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Improving Internet Cartography from a Different Point of View

PhD Work Plan

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1 INTRODUCTION

Context. Recently, the need for guarantees in traffic delivery with efficiency and resilience (YAP et al., 2017; SCHLINKER et al., 2017; MARCOS et al., 2018) is leading Autonomous Systems (ASes) to interconnect at peering infrastructures, such as Internet Exchange Points (IXPs) and colocation facilities (GIOTSAS et al., 2015). These infrastructures simplify interconnection among networks within a region, improving network performance due to lower latency and routing efficiencies (e.g., less AS hops for end-to-end paths) (CHATZIS et al., 2013b). Consequently, this trend is causing the flattening of the Internet making inter-domain traffic to bypass transit providers and flow directly between edge networks (LABOVITZ et al., 2010).

Motivation. A key point to achieve the goals of network performance and resilience is to understand what is occurring in the Internet topology. Such task is challenging due to the growing complexity of networking infrastructure and security and commercial aspects (GIOTSAS et al., 2015). Obtaining geolocation inferences about peering interconnection (e.g., multilateral agreements (GIOTSAS et al., 2013)) and topology (e.g. router IP addresses (SCHEITLE et al., 2017; HUFFAKER; FOMENKOV; CLAFFY, 2014)) can enhance the understanding of the dynamics of Internet traffic, improve traffic delivery and infrastructure planning (CALDER et al., 2013) and increase responsiveness to outages and attacks (GIOTSAS et al., 2017; MARCOS et al., 2018).

In this context, IXPs emerge as potential candidates to improve the mapping of the Internet. These infrastructures play a global role, since they have large volume of information on data and control planes and carry traffic from a significant fraction of the Internet (CHATZIS et al., 2013a). Besides, they are increasingly being deployed all over the world, supporting a growing number of network members and peering interconnections (GIOTSAS et al., 2017).

Recent work focus either in generating geolocation inferences about peering interconnections or topology elements. In the former group, (GIOTSAS et al., 2015; AUGUSTIN; KRISHNAMURTHY; WILLINGER, 2009) provide accurate results to geolocate interconnections, but cannot scale to large scenarios with several facilities, IXPs, and ASes, given a large amount of decentralized active probing campaigns needed. For the latter group, (GHARAIBEH et al., 2017) shows that current commercial and public databases are not accurate in geolocating router at neither country- nor city-level. (HUFFAKER; FOMENKOV; CLAFFY, 2014; SCHEITLE et al., 2017) propose methods to accurately geolocate routers based on geography-related strings in hostnames and validate the results with active measurements from different decentralized probes. However, their scope is restricted since only a small subset of routers have apparent geographic hints in their DNS names.

Proposal. This work investigates the potential of IXPs as anchors to improve the Internet mapping and generate geolocation inferences of peering interconnections and topology elements. Our goal is to develop a precise and systematic approach to increase geolocation knowledge while making it scalable, automatized, and without incurring significant processing and networing overhead. We plan to explore current relationships with the first and third largest IXPs in Brazil (IX-SP and IX-RS) to deploy and validate our methodology.

Expected contributions. We expect that leveraging IXPs as scalable vantage points will enable higher visibility and knowledge about the geolocation of peering interconnections and network elements. The broader vision will allow us to identify gaps in existing physical and measurements (BGP) infrastructures, observe how the connectivity between ASes varies in developing areas (e.g., Latin America) and across different regions, increase knowledge about redundancy, and investigate approaches to identify IXPs not present in public databases. Recent events ('ROUTER. . . , 2018; ROUTER. . . , 2015) show how failure in topology elements can delay or even cause disruption in services, affecting thousands of people. Mapping network topology and peering interconnections precisely could help to troubleshoot and diminish the time to repair similar problems.

Outline of the proposal. Chapter 2 provides background and terminology. Chapter 3 presents the state-of-the-art and the main related work. In Chapter 4, we present the proposal work. In Chapter 5, we show the expected methodology, set of steps and schedule. Chapter 6 provides the expected results and main contributions. Finally, in Chapter 7, we present the expected coursework of the Ph.D. course.

