On the Consolidation of the Internet Domain Name System

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***Abstract*— Several parts of society have expressed rising alarm about the Internet's consolidation in recent years. One of the critical concerns raised by this trend toward consolidation of infrastructure, traffic, users, and services is the concentration of many essential Internet resources among a small number of providers. Some consequences of such consolidation (single points of failure) were exposed in 2016 and 2019 in large-scale Distributed Denial of Service (DDoS) attacks on two DNS providers. In this paper, we study the Domain Name System (DNS) industry's consolidation in light of multiple country-code Top-Level Domains (ccTLDs) and generic top-level domains (gTLDs) by resolving and evaluating the authoritative name-servers (NS) for all domains in each TLD during five years. We show that, the Top 5 DNS providers account for more than 20% of all domains and, more shockingly, the Top 100 providers account for about 80% of the entire examined IPv4 domain namespace. We also reveal that domains in certain TLDs are highly concentrated in the hands of a few providers. For example, Estonia's (`.ee`) Top 5 providers will hold around 78% of the total TLD namespace in 2021. Additionally, we examine the domain concentration per TLD in terms of provider location origin. We notice a strong presence of local companies in Europe's top-level domains, emphasizing the Russian Federation.**

I. Introduction

In recent years, different segments of the society have expressed growing concerns with regard to the *consolidation* of the Internet [1]–[14]. One of the major worries about the concentration of *infrastructure*, *traffic*, *users*, and *services* relates to critical Internet resources being provided and controlled by a small number of players. This situation leads to severe risks [3] [4] to the Internet ecosystem, from both technical and sociopolitical standpoints. From the technical perspective, the centralization in the hands of few providers leads to a larger attack surface for malicious parties to exploit. From the sociopolitical perspective, in turn, centralized Internet services, social media, and advertisements create monopolies of information, which raises privacy concerns depending on the jurisprudence of each location [4].

Concrete consequences of the Internet centralization have been witnessed, for example, in the large-scale Distributed Denial of Services (DDoS) attacks against two authoritative DNS service providers, in 2016 [15] and 2019 [16]. In both events, portions of the DNS infrastructure became unreachable. Numerous websites, including Netflix, Twitter, Reddit, and the New York Times, were unavailable for several hours. The Dyn DNS infrastructure attack [15], in particular, exemplifies one of the main issues resulting from Internet centralization: infrastructure shared between websites and hosted by third parties can lead to sites that were not the target of the attack becoming unreachable as collateral damage.

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Because of the growing concerns over Internet consolidation, a number of research initiatives took place, observing diverse aspects of this issue. In terms of service centralization, for example, some researchers investigated how e-mail providers operate in the current Internet market [17]. In another front [18], researchers have investigated the centralization of the Internet hosting industry, in order to showcase how hosting providers are operating along the Internet and whether they are leading to further centralization. Other works [6] [19] [7], in turn, study how DNS traffic and infrastructure is distributed, aiming to asses the robustness of DNS.

In the current scenario of the Internet consolidation research, there is no work that has observed how the DNS industry is globally split among third-party providers, and how this industry landscape has evolved over time. Understanding this aspect of the DNS industry is a crucial step towards uncovering how resources are being controlled by stakeholders in the Internet ecosystem. Thus, in this paper, we examine the consolidation of the DNS industry by observing a set of 16 ccTLDs (including `.ca`, `.ru`, and `.nl`) and 3 generic TLDs (gTLDs) (*i.e.,* `.com`, `.org`, and `.net`). We resolve and analyze the authoritative nameservers (NS) for all domains in each TLD of our dataset, mapping each NS Autonomous System (AS) to its parent organization, allowing us to measure the market share of each DNS provider and assess the DNS consolidation. We also observe how such consolidation evolved over time by investigating the DNS market share of top providers over a 5-year window. To carry out our study, we look into a dataset extracted from the OpenIntel project [20]. OpenIntel hosts long-term data comprising of daily DNS measurements for all domains lying under the major TLDs of the Internet.

The remainder of the paper is organized as follows. In Section II, we present related work on measurements of different aspects of DNS consolidation. In Section III, we introduce the methodology employed in our research, while in Section IV, we detail the dataset retrieved from the OpenIntel. By analyzing such dataset we come up with a set of results that are presented and discussed in Section V. Those results reveal the market share of top DNS providers by year, TLD,

and origin location. Finally, in Section VI, we close the paper presenting concluding remarks and future work.

II. Related Work

Radu *et al.* [21] present a study of emerging consolidation trends in the recursive DNS services industry, with a focus on its evolution over the last decade and empirical evidence of the changes that occurred between 2016 and mid-2019. The analysis, based on active measurements from 100K users' mobile platforms and probes, revealed a reliance on public DNS resolvers in the first half of 2019, with more than 50% of DNS requests. Results also show that Google and Cloudflare have a large concentration of power, since they control half of the overall market. The outlook for DNS in browsers is similar, with the first company solidifying its position and restricting options for market entry and competition.

