The Internet: A System of Interconnected Autonomous Systems

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***Abstract*—The Internet, a global system of interconnected networks, has already become a de-facto utility serving billions of people worldwide. Individuals, companies, educational institutions and government agencies use the Internet for communication, entertainment, marketing, administration, collaboration and citizen participation. On the other hand, the Internet is a highly engineered, globally scaled, complex system formed by tens of thousands of autonomous networks operating independently. In this study, we first present a taxonomy of autonomous systems (ASes) which is definite and compatible with the current AS-level structure of the Internet. Then, we analyze different classes of ASes to shed light on the complex structure of the Internet. We believe that our approach and findings will help telecom practitioners gain more insight into the structural and operational characteristics of the Internet and enhance their network infrastructures.**

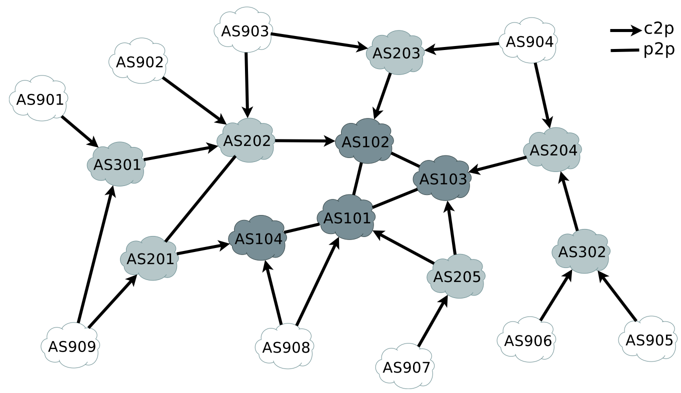

Fig. 1: A simplified example of the AS-level Internet topology

I. Introduction

The Internet, a global system of interconnected networks, is a highly engineered, large scale complex system which has no central governance. The communication infrastructure is formed by tens of thousands of autonomous systems bringing various organizations and individuals together. An *Autonomous System (AS)* in the Internet corresponds to a group of networks administered by one or more network operators with a well defined routing policy [11]. Each AS in the Internet is uniquely identified by an autonomous system number. The ASes altogether, enable the global Internet communication by connecting with each other in different forms. Individual users, small businesses and ASes located at the edge of the Internet participate in the global infrastructure by means of other ASes called Internet Service Providers (ISPs). Typically, ISPs are business entities providing Internet access service to their customers while getting the same service from one or more upstream ISPs. At the core of the Internet, a small number of ISPs peer with each other with settlement-free interconnections and attain the "global" communication infrastructure.

The majority of the the ASes (around 85%) are located at the edge of the Internet and they are solely Internet access consumers. That is, they pay to ISPs to acquire global Internet access. Note that these ASes may be content or service providers, yet they are consumers in terms of the Internet access service. The ASes forming the communication infrastructure however, are Internet access consumers and providers, simultaneously.

Internet access service is provided and consumed with respect to business relations among ASes. That is, ASes are connected to each other via business relations that define Internet access services. Moreover, the inter-AS traffic in the Internet is usually routed according to the business relations among ASes [16]. Therefore, analyzing the business relations among ASes helps us to understand the complex communication infrastructure of the Internet at the AS level.

Traditionally, business relations are categorized as customer-to-provider (c2p), peer-to-peer (p2p) and sibling-to-sibling (s2s) [8]. In a c2p relation, the provider AS provides global reachability to its customer AS. In return, the customer pays to the provider for the traffic exchanged between them. In a p2p relation, two peer ASes provide mutual reachability to each other and their customer ASes, recursively. Peer ASes typically engage in settlement-free business agreements which means that neither party pays to the other for the traffic exchanged. In the less frequently observed s2s relation, two ASes provide full reachability to each other because they are operated by the same organization. More complex relations such as hybrid relations and partial relations are reported in the Internet as well [9]. However, c2p and p2p relations abstract the majority of the business agreements between ASes for practical purposes [16].