2 BACKGROUD

In this chapter, we present some background related to the area of the proposed plan. In Section 2.1, we describe the concepts of Peering Infrastructures, defining Internet Exchange Points (Subsection 2.1.1) and Colocation Facilities (Subsection 2.1.2).

2.1 Peering Infrastructures

Peering infrastructures are comprised of both Internet exchange points (IXP) and colocation facilities. They are responsible for exchanging a growing volume of traffic between different networks, support thousands of network members, and are widely available all over the world.

2.1.1 Internet Exchange Points

Internet Exchange Points are physical network infrastructures where a set of autonomous systems can interconnect their networks to exchange traffic. These infrastructures provide a shared switching fabric to support the traffic resulting from public and private peering of its network affiliates and are responsible for interconnecting almost half of the Internet (AGER et al., 2012; CHATZIS et al., 2013a; RICHTER et al., 2014).

Historically, they can be considered as the successors of Network Access Points (NAPs), which were responsible for the smooth transition from the monolithic government network to the modern Internet (CHATZIS et al., 2013b). Since 1995, the four existing NAPs have been replaced by more than 800 IXPs in 200+ cities around the world, interconnecting 50k+ networks (AGER et al., 2012; GIOTSAS et al., 2015). As these infrastructures are mainly located in every major metropolitan area, they associate with Colocation Facilities to reach city-level interconnection with other networks (GIOTSAS et al., 2015).

2.1.2 Colocations Facilities

Colocation facilities (Colos) are physical locations that provide essential infrastructures like power, space, cooling, physical security, storage, and networking equipment to their associated companies. Their platform connects the member's network to various IXPs, transit networks, cloud/content providers and other ASes in multiple locations worldwide. These provided amenities lower the infrastructure costs and drive small and medium providers to house their equipment (storage, server, routers) in the Colos. Large carrier-neutral companies such as Equinix and Telehouse are the leading operators of colocation facilities all over the world (GIOTSAS et al., 2015; KOTRONIS et al., 2017).

3 RELATED WORK

This chapter presents the state-of-the-art on the main topics related to the proposed work. To elucidate the importance and evolving role of peering infrastructures in the Internet topology, in Subsection 3.1 we discuss the most relevant studies that analyze the operational and internal characteristics of these infrastructures. In Subsection 3.2 and 3.3, we present the efforts to improve the accuracy of mapping peering interconnections and topology elements to physical locations.

3.1 Peering infrastructures and operation

The role of peering structures is increasingly essential for the exchange of inter-domain traffic on the Internet. Studies reveal that existing Internet Exchange Points are responsible for transferring amounts of data similar to Tier 1 Internet Service Provider (ISPs) (AGER et al., 2012). Chatzis et al. (CHATZIS et al., 2013a) report that one of the largest European IXPs can observe traffic from a large portion of the Internet, including 42K+ routed ASes, almost all 450K+ routed prefixes and around a quarter billion IP addresses from all the countries around the globe.

Richter et al. (RICHTER et al., 2014) point that the membership rates of ASes connecting to these infrastructures have a growth of 10-20% annually and a growth in traffic rates of 50-100% per year. Kotronis et al. (KOTRONIS et al., 2015) show that about 40% of IP prefixes advertised on the Internet can be reached directly from around 5 IXPs. Besides, despite the focus to deploy peering infrastructures in Europe and USA (CHATZIS et al., 2013b), studies reveal that developing regions as Latin America, and Africa are recently increasing the adoption of IXPs to enhance network performance (BRITO et al., 2016; FANOU; VALERA; DHAMDHERE, 2017).

The mentioned studies show that these infrastructures are becoming available worldwide and have a broad vision of the Internet. Thus, they present an potential opportunity for generating rich geolocation inferences and improve knowledge about the Internet topology.

