferences.

Digitalized Documents: we gathered digitalized documents concerning Internet's public policies applied by LatAm's governments, e.g. legal documents, newspapers, websites, presentations.

3 PUBLIC POLICIES AND IXPS

We investigated the public policies behind the creation of IXPs in Latin America. For this, we relied on the set of digitalized documents we gathered. Table 1 shows the organizations that currently run these IXPs and that fostered their creation. All in all, **out of 16 national IXPs currently operating in LatAm, governments were involved in the creation of more than 55% of them.**

The president of Costa Rica signed an Executive Order [45, 48] while parliament in Bolivia passed a law [25]. Also, federal agencies such as Senatics in Paraguay [28], PUC in Belize [50] and SENACYT in Panama [30] fostered IXP's creation. Regulators were involved in Mexico (IFT) [39], Honduras (CONATEL-HN) [15] and Paraguay (CONATEL-PY) [31]. In Brazil, the Internet Steering Committee (CGI), a multi-stakeholder board with several state representatives, was responsible for creating IX.br, the Brazilian IXP [3]. On the other hand, Table 1 also indicates that, similar to the European IXP model [10], in Latin America a large number of non-profit organizations created and run IXPs. In particular, CABASE (AR) and CCIT (CO) are operated by organizations related to local ISPs associations as it happens in IXPs outside the region, e.g. DE-CIX (DE) [13] and JINX (ZA) [33]. Further, Belize, Honduras and Paraguay have delegated IXP operations to universities. Finally, presence of state regulations also influenced the development of peering facilities in Chile. Undersecretary of telecommunications singed Resolution 1483 [49] in 1999 which forced traffic between Chilean ISPs to be carried by their local infrastructure. To fulfill this requirement, ISPs rapidly joined NAP Chile, a Chilean IXP. More recently, in 2016, PIT Chile was established on top of the dense interconnected infrastructure of NAP Chile, though bringing significant changes to the Chilean peering ecosystem: whereas NAP Chile was strictly limited to domestic ASes, PIT Chile was envisioned as a neutral IXP also allowing the presence of non-national ASes.

4 EVOLUTION OF IXPS

Many of the IXPs in Latin America have already been running for years. Consequently, we aim to understand whether these IXPs have been able to consolidate in their region, as so have others in different geographical areas. We look at IXPs': i) network topology ii) members, i.e., connected networks; iii) ASes connected via members (visible ASes), and; iv) transit providers role. Most countries that host a BGP monitor (see Table 1) have small IXPs (e.g. with less than 30 connected networks that announce less than 2M unique

[3]http://routeviews.org/route-views.saopaulo

[4]PCH has presence in a Bolivian IXP with no members [38], that is thus not considered.

[5]ftp://ftp.lacnic.net/pub/stats/lacnic/

[6]data.caida.org/datasets

	Country	AR	BO	BR	BZ	CL	CO	CR	CU	EC	HT	HN	MX	PA	PY	PE	TT
	Sponsored by	CABASE	Law	CGI	PUC	PIT CL	CCIT	Ex.Ord.	State	IXP.EC	AHTIC	CONATEL	IFT	SENACYT	SENATICS	NAP.PE	TTIX
	Operated by	CABASE	State	NIC.br	UoBZ	PIT CL	CCIT	NIC.cr	NAP.CU	IXP.EC	AHTIC	UNAH	CITI	InteRED	NIC.py	NAP.PE	TTIX
BGP TDs	Monitor	PCH		RVs/LGs	PCH	PCH		PCH		PCH	PCH	PCH	PCH		PCH		PCH
	#Memb	127	×	1156	6	72	×	28	×	5	4	4	6	×	15	×	5
	#AggIPs	7.9M		26M	67K	19.4M		401K		28K	102K	131K	795K		1.5M		196K

Table 1: IXPs in Latin America. Colors blue, yellow and magenta represent state agencies, non-profit organizations and universities, respectively. #AggIPs is computed on the address space announced by IXP members (excluding their customer cone and repeated prefixes due to MOASes). LatAm countries without IXPs and European overseas territories are excluded.