Figure 1 shows an overly simplified example of the Internet topology at the AS-level for illustration purposes. The topology in the figure consists of 20 ASes and 26 links representing the relations between the ASes. In reality, the Internet is compromised of tens of thousands of ASes and hundreds of thousands of links between them. In the Figure, the clouds represent ASes. The ASes that are located at the edge of the Internet are shown in white. The ASes that provide Internet access to its customers and peers by transiting their traffic are

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shown in gray. The ASes forming the core of the topology and facilitate global reachability are shown in dark gray. Finally, arrows indicate c2p relations and lines represent p2p relations among ASes, respectively. The preferred AS Paths in the Internet are usually consistent with the relations among the ASes. In general, an AS path consists of zero or more c2p links (upstream) followed by zero or one peer link and then, followed by zero or more c2p links (downstream) [8]. For example $\{AS906, AS302, AS905\}$, in Figure 1, is a path from $AS906$ to $AS905$ which passes through a common provider appearing on both upstream and downstream subpaths. Similarly, $\{AS908, AS101, AS103, AS204, AS302, AS905\}$ is a path from $AS908$ to $AS905$. The upstream subpath from the source AS, $AS908$, reaches to a core AS, $AS101$, then takes a peer link to another core AS, $AS103$, and then follows a downstream subpath toward the destination AS, $AS905$. In practice, ASes do not always choose the paths that follow an upstream subpath to the core of the topology and then follow a downstream subpath from the core. However, *the availability of the paths passing through the core of the Internet provides the necessary foundations for the global Internet reachability*.

In this study, we first present a taxonomy of ASes which is definite and compatible with the current AS-level structure of the Internet. Our taxonomy loosely borrows the terms from geometry and is based on the relations in an AS-level Internet topology map. We classify the ASes into four groups according to their neighboring relations in the topology map: *axial ASes*, *pole ASes*, *medial ASes* and *locus ASes*.

Axial ASes constitute the core of the semi-hierarchical Internet infrastructure by peering with one another. In Figure 1, the dark gray ASes, $AS101$, $AS102$, $AS103$ and $AS104$, are the axial ASes. *Pole ASes* are those axial ASes which participate in the largest clique of peers at the core. In Figure 1, the axial ASes $AS101$, $AS102$ and $AS103$ constitute the set of pole ASes. *Medial ASes* have at least one customer AS and one provider AS and they connect their customers to the Internet via their provider ASes. In Figure 1, the light gray ASes are the medial ASes. *Locus ASes* constitute the verge of the Internet infrastructure by participating in the Internet via their providers. In Figure 1, white ASes are the locus ASes.

Next, we analyze each class of ASes to shed light on the structure of the Internet at the autonomous system level. We found that the majority of ASes that belong to governments and government-related organizations directly peer with ASes at the core of the Internet. Internet exchange points (IXPs) and datacenters prefer to peer with ASes at the core of the Internet as well as medium to large scale ISPs. Large scale Internet Service Providers are located closer to the pole ASes in the Internet and they practice peering more frequently compared to the ASes located farther. Moreover, we observed that peering is a more common practice in ISPs that are associated with the economically developed countries. Finally, our findings show that locus ASes exhibit diversity in terms of their average closeness to the core of the Internet with respect to their associated countries.

We believe that our approach and findings will help telecom practitioners gain more insight into the structural and operational characteristics of the Internet and enhance their network infrastructures.

The rest of the paper is organized as follows. Section II presents the related work. In Section III, we present a classification of ASes based on their relations in an AS-level Internet topology map. In Section IV, we introduce the dataset used in this study. Sections V, VI and VII present detailed analyses on axial, medial and locus ASes in the Internet, respectively. Finally, Section VIII concludes the paper.

II. Related Work

Many successful studies on AS relation inference and AS-level Internet topology mapping have been introduced in the last two decades [5], [6], [16], [18].

AS topology mapping and inference techniques can be categorized according to the employed source(s). Path trace based approaches use `traceroute`-like tools [1], [21] to collect path traces from multiple vantage points and employ IP address to AS number mapping techniques to build the links between ASes [3], [17], [7]. BGP routing table based approaches passively collect BGP updates and use the advertised paths to construct an AS-level topology map of the Internet [24], [23], [22]. Most of the studies in this category focus on not only mapping the Internet at the AS-level but also inferring the types of business relations between the ASes [8], [18], [9]. Internet Routing Registry (IRR) databases and BGP looking glasses (LG) are usually used to augment existing AS-level Internet topologies [12], [13].

In this study we analyze the Internet as a system of autonomous systems. Our work is complementary to existing efforts in the sense that we leverage Internet topology maps collected, constructed and annotated by the existing projects.