Moura *et al.* [6] provided an analysis of DNS traffic collected at a DNS root server and two ccTLDs (one in Europe and one in Oceania) that revealed concentration indicators: over 30% of all requests to both ccTLDs were made via five big cloud providers (Google, Amazon, Microsoft, Facebook, and Cloudflare). Unlike previous efforts, the authors highlighted one advantage of centralization: anytime the cloud provider improves its infrastructure, for example, in terms of security measures like QNAME minimization, a larger number of clients immediately benefit.

Kashaf *et al.* [7] looked into the prevalence and impact of third-party dependencies in three infrastructure services: DNS, CDNs, and CA certificate revocation checks. They looked at both direct dependency (*e.g.* from a website with a DNS provider) and indirect dependency (when a website uses a CDN which in turn also depends on a DNS provider). The authors discovered that 89% of Alexa's Top 100K websites rely on third-party DNS, CDN, or CA providers, meaning that if these third-party providers fail, these websites will face service disruption. The survey also reveals that third-party service usage is concentrated, with the top three CDN, DNS, and CA providers affecting between 50% to 70% of the Top 100K websites. It's worth noting that the authors use just NS record labels (*e.g.*, `dnsns1.example.com`) to measure concentration in their research of DNS dependencies. Because multiple nameservers can be employed on a single IP address, the analysis can mask possible cases of concentration.

Wang *et al.* [13] studied the consolidation of both DNS and Web hosting. The authors observed only top 10K domains of the Tranco list [22] and define whether each domain would be either affected or unreachable in the event of a DNS provider outage. A domain is classified as *affected* if at least one of the domain's name servers is hosted by an organization and that organization is down; an *unreachable* domain, in turn, is one where all of its name servers are hosted by the same organization and that organization is down. Results show that two companies (Amazon and Cloudflare) are solely responsible for hosting the name servers for almost 40% of the Tranco top 10K domains. They also showed that only five companies (Cloudflare, Amazon, Akamai, Fastly, and Google) host over 62% of the Tranco top 10K index pages, as well as the majority of external page resources for these sites.

Although aforementioned work advanced the knowledge about DNS centralization, these studies accounts for only a fraction of possible consolidation points in the Internet. For example, no prior study has provided analysis over a much larger number of domains (around 200M domains), as we do in this paper. Also, no comparison of centralization in different ccTLDs and gTLDs has been done so far. Additionally, different from previous works, we look at aspects of centralization by considering not only the current picture but also the historical behavior of it over the last 5 years. And finally, we break down the numbers to analyse concentration: *(i)* of top providers; *(ii)* providers' market share; *(iii)* concentration by each TLD; and *(iv)* by location characteristics.

III. Methodology

In order to have a large-scale analysis, we depend on large-scale DNS measurement data. Access to zone files is generally restricted and requires legal agreements with registry operators. Ultimately, this means that it is impractical to cover the entire global DNS namespace, particularly considering certain ccTLDs (e.g., `.cn`, `.de`). Yet, the OpenIntel project [20] stores DNS data from over 60% of the global DNS namespace. Every day, OpenIntel takes a snapshot of entire zone files and uses active querying to list the records defined under domain names. The data provided by OpenIntel includes zone files from gTLDs such as `.com`, `.net`, and `.org`, as well as 16 ccTLDs for many continents (such as `.ru`). OpenIntel also covers almost all new gTLDs available through ICANN's Centralized Zone Data Service (such as `.example`), which currently accounts for around 1200 new gTLDs. For each domain, OpenIntel gathers the NS [23] records as well as IPv4 and IPv6 addresses (defined as A [24] and AAAA [25] records, respectively) associated with each NS record. For example, the domain `www.google.com` has `ns1.google.com` as `NS` record, which, in turn, has `216.239.32.10` as A record and `2001:4860:4802:32::a` as AAAA record.

We enriched the data queried from OpenIntel by mapping the IP addresses (A/AAAA records) associated with each domain's NS records to the Autonomous Systems (ASes) that announce these addresses using CAIDA prefix-to-AS data [26]. Also, we use AS-to-organization data [27] to map AS numbers to organizations and countries. Finally, we map country-codes to one or more official languages using a country and languages dataset [28].

There are some limitation in our methodology. *Parked domains:* A parked domain is one that has been registered but is not linked to an online service such as a website or email hosting. In other words, it's a domain name that was purchased but isn't currently in use. It is instead "parked" for later use. We still consider the infrastructure where the website is apparently hosted if a domain name links to a non-responsive, parked, or redirecting website; defining this typology of websites is left for future work.

IV. Datasets

We queried OpenIntel for historical data from a five-year period (2017–2021), which allow us to track the growth (or decrease) of the DNS industry concentration. To that end, we defined a specific date (September 1st) as an anchor point to run our queries for every year. Table I summarizes the dataset, when considering all TLDs aggregated together. The resulting dataset contains 11–19 TLDs, depending on which year its measurements for the TLD started, which collectively encompasses 147–181 million domains resolved by 2.4M–2.8M (IPv4) NSes and roughly 365k IPv6 NSes. These are served by around 26k ASes using IPv4 and 4.5k ASes using IPv6.