IPs). Since this limits the conclusions that can be drawn in them, our analysis mainly focuses on the bigger IXPs of AR, BR and CL.

4.1 IXP Networks Topology

We used PeeringDB, digitalized documents and previous knowledge, to look for organizations that run multiple IXPs in LatAm. We found that, as of July 2019, IX.br, CABASE and PIT Chile run 31, 28 and 6 regional IXPs respectively in Brazil, Argentina and Chile. Next, we would like to study how these organizations coordinate and interconnect their IXPs. In CABASE, regional IXPs such as CABASE-BUE (AS11058) or CABASE-COR (AS52374), are independent and have their own ASNs. In addition, they are all connected to a central node, CABASE-RCN (AS52376), that just interconnects the IXPs (it is not a regional IXP that has members). Through CABASE-RCN, a *Mandatory Multilateral Peering Policy* (MMPP) is enforced: prefixes advertised in one regional IXP are further advertised by the central node in all regional IXPs, as can be seen in Fig. 1 for CABASE-BUE and CABASE-COR. We further verified this contrasting PCH's BGP-TDs collected in multiple of regional IXPs of CABASE. On the other hand, PIT Chile is structured as CABASE: regional IXPs are also connected to a central node, PIT Chile-SCL (AS61522), but that is actually a regional IXP itself. While Chilean regional IXPs are visible as members of PIT Chile-SCL, since PIT Chile only hosts a collector in the latter regional IXP and does not impose any peering policy, we cannot ensure if the reciprocate is also valid. Finally, IX.br runs a single ASN (AS26162) and does not have a centralized topology.

4.2 IXP Members

To identify IXP members or *connected networks* of every regional IXP we used BGP-TDs dumped in July 2019. In particular, for CABASE-BUE and PIT Chile-SCL we got them from PCH, and for IX.br from its LGs. Note that the need of data from an unique collector in CABASE and PIT Chile, but from many for IX.br, results from the fact the first two have a central node in their network (see Sec. 4.1). While in CABASE we used tables from CABASE-BUE, which is not the central node but sees all announcements due to the MMPP imposed, for PIT Chile we got them from PIT Chile-SCL, their central node. On the other hand, since IX.br does not have a central node, we used a LG per regional IXP. Finally, IXP members were inferred as the first AS found in each AS path after the IXP's ASNs (e.g., Route Server, regional IXPs). We further verified that, despite the LGs' BGP-TDs in Sao Paulo (SP) and Curitiba (PR) are partial (see Sec. 2), the number of members seem not to be compromised: while RV sees 1156 peers in IX.br-SP, the LG in the same regional IXP reports 1164.

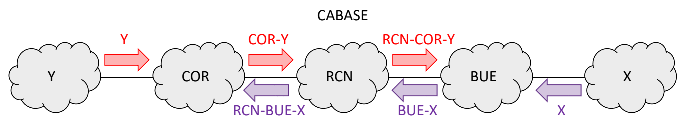


Figure 1: Topology of CABASE (for 2 regional IXPs) and its Mandatory Multilateral Peering Policy. Arrows indicate BGP announcements and their respective AS path. RCN is a central node that interconnects regional IXPs (e.g. BUE, COR) and forwards all announcements to all regional IXPs.

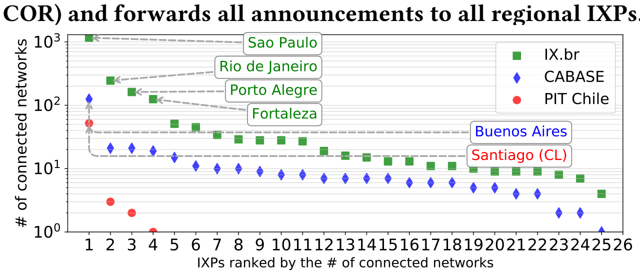


Figure 2: Number of connected networks to regional IXPs in IX.br, CABASE and PIT Chile in July 2019.