3.2 Mapping of peering interconnections and infrastructures

Measuring and mapping the Internet at AS-level is valuable to understand the underneath structure of the topology. However, it considerably abstracts rich information about connectivity between networks at the Internet. Accurate knowledge of interconnection geolocation facilitates network troubleshooting, outage detection, and attack diagnosis. Recent efforts attempt to infer peering matrices (i.e., who peers with whom at which IXP) and map interconnections to physical locations where they occur.

Augustin et al. (AUGUSTIN; KRISHNAMURTHY; WILLINGER, 2009) proposes a method to detect IXPs, identify IXP-specific peering matrices and better understand the IXP substrate of the Internet's AS-level ecosystem. The mechanism detected 278 IXPs and discovered the existence of about 44K IXP-related peering links. However, the method has a very high cost of time and active measurements. Kotronis et al. (NOMIKOS; DIMITROPOULOS, 2016) extend the traceroute tool with the capability of inferring if and where an IXP was crossed. Results show that approximately one out of five paths crosses an IXP and that IXP-paths usually cross no more than a single IXP.

Giotsas et al. (GIOTSAS et al., 2015) propose an algorithm to infer the physical interconnection facility where an interconnection occurs among all possible candidates. The methodology provides accurate results but is unable to scale to large scenarios involving several colocation facilities, IXPs and ASes, given a large amount of active probing resources needed. The initial process of mapping networks and IXPs to facilities, required by the methodology, is manual and time-consuming to be developed/updated.

3.3 Mapping of topology elements

The geolocation of network elements, mainly mapping the IP addresses of routers to physical locations with precision is a crucial task. Precise knowledge of router geolocation helps to detect BGP threats, estimate the geographic presence of ASes and customize content delivery. It is possible to geolocate IP addresses through public or commercial databases, delay-based or DNS-based methods.

Gharaibeh et al. (GHARAIBEH et al., 2017) compare router geolocation coverage and reliability in four popular geolocation databases. The authors show that despite having a high coverage at country-level, databases are not accurate in geolocating routers at neither country- nor city-level, even if they agree significantly among each other. The work of Huffaker et al. (HUFFAKER; FOMENKOV; CLAFFY, 2014) and Scheitle et al. (SCHEITLE et al., 2017) propose methods to geolocate routers based on geography-related strings in hostnames and validate the results with active measurements from different decentralized probes. Despite showing accurate results, the scope of both proposals is restricted since only a small subset of routers have apparent geographic hints in their DNS names.

The work mentioned in the two previous subsections (3.2 and 3.3) shows vast potential and opportunity to improve the generation of geolocation inferences. Current solutions either rely on a large number of active measurements and decentralized probes to be able to achieve accurate results or provide rich inferences for just a subset of topology elements.

4 PROPOSED WORK

Based on studies on the characteristics of Internet Exchange Points, it is shown that they are promising candidates for the emergence of new solutions involving Internet mapping. Their central roles in topology enable higher visibility and knowledge about the network, showing potential in generating geolocation inferences.

This Ph.D. work plan seeks to investigate new techniques to explore IXPs as anchors to improve the Internet mapping and generate geolocation inferences of peering interconnections and topology elements. Our goal is to develop a precise and systematic approach to increase geolocation knowledge while making it scalable, automatized, without incurring significant processing and networing overhead and examine the accuracy of using these infrastructures as vantage points. We plan to produce a methodology that can be used by academia and industry for the development of new researches and by network operators to apply to practical situations. Such solution will combine different sources of public information as targeted traceroutes and BGP information. We plan to explore current relationships with the two largest IXPs in Brazil (IX-SP and IX-RS) to deploy and validate our methodology.

First, we aim to enhance geolocation inferences in developing regions such as Latin America, which show rich, but weakly examined, peering infrastructures (IX..., 2018; BRITO et al., 2016). Next, we aim to extend our methodology to other worldwide available IXPs and develop a better understanding of the geolocation characteristics of these infrastructures in the Internet Topology.