III. Taxonomy of ASes

Traditionally the ASes in the Internet are categorized as *stub ASes*, *transit ASes*, *tier-3 ASes*, *tier-2 ASes* and *tier-1 ASes*. Roughly, stub ASes correspond to the ASes at the edge of the Internet which have a single provider; transit ASes are the ISPs which relay the traffic between any two ASes; tier-3 ASes are small scale (typically regional) ISPs; tier-2 ASes are large scale (typically national) ISPs and tier-1 ASes are very large scale (typically intercontinental) ISPs which peer with each other at core of the Internet. A significant problem with the traditional taxonomy of ASes is that the exact definitions of AS categories exhibit variation in different studies, contain ambiguity, involve subjectiveness and sometimes do not match the reality [20]. For example, ISPs that serve their coverage area only through settlement-free business relations are called *tier-1 ASes*. Another definition requires those ISPs to participate in the largest settlement-free clique in order to be called *tier-1 ASes*. Definitions of *tier-2* and *tier-3* ASes are ambiguous. On the same note, a *stub AS* is defined as an AS that has a single upstream provider without any customers. However, an AS in the Internet is required to have at least two upstream providers. In fact, unadvertised backup links causes the *stub ASes* to look like single-homed ASes in the Internet topology graphs.

In this study, we first present a taxonomy of ASes which is definite, regular and compatible with the current AS-level structure of the Internet. Our taxonomy loosely borrows the

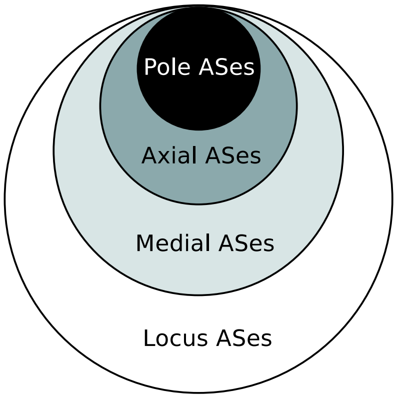


Fig. 2: Taxonomy of ASes in the Internet

terms from geometry and is based on the relations in an AS-level Internet topology map. We classify the ASes in an AS-level Internet topology map into four groups according to their neighboring relations: *axial ASes*, *pole ASes*, *medial ASes* and *locus ASes*.

Axial ASes are these ASes that do not have any providers. Axial ASes constitute the core of the semi-hierarchical Internet infrastructure by peering with one another. Although axial ASes do not have providers, they may have one or more customer ASes. Axial ASes are typically large scale Internet service providers, Internet exchange points, datacenters as well as the networks of government-related institutions. In Figure 1, the dark gray ASes, $AS101$, $AS102$, $AS103$ and $AS104$, are axial ASes because they do not have any providers.

Pole ASes are those axial ASes which participate in the largest clique of peers at the core of the Internet infrastructure. These ASes usually correspond to the Internet service providers which provide global connectivity to each other and to each other's non-clique peers and customers. Note that the set of pole ASes is a subset of the axial ASes. In Figure 1, the axial ASes $AS101$, $AS102$ and $AS103$ form the largest clique and they constitute the set of pole ASes.

Medial ASes are these ASes which have at least one provider AS and at least one customer AS. Medial ASes connect their customer ASes to the Internet via their providers. These ASes are usually national or regional Internet service providers that connect downstream ISPs/ASes to the Internet via upstream ISPs. Some of the medial ASes also provide Internet access to residential users and small businesses. They charge their customers for the traffic exchanged while paying to their providers for the same service. Note that medial ASes frequently peer with other ASes to reduce their overall cost of operations. In Figure 1, the light gray ASes are medial ASes because they have at least one provider and one customer AS.

Locus ASes are these ASes which have at least one provider AS and do not have any customer AS. In general, locus ASes are networks that belong to individual organizations or they are local ISPs providing Internet connectivity to residential users and small businesses. Since they do not provide Internet access to other ASes, they are visualized at the verge of an Internet topology map. Although observed less frequently, some locus ASes peer with each other. These peering locus ASes are usually part of the same organization operating at different geographic regions, e.g, financial institutions. In Figure 1, white ASes are locus ASes because they have at least one provider and no customer AS.

Figure 2 summarizes the taxonomy of ASes. Ordinarily, the pole ASes form the nucleus of the semi-hierarchical Internet topology map while the rest of the axial ASes form the core. The medial ASes constitute the interior part and the locus ASes form the verge the Internet topology map as shown in Figure 2. The intersecting boundaries at the top of the figure reflect the fact that ASes in different groups may connect with each other without any restrictions. For example, a medial, axial or pole AS can be the provider of a locus AS.