Fig. 2 displays the number of connected networks per regional IXP in IX.br, CABASE and PIT Chile (in the ones missing of IX.br and PIT Chile, BGP-TDs showed no members). In the three IXPs, the largest regional IXP is around an order of magnitude bigger than the second one: -Sao Paulo: 1156, Rio de Janeiro: 245- in BR, -Buenos Aires: 127, Cordoba: 21- in AR and -Santiago de Chile: 72, Arica: 3- in CL. The population of the metropolitan areas where the regional IXPs are deployed seems to have an impact on this result, with 21.3, 6.3, 15.3, 1.8 and 5.6 million inhabitants respectively in Sao Paulo, Rio de Janeiro, Buenos Aires, Cordoba and Santiago de Chile. Considering that these Latin American IXPs mainly attract local ASes (see Sec. 4.3), the number of delegated-and-active ASes in each country, with 6458, 791 and 241 respectively in BR, AR and CL, might also explain the difference in size between them.

4.3 Visible ASes

ASes connected via members, or *visible ASes*, correspond to the set of ASes seen in BGP-TDs, i.e. that appear in the AS paths of prefixes announced at the IXP. This metric is relevant since, despite some ASes might not be members of the IXP, they might still indirectly benefit from it. We are interested in the impact of IXPs in their domestic region, and also in how many foreign networks are attracted to Latin American IXPs. Moreover, we want to understand if IXPs in other regions show similar behaviors. To perform this analysis, we used PCH's BGP-TDs for all IXPs, except for IX.br where we

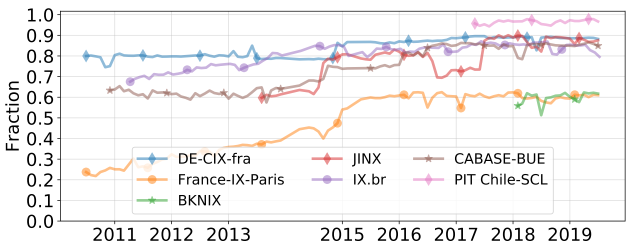


Figure 3: Fraction country's delegated-and-active ASNs visible at the IXPs.

used data from RVs. In addition, we used RIR delegation files to determine the set of ASNs delegated to each country.

4.3.1 Domestic impact. First, leveraging CAIDA's AS relationship files, we determined *all* delegated-and-active ASNs for each country, and thus for each IXP. For this, we simply filtered out delegated but inactive ASNs, i.e., ASNs with no inferred AS relationships. Then we looked for ASes that: i) are visible in each IXP and; ii) are local, i.e., own an ASN delegated to the country where the IXP is deployed. Fig. 3 displays the ratio of local visible ASes to *all* delegated-and-active ASNs for the biggest IXPs in Latin American: IX.br-SP, CABASE-BUE and PIT CL-SCL. Moreover, the figure also shows results for France-IX, DE-CIX, JINX and BKNIX.

Fig. 3 reveals that 80% of the Brazilian and Argentinian country delegated-and-active ASNs are visible at IX.br-SP and CABASE-BUE, respectively. This fraction is similar to the one observed in DE-CIX (Frankfurt) and by far larger than in France-IX (Paris), despite the large wealth gap (i.e. GDP per capita) between the European Union and Latin America [7]. Indeed, even though LatAm spans a larger geographical extension, IXPs of the region have still managed to deploy an infrastructure that allows them to host a large fraction of their local ASes. In addition, while DE-CIX has been stuck in this fraction value since 2011, CABASE-BUE and IX.br-SP have been steadily growing since the beginning of the decade when they just had around 60%. The Brazilian IXP network growth in the past decade was driven by the investments in telecommunications to host the 2014 FIFA World Cup as well as the 2016 Summer Olympics [18, 34]. On the other hand, CABASE's fraction of visible ASes, as well as number of regional IXPs, has increased since Google joined the IXP in late 2011.

In addition, Fig. 3 also shows that PIT Chile-SCL, that started operating in 2016, has a striking fraction of 90% even from the first snapshot we got from the PCH collector in 2017. This is the highest historical value in Latin America, and indeed high for an infant IXP: for example, BKNIX, which was launched in 2015, covers just 60% of the current delegated-and-active ASNs in Thailand. To grow rapidly, PIT Chile leveraged Chilean public policies (see Sec. 3).