Research Questions. In this work, we aim to answer the following research questions: can IXPs be used as vantage points to generate geolocation inferences about peering interconnections and Internet topology? Which and how many are necessary to have a precise vision of the Internet? What are the implications of using this approach concerning computational cost, network traffic, and privacy? How can new data sources improve the Internet mapping? Is it possible to be precise using less information than related work? How is it possible to measure in a scalable and automatized way?

Risks and limitations. There are a few challenges and risks in the proposed research. Due to the low representation of existing measurement projects in developing areas (e.g., Latin America), there could be gaps in infrastructure and methodologies which could affect our geolocation inferences. We could face performance problems as IXPs not being good vantage points (VP) to improve Internet mapping or providing inaccurate results when using few IXPs given that their visibility, individually, may not perfect. Besides that, we could also face bureaucratic challenges as IXPs could not see a clear advantage of being used as VPs.

5 METHODOLOGY

In this chapter, we present the methodology, schedule, and collaboration of the proposed work. First, we outline the main steps needed to develop the research described in this plan (Section 5.1). Next, in Section 5.2, we detail a proposed schedule for the entire Ph.D. period, composed of actions and their expected duration. Finally, we conclude describing the intended collaboration with one of the leading research groups in the topic of the Ph.D. plan (Section 5.3).

5.1 Steps

1. **Monitoring and study of state-of-the-art**: we will perform an in-depth state-of-the-art study and monitoring of themes related to the work during all the duration of the Ph.D. Also, in the initial period of the course, we will conduct a detailed examination and reproduction of the main related existing methodologies.
2. **Methodology modeling**: in this step, we will develop a systematic methodology using IXPs as vantage points to map and produce geolocation inferences, seeking to answer the proposed research questions. Also at this stage, we will analyze the potential data to be used and design the data collection campaigns and data preparation.
3. **Data collection**: in this phase, we will perform the data collection designed in the previous step. At this stage, we will execute active measurements campaigns and collect data already available from different sources. We will employ targeted traceroutes performed by IXPs as anchors at scale and correlate with BGP information. In order to improve our measurements, we will also leverage other vantage points as RIPE Atlas (RIPE. . . , 2018), Looking Glass (Periscope (GIOTSAS; DHAMDHERE; CLAFFY, 2016)) and CAIDA Ark (CAIDA. . . , 2018). To obtain information about peering infrastructures, we will use datasets as PeeringDB (PEERINGDB. . . , 2018), PCH (PACKET. . . , 2018), Inflect (INFLECT. . . , 2018), IXP, ASes, and Network Operating Centers (NOCs) websites and lists provided in regional consortia of IXPs.
4. **Data preparation**: in this point, the collected data will be preprocessed and prepared, including the combination of data from different sources, to serve as input

for the proposed methodology. The collection of control plane information (BGP) and measurements campaigns tends to generate a significant amount of data. In order to process all data efficiently and without imposing resource and performance overheads to the IXP, we plan to use cloud environments (e.g., Azure) capable of dealing with a massive volume of data.

5. **Methodology evaluation**: in this step, we will use de collected and preprocessed data to evaluate and validate the effectiveness of the developed methodology, identifying its features and limitations.
6. **Methodology validation**: the final step of the study, we will validate the obtained results of the proposed methodology. For the validation, we plan to contact network operators and IXPs, use privileged data from inside the IXPs as flow samples, make use of ground-truth datasets and include other sources of information to improve the verification of our results.

5.2 Proposed schedule

1. In-depth state-of-the-art study and monitoring about themes related with thesis;
2. Development of a systematic methodology using IXPs as vantage points to map and produce geolocation inferences;
3. Qualification Exam;
4. Examination of proficiency in English;
5. Examination of proficiency in a foreign language;
6. Data collection and preprocessing
7. Period reserved for doctorate sandwich;
8. Evaluation, review and reassessment of the proposed methodology;
9. Validation the obtained results of the proposed methodology;
10. Thesis Proposal Defense;
11. Improvement of the methodology considering the results obtained in previous activities, also considering contributions and recommendations of the evaluation committee of the thesis proposal;
12. Thesis writing;
13. Thesis defense;
14. Participation in conferences and symposia related to the theme of the thesis;
15. Writing and submitting articles for conferences and periodicals based on the results obtained during the studies and evaluations, related to the theme of this doctoral proposal.