IV. Preliminaries

The AS-relations dataset [2] and AS-to-organization mapping dataset [4] used in this study are collected in June, 2015 from CAIDA and CIDR-Report, respectively. CAIDA constructs AS-level Internet topology maps using passively collected BGP data from UO routeviews project [24] and RIPE remote route collectors [19]. CIDR-Report compiles AS-to-organization mapping information from national and regional Internet registries. The AS-to-country mappings reflect the countries that the ASes operate in. These mappings are mostly accurate for the ASes located at the edge of the Internet and for the regional ISPs. However, large scale ISPs usually have international components and operate at multiple countries.

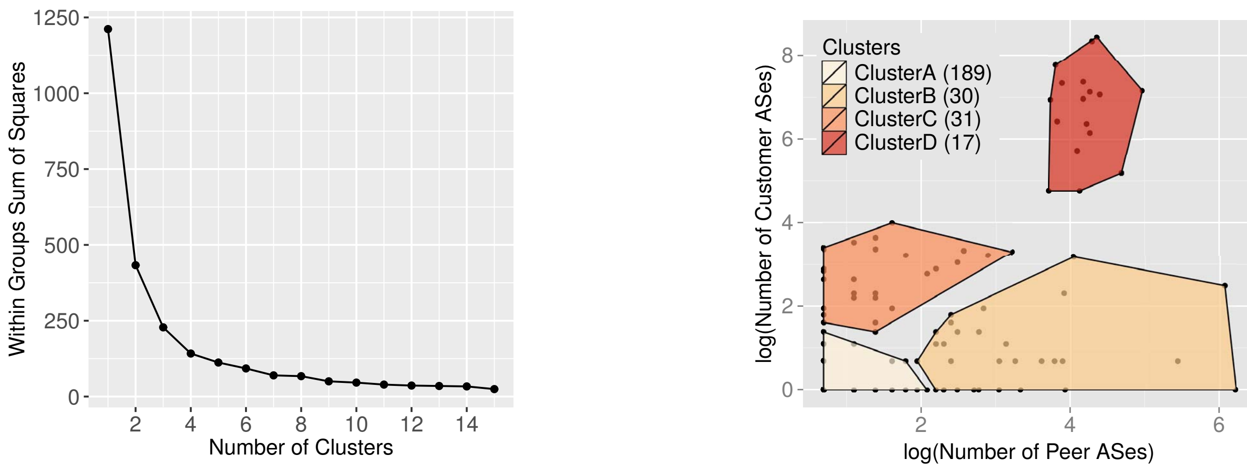
TABLE I: Distribution of ASes w.r.t. different classes

Pole ASes	Axial ASes	Medial Ases	Locus ASes
17	267	7593	43033

Our original dataset consists of 50,966 ASes in total. Out of 50966 ASes, we omitted 73 locus ASes because their associated country records were missing. In this study we analyzed 50893 ASes comprising of 17 pole, 267 axial, 7593 medial and 43033 locus ASes associated with 229 distinct country codes (Table I). The verge of the Internet topology consists of 43033 locus ASes which make up its largest portion. 7593 medial ASes provide Internet access to each other and to the locus ASes. 267 axial ASes fasten the medial and locus ASes together. Finally, 17 pole ASes establish the global connectivity among all ASes.

Since the axial ASes including the pole ASes usually have international components, we analyzed the distributions of the medial and locus ASes by their associated countries. Both distributions are highly skewed in the sense that there are many countries with a low number of medial and/or locus ASes and fewer countries with a high number of medial and/or locus ASes. The positive skewness in the AS distribution by country is an expected outcome because the number of ASes in a country depends on many factors including the population, dispersion, economic development, economic diversity, IT/education investments and political systems.

Table II shows the minimum, first quartile, median, mean, third quartile and maximum for locus and medial ASes by countries, respectively. Although the minimum number of



(a) Scree Plot

(b) Clusters

Fig. 3: Axial AS sum of squared errors scree plot and clusters

TABLE II: Summary Statistics for Locus and Medial ASes w.r.t. countries

	Min	Q1	Median	Mean	Q3	Max
Locus	0	3	10	187.90	74	13810
Medial	0	1	4	33.16	17	1702

locus and medial ASes are zero, each country in our dataset has at least one AS. 22 countries in our dataset is connected to the Internet through only one AS (either locus or medial). The majority of these countries are small island countries that have some type of political dependency to other countries while some of them are either economically underdeveloped and/or politically instable. Besides, there are 101 countries that have less than 10 ASes in total.