Finally, note that JINX, the IXP in South Africa, has also been increasing the fraction of visible country delegated-and-active ASNs over time. The similarities with the IXPs in Brazil and Argentina in terms of the same 20% of increase and the fact that the three IXPs have reached a value comparable to a big IXP such as DE-CIX, allows to speculate on a matureness process that replicates across continents: regions where the Internet is rather underrepresented seem to, after many years, have been able to attract as many local ASes as some well-established IXPs in Europe.

4.3.2 Foreign networks attraction. Fig. 4 shows[7] the prevalence of AS nationalities at each IXP, i.e., out of all visible ASes in an IXP, how many come from each country. As can be seen, the three bigger Latin American IXPs mainly provide local support: the largest fraction of visible ASes, around 75% in all cases, are from the countries where the IXPs are deployed. However, these IXPs are also able to extend to other countries in the region, which usually add up most of the remaining fraction in Fig. 4. These results are similar to the ones seen in BKNIK and JINX. Indeed, all these IXPs are not so internationally widespread, i.e., the ASes they host come from less than 50 different countries in all cases. All this is in clear contrast with what happens in European IXPs that rather act as international hubs: not only the number of visible nationalities is greater than 100 for France-IX and over 200 for DE-CIX, but also most of their visible ASes are actually not local regarding to where the IXPs are deployed (France-IX not shown). Despite these differences, it is remarkable that the US is always within the five most prevalent AS nationalities[8] for all IXPs: this is likely due to the advertisement of prefixes of relevant US-based companies (e.g., Google, Facebook, Netflix, CloudFlare, Fastly). Indeed, the fact that CDNs find in IXPs a way to remain close to their customers and to offer them a better service is particularly also true in Latin America, Asia and Africa.

4.4 Transit Providers

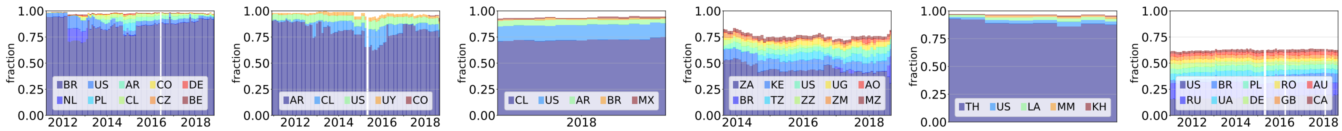
We are interested in how traffic is carried from/to Latin American IXPs by transit providers, i.e., intermediary ASes between IXPs and origin ASes seen in those IXPs. More precisely, since ASes in LatAm could be potentially scattered throughout vast geographic extensions, we would like to identify transit providers that have contributed to the consolidation of IXPs in their local country. Therefore, we look at the size of the set of visible ASes *per upstream AS*, i.e. the set of unique ASes that appear after each AS in AS paths. For this we used BGP-TDs dumped in July 2019 by PCH and RVs.

Table 2 displays for IX.br-SP, CABASE-BUE and PIT Chile-SCL the five upstream ASes that announced the largest visible AS sets. Results show a richer AS ecosystem in Brazil: Algar (AS16375) alone announces more downstream ASes in IX.br-SP than all the visible ASes seen in CABASE-BUE as well as in PIT Chile-SCL. On the other hand, looking at the nationality of the TOP5 upstream ASes in each IXP, we see mainly domestic transit providers. Yet, there are exceptions: Internexa (AS262589, Colombia (CO)) and Silica (AS7049, AR) in IX.br, Level3 (AS3549, US) in CABASE-BUE and Internexa (AS52880, CO) in PIT Chile-SCL.

In addition, Table 2 shows that Level3 is the largest upstream AS in CABASE-BUE (AS3549) and, though not displayed in Table 2, also ranked sixth in PIT Chile-SCL (AS21838, legacy number of an acquired network [40]). We further investigated Level3's role in both IXPs and determined that this US' ISP actually acts as a domestic transit provider in LatAm: 204 out of 209 and 37 out of 43 downstream ASes announced by Level3 in CABASE-BUE and PIT Chile-SCL were delegated by LACNIC to AR and CL, respectively.

