A Survey on the Current Internet Interconnection Practices

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ABSTRACT

The Internet topology has significantly changed in the past years. Today, it is richly connected and flattened. Such a change has been driven mostly by the fast growth of peering infrastructures and the expansion of Content Delivery Networks as alternatives to reduce interconnection costs and improve traffic delivery performance. While the topology evolution is perceptible, it is unclear whether or not the interconnection process has evolved or if it continues to be an ad-hoc and lengthy process. To shed light on the current practices of the Internet interconnection ecosystem and how these could impact the Internet, we surveyed more than 100 network operators and peering coordinators. We divide our results into two parts: (*i*) the current interconnection practices, including the steps of the process and the reasons to establish new interconnection agreements or to renegotiate existing ones, and the parameters discussed by network operators. In part (*ii*), we report the existing limitations and how the interconnection ecosystem can evolve in the future. We show that despite the changes in the topology, interconnecting continues to be a cumbersome process that usually takes days, weeks, or even months to complete, which is in stark contrast with the desire of most operators in reducing the interconnection setup time. We also identify that even being primary candidates to evolve the interconnection process, emerging on-demand connectivity companies are only fulfilling part of the existing gap between the current interconnection practices and the network operators' desires.

CCS CONCEPTS

• **Networks → Network management**;

KEYWORDS

Peering, Interconnection, Internet

1 INTRODUCTION

Traffic delivery requirements. Traffic delivery is a fundamental aspect of the Internet today as most of the traffic relates to applications such as streaming and gaming, which have strict service requirements [15]. Additionally, unpredictable traffic surges [19, 26] are challenging advanced traffic engineering strategies, and link failures [12] are causing disruptions of Internet connectivity, requiring network operators to find alternatives to deliver the traffic adequately while satisfying bandwidth and latency requirements for their end-users.

An evolving topology. A common approach for dealing with the above scenarios is to improve the connectivity in terms of the number of directly interconnected networks and connected capacity. Consequently, each network has more alternatives to steer inter-domain traffic. In the past years, ASes have become increasingly connected to peering infrastructures such as Internet eXchange Points (IXPs) and colocation facilities, as these could help to improve the quality of Internet traffic delivery with lower latency and higher throughput [2]. These infrastructures are now crucial elements of the Internet topology, providing physical interconnection among hundreds or even thousands of ASes. They allow environments with rich connectivity [1], resulting in a topology that is highly connected and flattened [7, 9].

Has the interconnection process evolved? While the Internet topology has evolved significantly, it is unclear whether the interconnecting continues to be performed in a highly ad-hoc and lengthy manner. On one hand, a recent survey by Packet Clearing House (PCH) indicates that more than 99% of the peering agreements are handshake-based [30], hinting that the interconnection process has evolved too and may be faster today. Additionally, in recent years, on-demand connectivity companies and proposals from academia have emerged, promising the provisioning of interconnection agreements in short-time frames [5, 8, 13, 18, 20, 24, 28, 29]. On the other hand, there are signs that operators still follow a largely manual, ad hoc process. Recent studies on peering infrastructures indicate that operators avoid using Route Servers due to security and routing control issues [6]. When so, operators need to assess the demand for a new interconnection (e.g., through monitoring systems) and identify a set of possible candidates (e.g., checking PeeringDB [25]), discuss the properties of the interconnection agreement (e.g., Service Level Agreement, length, peering or transit), sign a legal contract, and finally execute the agreement by configuring their border routers [23].

Understanding the current Internet interconnection practices. To shed light on the current interconnection practices[1] and understand the limitations of the interconnection ecosystem, we surveyed more than 100 network operators and peering coordinators (§2). We identify that interconnecting continues to be a process that requires days, weeks or even months to complete (§3). We also find that while the majority of network operators wants to reduce the interconnection setup time, companies offering on-demand connectivity services are falling short of fulfilling their desires, due to operators' unawareness, infrastructure constraints, and the companies businesses model (§4).

*Work done in part while author was at UFRGS.

[1] Our focus is on bilateral agreements.