TABLE III: Top 7 countries

Country	**Locus AS Count**	**Medial AS Count**
U.S.A.	13810	1702
Russia	3667	859
Brazil	2387	560
Poland	1485	258
Ukraine	1323	339
Greater Britain	1288	256
Germany	1182	252

Table III shows the top seven countries by the number of locus and medial ASes. In the table two Eastern European countries, Poland and Ukraine, find places among other economically more developed countries. It is known that both countries have significantly invested in their national Internet backbones. Besides, both countries are hosts to medium to large sized Internet exchange points. Lastly, having non-strict governmental regulations enables opportunities in telecommunication business in these countries.

In the following we analyze each group of ASes (axial, pole, medial and locus ASes) forming the global AS-level topology map of the Internet.

V. Analysis of Axial and Pole ASes

Axial ASes are those ASes that do not have any providers, i.e., they attain global Internet access through peering. There are 267 axial ASes in our dataset.

Analysis of these axial ASes shows that not all of them share the same characteristics in terms of the number of peers and customers. In fact, the sum of squared errors scree plot (Figure 3a) suggests that the axial ASes display four distinct clusters. Figure 3b visualizes the four clusters of axial ASes (computed by k-means clustering) based on the number of peers and customers at logarithmic scales. In the figure *clusterA*, *clusterB*, *clusterC* and *clusterD* consist of 189, 30, 31 and 17 ASes, respectively. Note that the points in *clusterA* highly overlap in the figure because most of the ASes in this cluster have the same number of peers and customers.

The axial ASes in *clusterA* have either none or a few customers. Besides, these ASes peer only with a few ASes at the core of the Internet infrastructure. Further analysis of *clusterA* shows that these ASes mostly belong to governments and government-related organizations such as military, research centers, academic institutions and national telecommunication institutions. These networks provide direct Internet access to government institutions rather than the residential users or enterprises. The strategic importance of such institutions justifies them having direct Internet accesses at the core. We believe that many of the ASes in this group engage in paid peering rather than settlement-free peering since the large scale ISPs do not economically benefit from these kind of peerings.

The axial ASes in *clusterB* have either none or a few customers while peering with many ASes at the core. Analyzing these ASes shows that they belong to large scale Internet exchange points (IXPs) and datacenters. Datacenters are centralized repositories providing storage, management

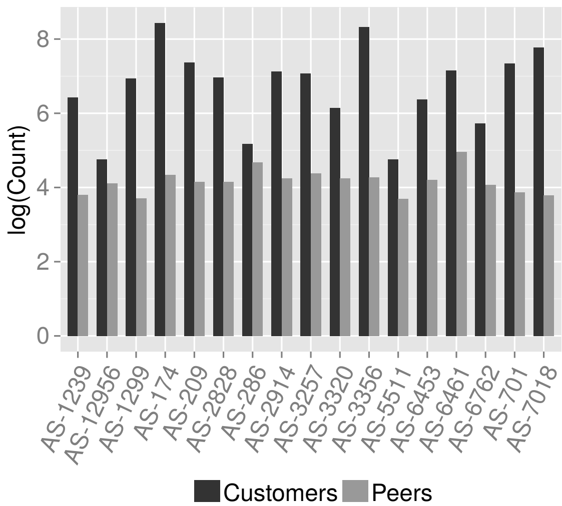


Fig. 4: Pole ASes by the number of customers and peers

and dissemination of large volumes of data, therefore, it is natural for them to have a higher number of peers. However, discovering large scale IXPs peering with many ASes was surprising because IXPs are establishments that enable cost effective peerings for ISPs. Through personal communication, we were able to attribute the peering structure of IXPs to the optional BGP route service provided by route servers at IXPs. Route servers facilitate and simplify prefix exchanges between the members of IXPs and require the participating members to peer with the IXPs' route servers via BGP. Although BGP route servers peer with other ASes, they do not exchange any traffic. Route servers only exchange routing advertisements. Finally, some IXPs peer to provide their customers with value-added services such as caching and content delivery as long as these services do not conflict with the services provided by their members.

The axial ASes in *clusterC* have a small number of peers and relatively more customers. We found that the majority of these ASes are either government-related umbrella organizations that have multiple subsidiaries, e.g., university systems, small sized Internet exchange points or Internet service providers (ISPs) that provide value-added services, e.g., web hosting and video streaming, in addition to the Internet access service. The umbrella organization ASes are providers to the ASes of their subsidiaries and the ISPs in this group provide value-added services to their customers.

The axial ASes forming the largest clique by peering are called pole ASes. The pole ASes in *clusterD* establish the global connectivity among all ASes. Our analysis show that the pole ASes, as a matter of fact, exhibit a natural cutoff in our dataset by having a high number of peers and a high number of customers (Figure 3b).