Finally, Table 2 also unveils the presence of state-owned ISPs among the largest upstream ASes: Internexa (AS262589, AS262195)

[7]For this analysis, we filtered out the large number of prefixes announced by Hurricane Electric (AS6939), probably just on account of its open peering policy [26], in IX.br, JINX, DE-CIX and France-IX.
[8]By nationality we mean an AS that have been delegated to the US



(a) IX.br-SP (b) CABASE-BUE (c) PIT Chile-SCL (d) JINX (e) BKNIX (f) DE-CIX-fra

Figure 4: Prevalent AS nationalities at IXPs in Latin America, Africa, Asia and Europe.

IX.br-SP	ASN	16735	262589	7049	61832	28329
	#	903	381	218	209	207
CABASE-BUE	ASN	3549	52361	7049	19037	11664
	#	219	113	100	82	81
PIT Chile-SCL	ASN	7004	22661	52280	19228	14259
	#	88	87	70	57	57

Table 2: Largest sizes (#) of visible AS sets *per upstream AS* in IX.br-SP, CABASE-BUE and PIT Chile-SCL.

and ARSAT (AS52361). Internexa is a partially state-owned Colombian AS in which the Ministry of Finance and Public Credit holds 51% of the shares while Medellin county (Colombia) holds another 10% [1]. On the other hand, ARSAT (AS52361) is a fully state-owned Argentinian transit provider [37]. Note that, while ARSAT's transit service focuses in Argentina, Internexa's transit footprint comprises foreign countries, such as Argentina and Brazil.

5 IXPS AND CONCENTRATION

We believe that the presence of monopolistic ASes may discourage the deployment/growth of IXPs. Hence, we look if the IPv4 address space delegated to Latin American countries is fairly distributed, i.e., if no AS owns most IP prefixes assigned to a country.

For this analysis, we queried CAIDA's *pfix2as* files of July 2019 and LACNIC delegation files. While the first were used to determine the set of *active* prefixes (seen in routing tables) and the ASes that originate them, the latter allowed to check the countries to which these network blocks had been delegated to. In the end, the combination of both datasets outputs a database indicating, for each Latin American country, all active prefixes and the ASes that originate them. However, we acknowledge some limitations of this methodology. First, prefixes delegated by other RIRs (not LACNIC) might be active in LatAm. Second, we cannot determine which of the announced addresses are actually used [12]. Third, prefixes delegated by LACNIC to Latin-American-based ASes can be used beyond the region. Fourth, presence of Carrier Grade NAT (CGN) could cause underrepresentation of ASes that, though originate small address space, have a large number of subscriptions, especially for mobile carriers [46]. While the use of geolocation databases may mitigate these problems, these sources are known to be inaccurate in many cases [43]. Consequently, refining the methodology followed to detect active prefixes in each country is left as future work.

We leveraged our database to compute the Herfindahl-Hirschman Index (HHI), a statistical measure of concentration that ranges from 1 (single monopolistic origin) to 0. This metric is used by the US Department of Justice to apply antitrust regulations [44] and in ecology to measure diversity (known as *Simpson's Diversity Index*). Fig. 5 displays HHI for Latin American countries with more than 1M delegated IP addresses. The right end shows countries with low concentration ratio, such as Brazil, Chile and Argentina. Indeed, these countries host the largest IXP networks. On the contrary, the left side includes countries such as Uruguay, Dominican Republic

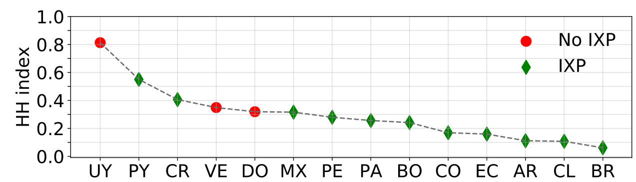


Figure 5: Herfindahl-Hirschman Index to determine originated address space concentration in countries that have been delegated more than 1M IP addresses.