2 SURVEY CHARACTERIZATION

Methodology. To prepare the survey, we first interviewed a peering coordinator from a tier-1 ISP, and three network operators from peering infrastructures, one from a large IXP, one from a medium-sized IXP, and one from a medium-sized colocation facility. Based on the interviews, we derived a set of questions about the current practices of the interconnection ecosystem and a list of the most relevant use cases (and consequences) for improving the interconnection process. Next, we got feedback from a subset of network operators to improve the structure and clarity of the questions. Then, we circulated our survey to several mailing lists of Network Operators Groups (NOG), including NANOG, RIPE, AusNOG, DENOG, LACNOG, APNIC-talk, ARIN-tech, IX.br, AFRINIC, AFNOG, between December 2017 and January 2018. We also have sent the survey to the AS members of a large European IXP and made it available through a blog post at ipspace.net website. We collected 106 answers from network operators and peering coordinators from ASes. To validate answers, we asked the survey respondents to provide their working/instutional e-mail addresses. Below we classify the respondents according to their *Region*, *AS Type*, and *AS Size*. Since we promised to the survey respondents that we would not reveal their identities, we cannot present results correlating multiple dimensions (e.g., a large content provider in Brazil).

Region. We asked the respondents to select the region(s) in which their AS is present. The participants could select among the five regions with Regional Internet Registries (RIRs). We classified the ASes that are present in two or more regions in the following groups: *multi* for ASes in two regions, *partially global* for ASes in three regions, *almost global* for ASes in four regions, and *global* for ASes present in all regions. The respondents could also not share the region of their ASes. Figure 1(a) presents the distribution of respondents by region. Among the respondents, 80.2% are present in a single region, 18.9% correspond to ASes with infrastructure in multiple regions, and 0.9% did not share their location. We note that while on a different scale, the regional distribution of respondents resembles the proportion of ASes registered in each of the five RIRs. To illustrate, as of today, 38.06% of the ASes are in the RIPE region, 32.18% are in the ARIN region, 17.49% are in the APNIC region, LACNIC accounts for the 10.38% of the ASes, and AFRINIC 1.89% [17].

AS Type. To characterize the type of the ASes, we asked the survey participants to select the terms that best describe their ASes. We classify the ASes into four different types, namely, Internet Service Providers (ISPs), Content Providers, Enterprise Networks (e.g., companies, Universities, Research and Education Networks), and Infrastructure Providers (e.g., IXPs, RIRs, DNS Providers). Figure 1(b) shows the AS types of survey respondents. The vast majority (70.8%) of the respondents operate ISPs, while 14.2% are Content Providers, 7.5% are Enterprises, and 7.5% represent Internet Infrastructure ASes. Regarding the ISPs, we can classify them into three different categories tier-1 (6.7%), transit (64%), and access networks (29.3%).

AS Size. Finally, to obtain characteristics of the AS size, we asked the operators to indicate an estimate of the number of end-users of their ASes. Options include five different sizes (very small, small, medium, large, and very large) and the possibility not to share this information. Figure 1(c) shows the characterization by AS size. The respondents of our survey are heterogeneous when considering their size in terms of end-users.[2] 23.6% are very small networks with up to 1000 end-users, 25.5% are small providing services to 1,001-10,000 users, 13.2% are medium-sized networks that offer connectivity to 10,001-100,000 customers, and 12.3% are large networks with 100,001-1,000,000 users. Finally, 8.5% represent very large networks with more than 1,000,000 end-users. 17% of the survey respondents preferred not to share the size of their networks.