Figure 4 shows the number of customers and peers in logarithmic scale for 17 pole ASes that we found in our dataset. Although the pole ASes have many customers and peers, the figure does not suggest any correlation among them.

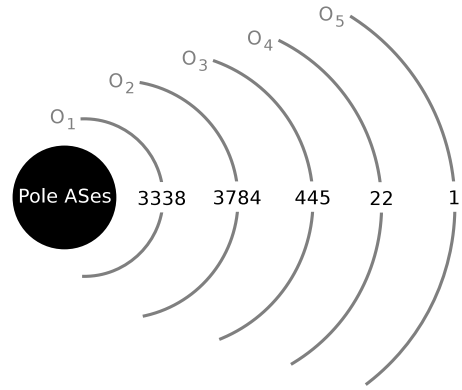


Fig. 5: Medial AS distribution by orbits

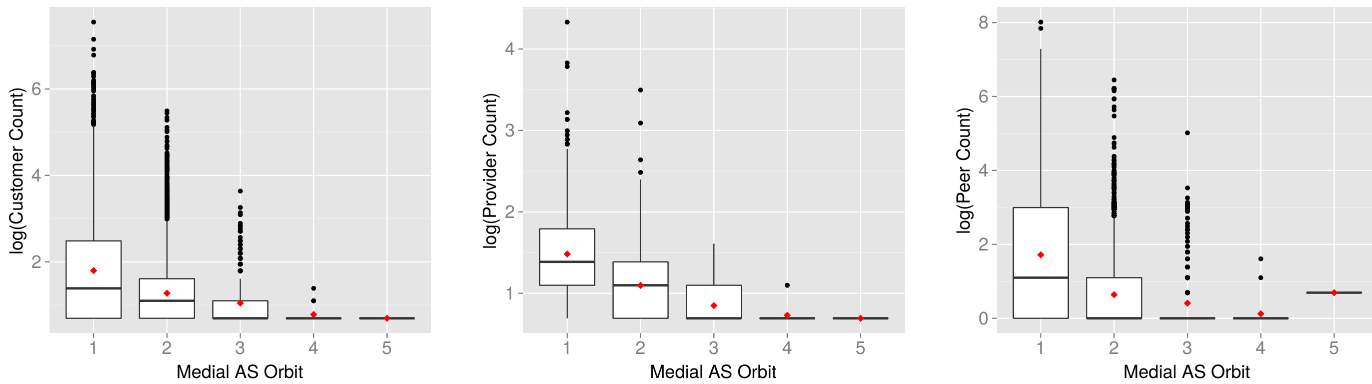
VI. Analysis of Medial ASes

Medial ASes are those ASes that have at least one customer and one provider ASes. Medial ASes enable the Internet access for their customers by connecting them to the rest of the network through their provider(s). In this section we, first, analyze the distances of medial ASes to the pole ASes; then, we look at the neighboring relations of the medial ASes with respect to the distances; and lastly, we investigate peering as a practice of networking in different countries.

We introduce *orbit* as a measure to analyze the medial ASes. The orbit of a medial AS is the length of the shortest AS path(s) that consists of only c2p links from the medial AS to any pole AS. The orbit of a medial AS is roughly its hop distance to the closest pole AS. Figure 5 shows the distribution of the orbits of the medial ASes in our dataset. In the figure, around 44% of the medial ASes are located on the first orbit, i.e., at least one of their providers is a pole AS. Almost 50% of the medial ASes are located in the second orbit, i.e., they can reach to a pole AS via one provider. Around 6% of them are located on the third and fourth orbits and only one medial AS is located on the fifth orbit.