	UY		VE		CR		MX	
ASN	6057*	19422	8048*	6306	11830*	52228	8151	13999
ip-cnt$_{cc}$	2.38M		5.15M		2.42M		24.9M	
ip-cnt	2.15M	90.1k	2.84M	629k	1.52M	197k	13.7M	2.05M
ip-frac	0.90	0.04	0.55	0.14	0.63	0.08	0.55	0.08

Table 3: The two largest origin ASes per country. $*$ indicates state-owned ASes.

and Venezuela, that do not have any IXP, and Paraguay, Costa Rica and Mexico, all possessing an HHI of more than 0.3.

We take Uruguay, Venezuela, Costa Rica and Mexico as cases of study and display in Table 3 the first and second dominant ASes that concentrate most of the IPs delegated to these countries. In all cases, the first dominant AS not only originates between 55% to 90% of its respective national address space, but also owns at least 47% more than the second. In particular, countries dominated by large state-owed providers such as Venezuela (CANTV) and Uruguay (ANTEL) are not even planning to release an IXP [14, 24]. Costa Rica is the opposite example: while the state owns ICE, the main ISP that originates 63% of the national address space, the first national IXP was created by an executive order in 2014 (see Sec. 3). Remarkably, ICE has never joined the IXP [41]. Mexico is another country with high HHI whose IXP just has 6 members. We suspect that, despite the fact that the creation of the IXP in 2014 was sponsored by the Mexican government as a recommendation of the OECD [11], the absence of Telmex (AS8151) [32], by far the first dominant AS in the country, discouraged the IXP growth.

6 RELATED WORK

Although Latin America is underrepresented in Internet measurement projects, some studies have specifically looked at this region. Berenguer *et al.* [8] studied how the BGP view of RIPE RIS and RouteViews in LatAm can be extended by additionally using BGP dumps collected in looking glasses of the region. Brito *et al.* [9] carefully studied the composition and interconnection of Brazilian public exchange network in three snapshots, and then compared Brazilian IXP size in terms of connected networks and peering policy prevalence with IXPs in other regions. Formoso *et al.* [23] used RIPE Atlas probes in Latin America to create an inter-country latency matrix as a way to detect fairly asymmetric paths and poorly interconnected countries.

In addition, there is a vast body of literature that studied IXPs. Dhamdhere *et al.* studied how IXPs contributed to the AS ecosystem and to flatten the Internet [17], while Augustin *et al.* carefully quantify the number of peering links seen at IXPs [4]. Other papers also analyzed the anatomy of a large European IXP [2] as well as the role of IXPs in the African AS ecosystem [19–21].

7 CONCLUSIONS AND FUTURE WORK

This study contributes four findings regarding to Internet topology research. First, we found that Latin American states have been involved in the creation of national IXPs in several ways: legislation, regulation, sponsoring, funding, operations and serving traffic from/to IXPs. Second, we discovered three consolidated IXPs, IX.br-SP, CABASE-BUE and PIT Chile-SCL, that gather mainly local but also regional ASes. Third, we compared these IXPs with others deployed in other continents and found that some IXPs in developing regions not only have had a similar growth in the last years, but also seem to have reached matureness, i.e., have been able to attract as many local ASes as so do some well-established IXPs in Europe. However, European IXPs have also managed to gather members from different regions, a market that could be exploited in the future by the less renown, and rather local, IXPs in Latin America, Asia and Africa. Fourth, we studied the correlation between the existence of ASes concentrating address space, and the IXP development and consolidation. Indeed, in several Latin American countries the existence of monopolistic ASes, some state-owned, seem to have prevented the proliferation of IXPs.

This work suggests several promising directions. First, our work could be extended by studying CDN deployment in LatAm and their co-location at IXPs. Second, we would like to compare IXP peering policies throughout LatAm IXPs. Third, we want to investigate IPv6 rollout in LatAm and the role of IXPs in such process.

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REFERENCES

[1] Accionistas ISA. 2019. http://www.isa.co/es/nuestra-compania/Paginas/quienes-somos/composicion-accionaria.aspx. (2019).

[2] B. Ager, N. Chatzis, A. Feldmann, N. Sarrar, S. Uhlig, and W. Willinger. 2012. Anatomy of a large European IXP. *CCR* 42, 4 (2012), 163–174.