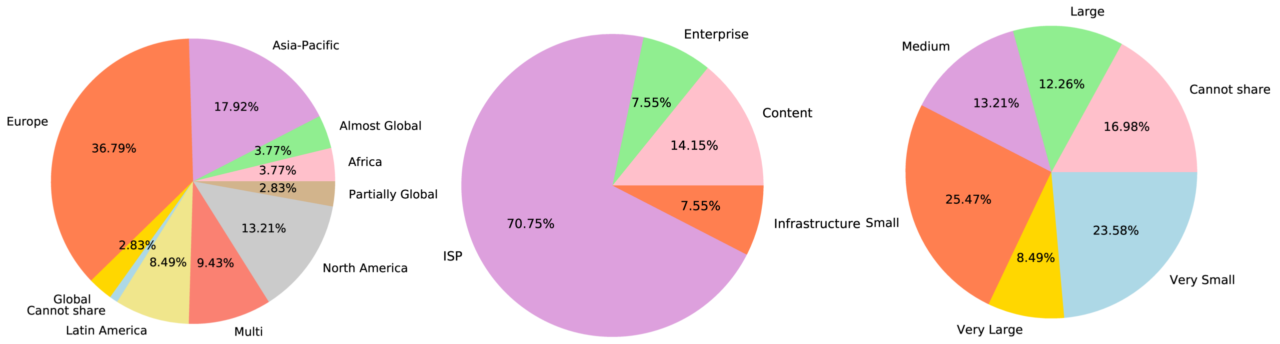
3 INTERCONNECTION STATUS QUO

To understand the current interconnection practices, we asked the respondents four questions (*i*) *how long does it take on average to establish a bilateral agreement?*; (*ii*) *what are the reasons to establish an interconnection agreement?*; (*iii*) *what are the reasons to renegotiate the parameters of an existing interconnection agreement?*; and (*iv*) *what parameters network operators use do discuss when establishing an interconnection agreement?*. Below we describe the overall results and highlight the main differences (if they exist) when comparing the answers by region, AS type, and AS size.

How long does it take on average to establish a bilateral agreement? We divided the interconnection process into four steps [23], namely *identifying a potential interconnection partner*, *discussing the properties of the interconnection agreement*, *legal procedures*, and *implementing the agreement*. We then asked network operators to specify the average time (e.g., hours, days, weeks) required in each of these steps and to complete the overall process. Valid answers also included *question does not apply* (e.g., an AS may never require legal procedures), *question unclear*, and *information cannot be shared*. Figure 2 shows the summary of the answers.

Among the different steps, finding an interconnection partner is the fastest one, requiring hours or at most days for the majority (78.3%) of ASes. Possible reasons include the facts that ASes tend to have monitoring systems that indicate candidate ASes and because PeeringDB [25] and websites from IXPs and colocation facilities usually provide information about their members, including contact details, which helps to accelerate the process. It is not uncommon, however, to observe in mailing lists NOGs, operators asking for contact information of a given AS [21], which may indicate that sometimes is not trivial to find the person responsible for establishing agreements in some ASes. Discussing the properties (e.g., technical and pricing aspects) of the interconnection agreement demands mostly days (40.6%) or weeks (23.6%) to be completed. Regarding the legal phase, 11.3% of the ASes answered that this step does not apply to them. These cases could be related to the fact that some ASes have an open peering policy, thus interconnecting to all ASes interested in exchanging traffic. A recent survey by Packet Clearing House (PCH) shows that more than 99% of the peering agreements are handshake-based. After completing the legal step, ASes need to configure their routers (equipment) to reflect the new settlement. Similarly to finding a potential interconnection partner, such a procedure tends to require hours (34.9%) or days (35.9%) to complete. Finally, according to the respondents, the overall interconnection process usually requires days (6.6%),

[2] Or AS members in the case of ASes operating IXPs.



(a) Region (b) AS Type (c) AS Size

Figure 1: Characterization of the survey respondents.

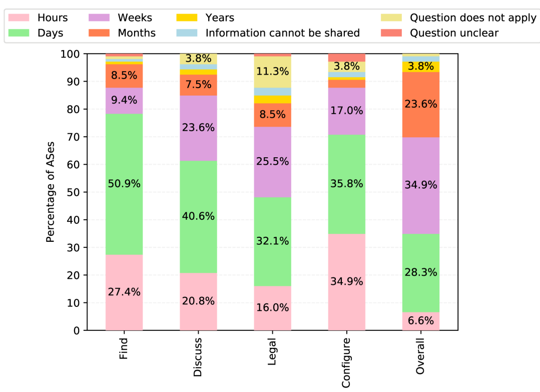


Figure 2: Average time to establish an agreement.

weeks (28.3%), or even months (34.9%) to be completed. When analyzing the results by specific properties (e.g., region, AS size, AS type), we identify that: (*i*) ASes located in Africa and Latin America have longer interconnection setup times, and (*ii*) that the same observation holds for very small and very large ASes.

What are the reasons to establish an interconnection agreement? We asked the network operators to select one or more alternatives that represent reasons to establish a new interconnection agreements. Possible answers were *increase capacity*, *decrease capacity*, *reduce costs*, *reduce number of hops*, *reduce latency*, *increase revenue*, *improve resilience*, and *other*. Table 1 presents the results.