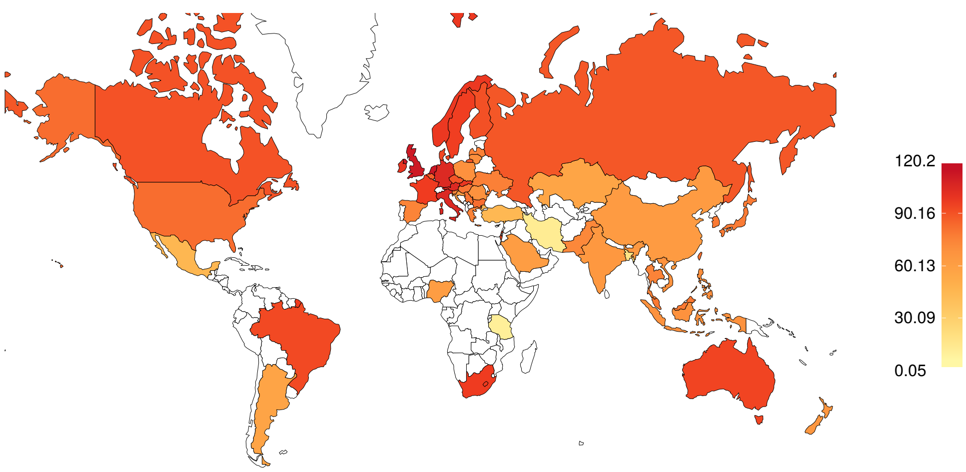
In addition, Figure 6 shows the number of customers, providers and peers of medial ASes with respect to their orbits. In the figure the distributions are visually different from each other and the number of customers, providers and peers decrease as one goes from an inner orbit toward an outer orbit. Kruskal-Wallis rank sum tests result in extremely small p-values suggesting that the differences between the distributions of customers, providers and peers with respect to the orbits of the medial ASes are statistically significant. The orbits reflect the fact that the smaller ISPs (in terms of the number of customers, providers and peers) are located at the outskirts of the Internet and larger ISPs are closer to the pole ASes.

Medial ASes occasionally peer among each other and sometimes peer with other axial ASes. Peering provides the medial ASes with two advantageous. First, the length of AS paths is reduced among the peers and their customers because the traffic takes the shortcut peer links instead of going all the way up from the source to the pole ASes and then down to the destination via provider ASes. Second, through peering medial ASes usually exchange traffic for free instead of paying to their immediate provider ASes on upstream and downstream paths.



(a) Customers (b) Providers (c) Peers

Fig. 6: Medial AS customer, provider and peer distributions by orbits



Top 7 Countries

Country	Mean Peering
Switzerland	120.20
Netherlands	79.45
Great Britain	74.18
Italy	48.50
Germany	47.04
Austria	46.70
Hong Kong	36.18

Bottom 7 Countries

Country	Mean Peering
Kazakhstan	2.11
Mexico	1.02
Turkey	0.96
Bangladesh	0.18
Iran	0.12
Tanzania	0.11
Nepal	0.058

Fig. 7: Medial AS average peer count by country

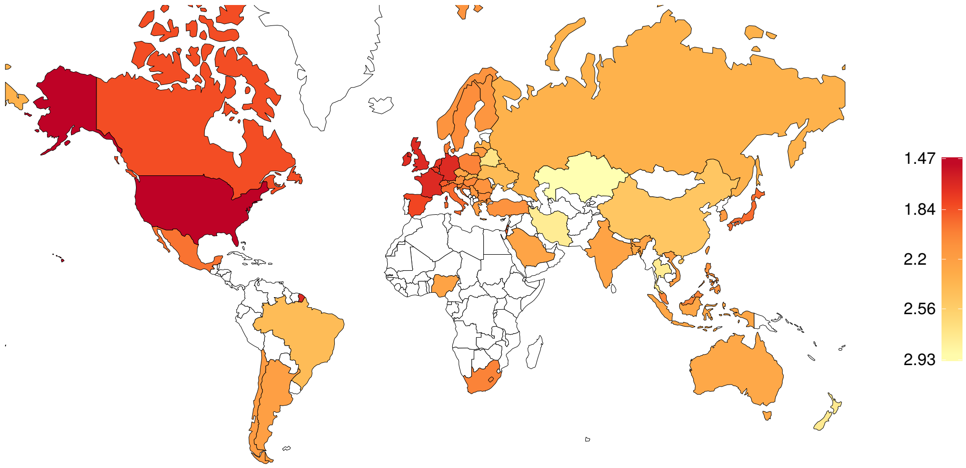
When we rank the countries by the total number of associated medial ASes, we see that the countries in the top 25% are associated with the 92% of all medial ASes. Figure 7 demonstrates that the medial ASes in the top 25% countries adopt peering, as a practice of networking, at different levels. The figure shows that peering is a more common practice in economically developed countries. Although the United States (1702), Russia (859) and Brazil (560) are the top three countries by the number of associated medial ASes, they were unable to make the top seven list by average peering. Brazil ranks 16 with 21.30 peers on the average, Russia ranks 21 with 17.06 peers on the average and the United States ranks 24 with 11.22 peers on the average. On the other hand, Switzerland, Netherlands and Great Britain placed in the top three while they have 64, 114 and 256 medial ASes, respectively.

VII. Analysis of Locus ASes

Locus ASes are those ASes that do not have a customer AS but have at least one provider AS. Locus ASes are typically networks that belong to organizations or small-sized, local ISPs providing Internet connectivity to residential users and small businesses.