[3] E. Ascenco. 2015. Peering in Brazil. https://ix.br/doc/nic.br.ptt.br.ais-sandiego.20150405-02.pdf. (2015).

[4] Brice Augustin, Balachander Krishnamurthy, and Walter Willinger. 2009. IXPs: mapped?. In *IMC 2009*. 336–349.

[5] World Bank. 2016. World Development Indicators: Rural environment and land use. http://wdi.worldbank.org/table/3.1. (2016).

[6] World Bank. 2018. The World Bank data: Urban population. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?page=1. (2018).

[7] World Bank. 2019. GDP per capita in LAC, EU, East Asia, TH, ZA. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=ZJ-EU-Z4-TH-ZA&year_high_desc=false. (2019).

[8] S. S. Berenguer, E. Carisimo, J.I. Alvarez-Hamelin, and F. V. Pintor. 2016. Hidden internet topologies info: Truth or myth?. In *LANCOMM 2016*. 4–6.

[9] S. H. B. Brito et al. 2016. Dissecting the Largest National Ecosystem of Public Internet eXchange Points in Brazil. In *PAM 2016*.

[10] Nikolaos Chatzis, Georgios Smaragdakis, Anja Feldmann, and Walter Willinger. 2013. There is more to IXPs than meets the eye. *CCR* 43, 5 (2013), 19–28.

[11] CITI. 2014. Inauguración del Primer IXP Mexicano. http://www.ixp.mx/noticias/14_04_30_inaguracion.php. (2014).

[12] Alberto Dainotti et al. 2016. Lost in space: improving inference of IPv4 address space utilization. *IEEE J. Sel. Areas Commun.* 34, 6 (2016), 1862–1876.

[13] DE-CIX. 2019. History of DECIX. https://bit.ly/2tuVHW2. (2019).

[14] Camara de Telecomunicaciones de Uruguay. 2019. El monopolio de Antel. http://www.telecomunicaciones.org.uy/index.php/el-monopolio-de-antel/. (2019).

[15] DEGT. 2016. Lanzan IXP-HN. https://blogs.unah.edu.hn/degt/lanzamiento-del-punto-de-intercambio-de-trafico-de-internet-de-honduras-ixp-hn/. (2016).

[16] Amogh Dhamdhere and Constantine Dovrolis. 2008. Ten years in the evolution of the internet ecosystem. In *IMC 2008*. 183–196.

[17] Amogh Dhamdhere and Constantine Dovrolis. 2010. The Internet is flat: modeling the transition from a transit hierarchy to a peering mesh. In *CoNEXT 2010*. 21.

[18] Governo do Brasil. 2014. R$ 1.8 Billion in Telecommunications Investments for 2014 FIFA World Cup. https://bit.ly/2OA86jp. (2014).

[19] Roderick Fanou et al. 2018. A System for Profiling the IXPs in a Region and Monitoring their Growth: Spotlight at the Internet Frontier. *IJNM* (2018).

[20] Rodérick Fanou, Pierre Francois, and Emile Aben. 2015. On the diversity of interdomain routing in africa. In *PAM 2015*. 41–54.

[21] Rodérick Fanou, Francisco Valera, and Amogh Dhamdhere. 2017. Investigating the Causes of Congestion on the African IXP substrate. In *IMC 2017*. 57–63.

[22] Peyman Faratin. 2007. Economics of overlay networks: An industrial organization perspective on network economics. In *Proceedings of the NetEcon+ IBC workshop*.

[23] Agustin Formoso and Pedro Casas. 2016. Looking for network latency clusters in the lac region. In *LANCOMM 2016*. 10–12.

[24] Freedom House. 2018. Freedom on the Net 2018: Venezuela. https://freedomhouse.org/report/freedom-net/2018/venezuela. (2018).

[25] Hernán Galperín. 2016. Localizing Internet infrastructure: Cooperative peering in Latin America. *Telematics and Informatics* 33, 2 (2016), 631–640.