Reducing latency is the most common reason (81.1% of network operators) to establish a new interconnection agreement. Other main reasons are reducing costs (66%), improving resilience (64%), increasing capacity (59.4%), and reducing the number of hops (56.6%). Such order is consistent when analyzing the answers by region, AS size, and AS type. Nine ASes, mostly the largest ones, also consider *other* reasons to interconnect, such as commercial aspects, to increase its footprint, to improve peering stats (e.g., AS-Rank), and to build political relationships.

What are the reasons to renegotiate the parameters of an existing interconnection agreement? Similarly, we asked the operators to identify the reasons to renegotiate the properties of an interconnection agreement. The set of alternatives is the same as the previous question. Table 1 shows the results.

The five main reasons to renegotiate an interconnection agreement are the same as the ones to establish a new agreement. However, for this scenario, they appear in a different order. The top motivation is to reduce the interconnection costs (53.8%), followed by increasing capacity (50.1%), and improving resilience (41.5%). Reducing latency (29.2%) and the number of hops (20.7%) complete the list. Interestingly (but not surprisingly), the main reason to renegotiate an agreement is an economic one, while the number-one motivation to interconnect with a new partner is performance-related. Other takeaways from the answers are the higher number (when compared to the previous question) of ASes that renegotiate an interconnection agreement to decrease capacity, and the 11.3% of ASes that selected *question does not apply*, probably indicating that they do not renegotiate interconnection agreements. Finally, when analyzing the answers by region and AS size, we identify that ASes with a global footprint and large ASes are the ones interested in increasing their revenues by renegotiating interconnection agreements.

What parameters network operators use to discuss when establishing an interconnection agreement? Finally, we asked network operators to indicate the parameters that they use to discuss when interconnecting. Figure 3 shows the results.

Bandwidth is the most common attribute pointed by the survey respondents (86%). Other relevant aspects are reachability (56.6%), the paths to steer traffic during the agreement (45.3%), the billing model (44.3%), the guarantee of the SLA properties (41.5%), and the agreement length (41.5%). There is no significant difference when comparing the results by region, AS size, and AS type.

4 LIMITATIONS AND FUTURE OF THE INTERCONNECTION ECOSYSTEM

To identify possible limitations on the interconnection ecosystem and understand how to tackle them in the future, we asked the network operators four questions: (*i*) *how important would be to evolve the interconnection ecosystem?*, (*ii*) *what is your perception of the emerging companies offering on-demand connectivity?*, (*iii*) *do you envision that the existence of on-demand connectivity alternatives*

Table 1: Reasons to establish and to renegotiate an interconnection agreement.

	Latency	Costs	Resilience	Incr. Capacity	Red. Hops	Revenue	Red. Capacity	Other	QNA
Establish	81.1%	66%	64.2%	59.4%	56.6%	12.3%	0.9%	8.5%	0%
Renegotiate	29.2%	53.8%	41.5%	50.9%	20.8%	8.5%	3.8%	5.7%	12.3 %

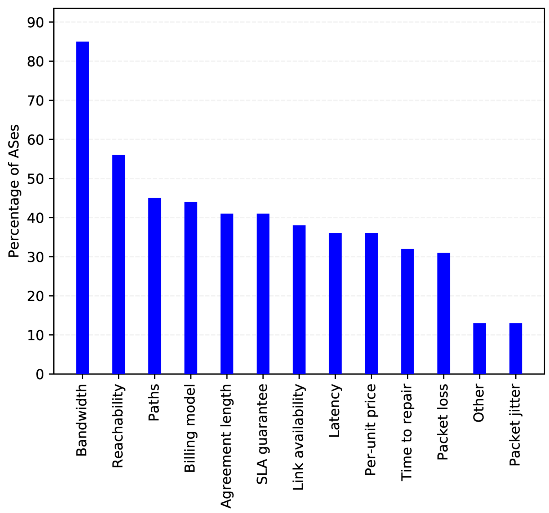


Figure 3: Parameters discussed before establishing an interconnection agreement.