The hop distance between two ASes has a direct impact on the overall traffic exchanged in the Internet as well as the service quality experienced by the end users. To illustrate, AS-level hop distances influence the overall traffic exchanged in P2P networks [15]. It is reported that AS-level hop distance has an impact on the network delay in the Internet [14]. Similarly, the closeness of locus ASes to content delivery networks affect the service quality in the Internet [10].

The availability of AS paths passing through the pole ASes provide the necessary foundations for the global Internet reachability. Therefore, the shortest path from a locus AS to a pole AS affects the performance of the entire system. Ideally, the closer a locus AS is to the pole, the better the overall performance is. We use the measure, *orbit*, that we introduced in Section VI to calculate the distance of a locus AS to the closest pole ASes. The length of the shortest AS path(s) that



Top 7 Countries

Country	Mean Distance
U.S.A.	1.47
Great Britain	1.64
France	1.65
Germany	1.65
Ireland	1.67
Netherlands	1.70
Belgium	1.74

Bottom 7 Countries

Country	Mean Distance
Brazil	2.41
China	2.50
Belarus	2.72
New Zealand	2.77
Thailand	2.77
Iran	2.78
Kazakhstan	2.93

Fig. 9: Locus AS average distance to a pole AS per country

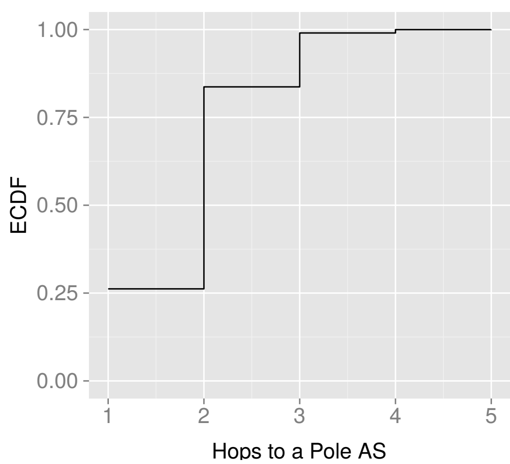


Fig. 8: Locus AS distribution by hop count to a pole AS

consists of only c2p links from a locus AS to any pole AS provides an upper bound for the closeness of the locus AS to other ASes in the Internet.

Figure 8 shows that 26% of locus ASes can reach to a pole AS by a single hop, i.e., they are directly connected to a pole AS, 57% have two hops distance to a pole AS, 15% have three hops distance and 2% have four or five hops to a pole AS where the overall average is 1.91 hops. The figure shows that the locus ASes in the Internet are very close to each other in terms of AS hop distances.

However, when we map the locus ASes to their associated countries we observe a diversity in the average hop distances of locus ASes to the pole ASes. Figure 9 demonstrates the average locus AS hop distance to a pole AS per country. The figure shows the top 25% of the countries in terms of the number of associated locus ASes. These countries accommodate 94% of all locus ASes in the Internet. The countries that have the shortest hop distance to the pole ASes are economically developed countries. Further analysis shows that many of the pole ASes are associated with the United States, Germany, Netherlands and France. Moreover, these countries accommodate many large sized IXPs which facilitate private peering among the pole ASes. Therefore, the locus ASes in these countries have shorter distances to the pole ASes and experience a better performance, on the average.

VIII. Conclusions

The Internet is a highly engineered, large scale complex system whitout a central governance. The global communication infrastructure is formed by tens of thousands of autonomous systems bringing various organizations and individuals together. These ASes enable the global Internet communication by connecting with each other in different forms.

In this study, we introduced a taxonomy of Autonomous Systems (ASes) which is definite and compatible with the current AS-level structure of the Internet. Then, we analyzed different classes of ASes to shed light on the complex structure of the Internet. We found that the majority of ASes that belong to governments and government-related organizations directly peer with ASes at the core of the Internet. Internet exchange points (IXPs) and datacenters prefer to peer with ASes at the core of the Internet as well as medium to large scale ISPs. Large scale Internet Service Providers are located closer to the pole ASes in the Internet and they practice peering more frequently compared to the ASes located farther. Moreover, we observed that peering is a more common practice in ISPs that are associated with the economically developed countries. Finally, our findings show that locus ASes exhibit diversity in terms of their average closeness to the core of the Internet with respect to their associated countries.

We believe that our approach and findings will help telecom practitioners gain more insight into the structural and operational characteristics of the Internet and enhance their network infrastructures.

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