5.3 Collaboration

The proposed Ph.D. is joint work with the University of California San Diego (UCSD). The collaboration aims to expand the existing relationship between both universities and presents the opportunity for a sandwich doctorate. The second year of Ph.D. is expected to be located at CAIDA/UCSD. The funding for the away period is yet to be determined.

Table 5.1: Schedule of activities during the Ph.D. period

Activities	2019/1	2019/2	2020/1	2020/2	2021/1	2021/2	2022/1	2022/2
1	■	■	■	■	■	■	■	■
2		■	■					
3		■						
4		■						
5		■						
6		■	■					
7			■	■				
8			■	■				
9				■	■			
10				■				
11					■	■		
12				■	■	■	■	
13								■
14	■	■	■	■	■	■	■	■
15	■	■	■	■	■	■	■	■

6 EXPECTED RESULTS

In this chapter, we present the expected results of the Ph.D. First, we describe the main contributions of the proposed work in Section 6.1. Finally, in Section 6.2, we present some of the leading journals (Table 6.1) in which the results obtained during the doctorate can be published and some of the main conferences related to the research areas involved in this plan (Table 6.2).

6.1 Main Contributions of the Thesis

The following contributions are expected with the development of the proposed work:

1. Analysis of the potential of Internet Exchange Points to be used as scalable vantage points to map and generate geolocation inferences, as well as its strengths and limitations;
2. Formalization of a methodology to improve the mapping of peering interconnections by exploiting the characteristics of the Internet Exchange Points, introducing new datasets and scalability;
3. Development of a prototype of the proposed methodology, allowing its applicability in practical situations and the development of new researches.

It is also expected that during the development of this work there will be the participation of master and scientific initiation students, performing work related to the doctoral thesis proposed in this plan. The participation in the training of these student's knowledge is then considered as one of the possible contributions.

6.2 Publications

The development of Ph.D. activities will generate results which will be used as a basis for the writing of articles for journals and congresses. Table 6.1 presents some of the main journals in which the results obtained during the doctorate can be published, while Table 6.2 presents some of the leading conferences of the research areas involved in this plan.

Table 6.1: Journals related to Ph.D.

Journal	Impact Factor	Qualis
Communications of the ACM	4.027	A1
IEEE/ACM Transactions on Networking	3.376	A1
Elsevier Computer Networks	2.516	A1
ACM CCR	2.008	B1

Table 6.2: Conferences related to Ph.D.

Conference	Acceptance Rate	H-index	Qualis 2016
ACM Internet Measurements (IMC) Conference	24.7%	75	A1
Network Traffic Measurement and Analysis Conference (TMA)	39.2%	–	–
Passive and Active Network Measurement Conference (PAM)	40.8%	–	A2
ACM Special Interest Group on Data Communication (SIGCOMM) Conference	18%	67	A1
ACM International Conference on emerging Networking EXperiments and Technologies(CoNEXT)	17.2%	35	A1
IEEE Conference on Computer Communications (INFOCOM)	20.9%	80	A1
USENIX Symposium on Networked Systems Design and Implementation (NSDI)	15.4%	62	A1

7 COURSEWORK

This chapter presents the expected coursework to be taken in PhD course. Table 7.1 shows the courses and the number of credits that will be taken during the PhD. All courses sums a total of 20 credits, agreeing with the minimum required for the PhD.

Table 7.1: Courses to be taken in PhD

Code	**Period**	**Period**	**Credits**
CMP410	Teaching Practice I	2019/1	1
CMP230	Computer System Security	2019/1	4
CMP182	Computer Network	2019/1	4
CMP411	Teaching Practice II	2019/2	1
CMP267	Novel Internet Architectures and Paradigms	2019/2	4
CMP223	Computer System Performance Analysis	2019/2	4
CMP600	Qualification Exam	2019/2	2

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