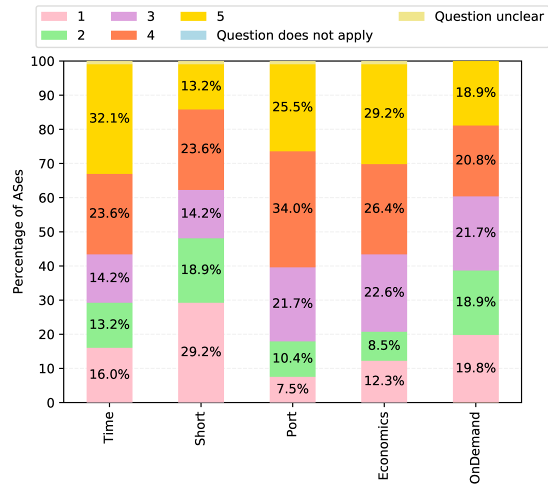


Figure 4: Operators' perception about possible improvements in the interconnection ecosystem.

might cause a negative impact on the Internet or in the way that networks do business?, and (*iv*) *would you mind if information about your interconnection agreements would be disclosed to other ASes in a solution for on-demand connectivity agreements?*.

How important would it be to evolve the interconnection ecosystem? We aimed at identifying the most relevant aspects of the interconnection ecosystem that could evolve. To derive a set of possible improvements, we interviewed four peering coordinators and network operators as described in Section 2. Based on the interviews we asked the operators' perception about *a*) *reducing the interconnection setup time*, *b*) *short-time interconnection for traffic engineering*, *c*) *increasing peering port utilization*, *d*) *benefiting from new economic opportunities*, and *e*) *ordering network services on-demand*. We requested the operators to give a score on a scale from 1 (not much relevant) to 5 (very relevant), indicating the relevance of each aspect. Figure 4 shows a summary of the answers.

Most operators (56%) have indicated that reducing the interconnection setup is a valuable improvement (scores 4 and 5). Such a condition is not surprising since operators have reported that interconnecting is a lengthy process (see §3). Interestingly, 80% of the content providers consider reducing interconnection setup time helpful. Being able to interconnect faster can provide benefits ranging from removing the burden from network operators to improving wide-area traffic delivery performance. Short time interconnection for traffic engineering purposes (e.g., dealing with traffic surges and link failures) is relevant for 37% of the survey respondents, while 14% were neutral (score 3). When clustering our analysis by AS size, we identify that the majority (56%) of the very small ASes consider this a significant improvement. Similarly, when grouping by AS type, 47% of the content providers are interested in this direction. Increasing peering port utilization has been indicated as a valid improvement for 60% of the network operators. Likewise, benefiting from new economic opportunities is essential for 56% of the survey respondents. Such a condition is not surprising since, in both cases, the AS will have gains. To illustrate, Deutsche Telekom recently reported that increasing resource utilization by 1% or 2% could result in saving millions of dollars in future infrastructure investments [3]. Finally, the ability to hire network services such as mitigation of Distributed Denial of Service (DDoS) attacks, access to cloud infrastructures, and network analytics solutions was considered essential (scores 4 and 5) by only 42% of the respondents.

What is your perception of the emerging companies offering on-demand connectivity? On-demand connectivity appears as one of the most prominent evolutions of the interconnection ecosystem, especially due to the lengthy nature of the current process and the need for improved traffic delivery. In response, new companies such as MegaPort, PacketFabric, Epsilon Infiny, and ConsoleConnect have emerged offering products that include on-demand physical connectivity between any two PoPs of their networks and direct connection to cloud providers. We then asked the network operators about their perception of such companies. We offered a set of alternatives that include *I never heard of them*, *I know what they offer but I do not need them*, *I know what they offer but they do not have what I need*, *I am planning to use them in my organization*, and *I am using them in my organization*. Operators could also specify *other* impression. Figure 5 shows the answers.

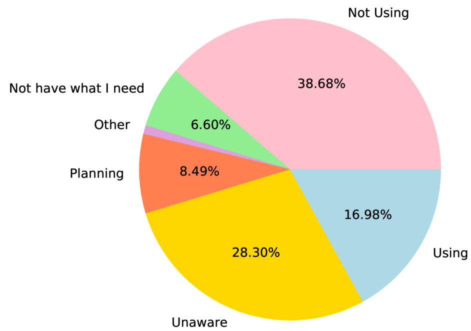


Figure 5: Operators' perception about on-demand connectivity companinies.

On-demand connectivity companies are relatively new in the interconnection ecosystem. However, most network operators are already aware of their existence, with only 28.3% of respondents reporting being unaware of such companies. While the operators' community is generally aware of these companies, their utilization is not widespread yet, with only 16.9% using them and 8.4% planning to use. A significant fraction (45.3%) is aware but not using such services because they do not need them (38.7%) or because the service required by the ASes is unavailable (6.6%). Interestingly, 0.9% of the respondents selected *other* and indicated that they are one of the on-demand connectivity companies. Analyzing the answers by region, we identify that most ASes that reported being using such services are located in Asia-Pacific, Europe, and North America. None of the respondents from Africa and Latin America and Caribbean are utilizing on-demand connectivity companies. These results are consistent with the location of the Points of Presence of the companies.