[26] Vasileios Giotsas, Matthew Luckie, Bradley Huffaker, and Kc Claffy. 2015. IPv6 AS relationships, cliques, and congruence. In *PAM 2015*. 111–122.

[27] Hamed Haddadi et al. 2010. Mixing biases: Structural changes in the AS topology evolution. In *TMA workshop*. Springer, 32–45.

[28] Ultima Hora. 2015. Proyecto de Senatics ayudara a abaratar acceso a internet. https://www.ultimahora.com/c864692. (2015).

[29] Packet Clearing House. 2019. Internet Exchange Directory. https://www.pch.net/ixp/dir#\protect\kern-.1667em\relaxmt-sort=reg%2Cdesc. (2019).

[30] InteRED. 2019. InteRED. http://intered.org.pa/intered/. (2019).

[31] ITU. 2016. Consultoria - IXP Paraguay. https://bit.ly/2Lay76N. (2016).

[32] ITU. 2016. IXP Mexico. https://bit.ly/2R5PCZL. (2016).

[33] JINX. 2019. About INX-ZA. https://www.inx.net.za. (2019).

[34] Julimar L. 2008. Resultados Copa do Mundo. ftp://ftp.registro.br/pub/gter/gter41/02-IX.br-update.pdf. (2008).

[35] Anukool Lakhina, John W Byers, Mark Crovella, and Peng Xie. 2003. Sampling biases in IP topology measurements. In *IEEE INFOCOM 2003*, Vol. 1. 332–341.

[36] Lixin Gao and J. Rexford. 2001. Stable Internet routing without global coordination. *IEEE/ACM Transactions on Networking* 9, 6 (2001), 681–692.

[37] Mapa del Estado. Jefatura de Gabinete de Ministros de Argentina. 2019. https://mapadelestado.jefatura.gob.ar/organismos.php. (2019).

[38] Mario Durán Chuquimia. 2013. Seminario sobre el PIT. http://desarrollotics.blogspot.com/2013/07/preparando-un-seminario-tecnico-sobre.html. (2013).

[39] IFT México. 2016. Consulta Publica. https://bit.ly/2OxPdxB. (2016).

[40] La Nacion. 2006. GBLX adquirió Impsat. https://www.lanacion.com.ar/economia/global-crossing-adquirio-impsat-por-us-336-millones-nid853038. (2006).

[41] La Nacion. 2015. ICE rechaza unirse a sistema para agilizar Internet a usuarios. https://bit.ly/37DSS3v. (2015).

[42] PeeringDB. 2016. https://www.peeringdb.com. (2016).

[43] Ingmar Poese, Steve Uhlig, Mohamed Ali Kaafar, Benoit Donnet, and Bamba Gueye. 2011. IP geolocation databases: Unreliable? *CCR* 41, 2 (2011), 53–56.

[44] S. A. Rhoades. 1993. The Herfindahl-Hirschman Index. (1993).

[45] MICITT (Costa Rica). 2019. IXP Costa Rica: Una oportunidad estrategica. https://micit.go.cr/index.php?option=com_content&view=article&id=6329. (2019).

[46] Philipp Richter et al. 2016. A multi-perspective analysis of carrier-grade NAT deployment. In *IMC 2016*. 215–229.

[47] RIPE NCC. 2019. RIPE Routing Information Service (RIS). https://www.ripe.net/analyse/internet-measurements/routing-information-service-ris. (2019).

[48] SCIJ. 2014. Decreto Ejecutivo 38388. https://bit.ly/2FljQ41. (2014).

[49] SubTel. 1999. Resolucion 1483. https://www.subtel.gob.cl/images/stories/articles/subtel/asocfile/res_1483conexiones_entre_isp.pdf. (1999).

[50] TeleGeography. 2016. Belize gets internet exchange point; BIXP becomes twelfth such facility in Caribbean. https://bit.ly/2sxgisc. (2016).

[51] UN. 2016. The World's Cities in 2016. https://bit.ly/36uMpaW. (2016).

[52] UN. 2017. World Population Prospects 2017. https://population.un.org/wpp/Download/Standard/Population/. (2017).

[53] University of Oregon. 2019. RouteViews. http://www.routeviews.org/. (2019).