As a complementary-related question, the survey respondents could also relate why they are not using or are not interested in the current on-demand connectivity services. The reported reasons can be divided into three groups, pricing, infrastructure, and interconnection process. Two respondents related that prices are too high and that these companies do not have a transparent pricing model. Regarding infrastructure, one operator said that the reason not to use those services is that they are not present in its region, while two other said these companies, in general, offer remote peering [4] solutions which some rather avoid [22]. Finally, two operators reported that they prefer to continue interconnecting without depending on a man-in-the-middle and that would increase the complexity of the process.

Do you envision that the existence of on-demand connectivity alternatives might cause a negative impact on the Internet or in the way that networks do business? To learn possible concerns of the operators' community regarding the utilization of on-demand connectivity services, we asked the operators if they have any concerns about potential impact on the Internet. Valid alternatives include *none*, *I expect the positives to outweigh any negatives*, *Impacting Internet routing stability*, *Exposing the existence of agreements between networks*, and *Exposing network business policy*. As in previous questions, operators could also specify *other* aspects. Each operator could select one or more alternatives. Figure 6 shows the answers distribution.

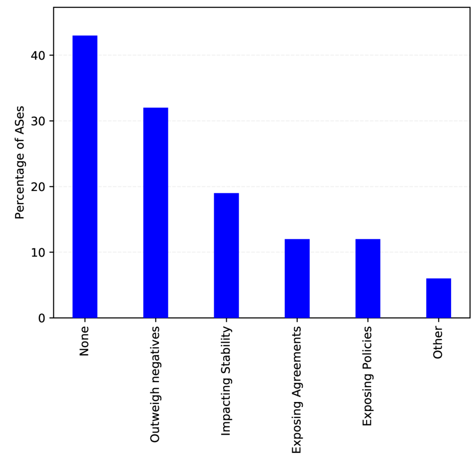


Figure 6: Operators' perception about possible impacts on the Internet due to on-demand connectivity.

43.3% of the network operators answered that they do not expect any negative impact on the Internet. 32.1% of the respondents indicated they acknowledge that on-demand connectivity might impact the Internet somehow but expect the benefits to outweigh possible issues. The main concern (19.8%) for network operators relates to impact Internet stability since the ability to interconnect in short time frames might result in disruptions if agreements are too short. Additionally, operators are equally concerned (12.2%) about exposing the existence of interconnection and exposing peering policies. Such an issue relates to the fact that companies for on-demand connectivity are acting as intermediaries in the interconnection process and might end-up having access to sensitive information. Finally, 6.6% of the respondents declared to have other concerns.

Would you mind if information about your interconnection agreements would be disclosed to other networks in a solution for on-demand connectivity agreements? Given that ASes might have concerns in sharing information about their interconnection agreements, we asked them to indicate the sensitive in sharing each piece of information. To that end, we divided the attributes in five different sets, namely *agreement type (e.g., peering, transit)*, *agreement length (e.g., 3 months)*, *pricing (e.g., $1 per Mbps)*, *SLA (e.g., latency, bandwidth)*, *ASes involved (e.g., A has an agreement with B)*, and asked the operators to give a score from 1 to 5, where 1 indicates that information is less sensitive and 5 represents data that is sensitive. Figure 7 presents the results.

The most sensitive information is pricing, which 56% of the operators have indicated a score of 4 or 5, followed by length (33%) and SLA (35.8%). The ASes involved, and the agreement model are less sensitive according to the network operators. The reason for that is because while the former three are strongly related to the AS' interconnection policy and are hard or impossible to infer, the latter two are less revealing and easier to infer by analyzing public routing information. Analyzing the results by region, we identify that ASes in North America are more open to sharing such pieces of

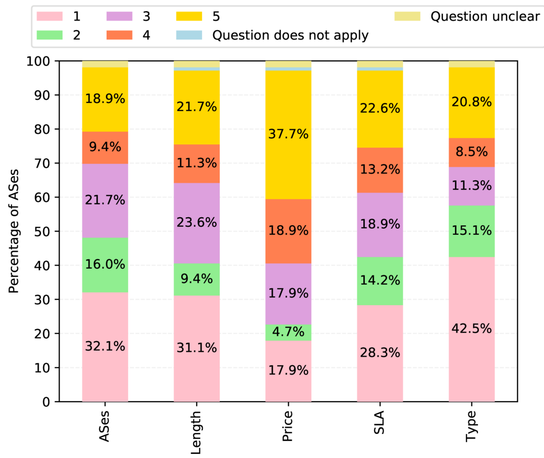


Figure 7: Operators' perception in sharing information about their interconnection agreements.

information when compared to ASes in other regions. We observe the same condition when comparing ISPs to Content Providers, Infrastructure, and Enterprise ASes.

5 FINAL REMARKS

While the Internet topology has significantly changed over the past decade to account for the new traffic requirements, the way ASes interconnect has not changed at the same pace. Today, despite the openness of network operators to handshake agreements and the emergence of companies offering on-demand connectivity, the interconnection process continues to require a long time for most ASes. While it is hard to know the exact reasons for that, our survey provides some revealing indications. First, legal procedures are still relevant since ASes may establish long-term agreements involving large amounts of money [23]. Such a step tends to be the most time-consuming of the process as it may require several meetings and human-interaction, motivating the development of multidisciplinary optimization strategies. Second, while on-demand connectivity can be an excellent alternative to accelerate the interconnection process, preserving the privacy of interconnection policies and business information is a concern for most network operators and none of the existing companies for on-demand connectivity guarantees that. Additionally, the lack of footprint of these companies in regions such as Africa and Latin America (where network operators have reported the most extended times to interconnect) prevents a fraction of ASes of benefiting from those solutions.

Regarding current practices, we have discovered that the main reasons to establish new interconnection agreements relates to performance aspects (e.g., latency, bandwidth), while economic aspects usually trigger the renegotiation process. Also, we identified that the most common parameters discussed by network operators when interconnecting are the capacity of the agreement, its reachability, and the paths that the AS will use to forward the traffic. Based on that, it is possible to infer that in general, the primary concern of ASes relates to traffic delivery performance. Similarly to previous efforts that surveyed network to understand interdomain routing policies [16], possible improvements at IXPs [10, 11, 14], and BGP hijacking prevention techniques [27], we expect our survey to increase the understanding of the community about the interconnection ecosystem and act as a starting point for more research towards an improved Internet interconnection ecosystem.

ACKNOWLEDGEMENTS

We are thankful to all network operators and peering coordinators for taking part in our survey. This research is (in part) supported by European Union's Horizon 2020 research and innovation program under the ENDEAVOUR project (grant agreement 644960), by CNPq Grant 310408/2017-2 and by CAPES/Brazil - Finance Code 001.

REFERENCES

[1] B. Ager, N. Chatzis, A. Feldmann, N. Sarrar, S. Uhlig, and W. Willinger. Anatomy of a Large European IXP. In *SIGCOMM*, 2012.
[2] A. Ahmed, Z. Shafiq, H. Bedi, and A. Khakpour. Peering vs. Transit: Performance Comparison of Peering and Transit Interconnections. In *ICNP*, 2017.
[3] F. Bornstaedt. New Levels of Cooperation between Eyeball ISPs and OTT/CDNs, 2017. Available at https://ripe75.ripe.net/archives/video/126/ – starting at 7min50s.
[4] I. Castro, J. C. Cardona, S. Gorinsky, and P. Francois. Remote Peering: More Peering Without Internet Flattening. In *CoNEXT*, 2014.
[5] I. Castro, A. Panda, B. Raghavan, S. Shenker, and S. Gorinsky. Route Bazaar: Automatic Interdomain Contract Negotiation. In *HotOS*, 2015.
[6] M. Chiesa, D. Demmler, M. Canini, M. Schapira, and T. Schneider. SIXPACK: Securing Internet eXchange Points Against Curious onlooKers. In *CoNEXT*, 2017.
[7] Y.-C. Chiu, B. Schlinker, A. B. Radhakrishnan, E. Katz-Bassett, and R. Govindan. Are We One Hop Away from a Better Internet? In *IMC*, 2015.
[8] Console. Console - The Cloud Connection Company, 2017. Available at https://www.consoleconnect.com/.
[9] A. Dhamdhere and C. Dovrolis. The Internet is Flat: Modeling the Transition from a Transit Hierarchy to a Peering Mesh. In *CoNEXT*, 2010.
[10] C. Dietzel and M. Bleidner. Design of Use Cases for Operators of IXPs, 2016. Available at http://www.h2020-endeavour.eu/sites/www.h2020-endeavour.eu/files/u86/D.4.2.pdf.
[11] C. Dietzel, M. Bleidner, G. Kathareios, M. Chiesa, I. Castro, S. Abdellatif, G. Antichi, M. Bruyere, E. Fernandes, and P. Owezarski. Design of Use Cases for Members of IXPs, 2016. Available at http://www.h2020-endeavour.eu/sites/www.h2020-endeavour.eu/files/u86/D.4.3.pdf.
[12] S. Duncan. Australian Internet slows to a crawl after undersea cable cut, 2017. Available at http://www.dailymail.co.uk/news/article-5146795/Aussie-internet-slows-crawl-undersea-cable-cut.html.
[13] Epsilon. Epsilon Telecommunications Limited – Connectivity made simple, 2017. Available at www.epsilontel.com/.
[14] R. Fanou, F. Valera, P. Francois, and A. Dhamdhere. Reshaping the African Internet: From scattered islands to a connected continent. *Computer Communications*, 2017.
[15] M. Ghasemi, P. Kanuparthy, A. Mansy, T. Benson, and J. Rexford. Performance Characterization of a Commercial Video Streaming Service. In *IMC*, 2016.
[16] P. Gill, M. Schapira, and S. Goldberg. A Survey of Interdomain Routing Policies. *SIGCOMM Comput. Commun. Rev.*, 2013.
[17] P. Maigron. Regional Internet Registries Statistics, 2019. Available at https://www-public.imtbs-tsp.eu/~maigron/RIR_Stats/RIR_Delegations/ByRIR/Stats-ByRIR.html.
[18] P. Marcos, M. Chiesa, L. Müller, P. Kathiravelu, C. Dietzel, M. Canini, and M. Barcellos. Dynam-IX: A Dynamic Interconnection eXchange. In *CoNEXT*, 2018.
[19] J. McGee-Abe. Apple devices behind DE-CIX Frankfurt 5.88Tbps data traffic rate, 2017. Available at http://www.capacitymedia.com/Article/3751343/Apple-devices-behind-DE-CIX-Frankfurt-588Tbps-data-traffic-rate.
[20] Megaport. Megaport - A Better way to connect, 2017. Available at http://megaport.com/.
[21] NANOG. AS16509 (Amazon) peering contact, 2019. Available at https://mailman.nanog.org/pipermail/nanog/2019-June/101689.html.
[22] G. Nomikos, V. Kotronis, P. Sermpezis, P. Gigis, L. Manassakis, C. Dietzel, S. Konstantaras, X. Dimitropoulos, and V. Giotsas. O Peer, Where Art Thou?: Uncovering Remote Peering Interconnections at IXPs. In *IMC*, 2018.
[23] W. B. Norton. *The Internet Peering Playbook: Connecting to the Core of the Internet.* DrPeering Press, 2014.
[24] PacketFabric. Packetfabric, 2017. Available at https://www.packetfabric.com/.
[25] PeeringDB. PeeringDB, 2018. Available at https://www.peeringdb.com.

[26] Sandvine. FIFA 16 - The Beautiful Game?, 2015. Available at http://www.internetphenomena.com/2015/09/fifa-16-the-beautiful-game/.
[27] P. Sermpezis, V. Kotronis, A. Dainotti, and X. Dimitropoulos. A Survey Among Network Operators on BGP Prefix Hijacking. *SIGCOMM Comput. Commun. Rev.*, 2018.
[28] V. Valancius, N. Feamster, R. Johari, and V. Vazirani. MINT: A Market for INternet Transit. In *ReArch*, 2008.
[29] T. Wolf, J. Griffioen, K. L. Calvert, R. Dutta, G. N. Rouskas, I. Baldin, and A. Nagurney. ChoiceNet: Toward an Economy Plane for the Internet. *SIGCOMM Comput. Commun. Rev.*, 2014.
[30] B. Woodcock and M. Frigino. 2016 Survey of Internet Carrier Interconnection Agreements. *Packet Clearing House*, Nov. 2016.