Year	TLDs	Domains	NS(v4)	NS(v6)	ASes(v4)	ASes(v6)
2017	11	147.38M	2.84M	364.99k	26.33k	4.11k
2018	13	154.48M	2.68M	331.34k	26.24k	4.37k
2019	14	161.52M	2.41M	214.26k	26.01k	4.54k
2020	17	173.09M	2.44M	244.23k	25.81k	4.74k
2021	19	181.86M	2.42M	242.99k	25.49k	4.93k

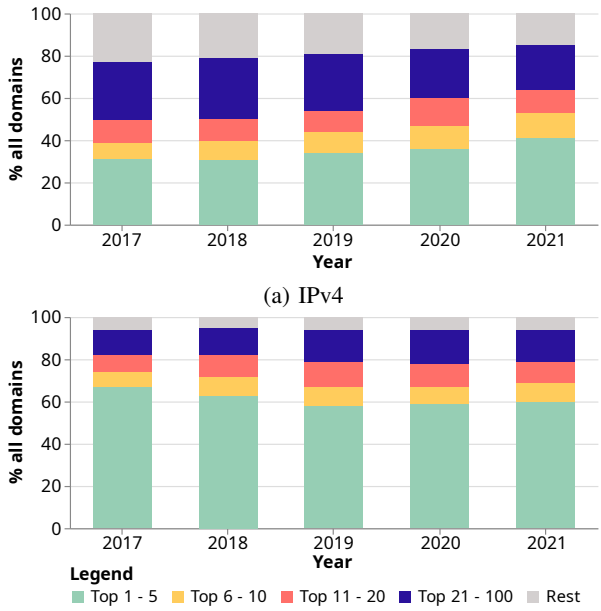
Table I: Aggregated datasets, measured on Sep 1st of each year.

V. Results

Using the datasets previously described, we performed a series of analyses to uncover if the DNS industry presents any consolidation and to what extent. We first analyze our dataset of aggregated TLDs, splitting them by year, aiming to identify whether there has been a concentration of domain names by specific DNS providers over time. This way, we have a more general and uniform view of the analyzed domain scope. Similarly, next, we investigate the industry concentration per TLD. Our goal with this analysis is to visualize the state of the market share in each country, and the generic TLDs which are shared globally. Finally, we investigate the location profile of the dominant companies in each TLD. With this, we can see any factor contributing to companies' presence from a particular location. For instance, we would like to know how large US-based companies are present in each zone.

First, we focus on showing the percentage of domains resolved by the Top DNS providers ASes across our aggregated dataset. We calculate the percentage of domains announced for the Top 5, 10, 20, and 100 DNS provider ASes on a yearly basis, trying to identify whether there is a large concentration of domain names in the analyzed domain namespace. To that end, for each each year we count the total number of domain NSes (both IPv4 and IPv6) announced by each provider AS, and aggregate them to get percentage of domains per AS for the Top-N providers.

For IPv4 (Figure 1a), we discover that the concentration of IPv4 addresses on the Top-N ASes has remained relatively stable, with the concentration percentage increasing slightly (1%-5%) relative to the the number of domains. We can also see that in 2017 the Top 1 to 5 DNS ASes account for around 30% of all domains that have NS with IPv4 records, with this concentration increasing over the following five years, ending at about 40% in 2021. When looking at the Top 1 to 100 ASes of DNS providers, we get a shocking number, which shows that about 80% of the total 1.36M analyzed domains is concentrated in these ASes.



(a) IPv4

(b) IPv6

Figure 1: Top DNS Providers Concentration per Year

A. Top DNS Providers per Year

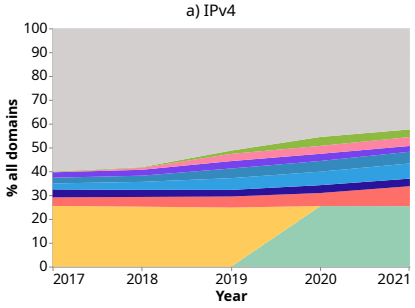
As for IPv6 (Figure 1b), our results show that the centralization is by far higher when considering the Top 1 - 5 ASes, which collectively account for 60% to 65% of all domain names. It is also important to note that the Top 1 to 100 represents round 96% of the IPv6 domain scope. Despite being far more concentrated, we observe a reversal trend of the IPv6, with the concentration in the Top 1 - 5 is decreasing over the years. This effect is likely due to increased IPv6 adoption by smaller providers, resulting in a proportionally less concentrated market in larger providers.

Next, we inspect the market share in terms of resolved domains by each individual AS per year. Figure 2 shows the Top 10 ASes concentration over the years 2017 to 2021. As we can see, the top ASes have not stayed the same over the years. We highlight GoDaddy - AS 26496 (in yellow), which remained as the most concentrated from 2017 to 2019. However, in 2020 we see a shift in concentration, with Host Europe GmbH - AS 44237 (in green) becoming the most concentrated afterward. This behavior can be observed for both IPv4 and IPv6. The cause of this behavior is that the US-based provider GoDaddy acquired the company Host Europe GmbH (its competitor) [29] and from 2019 onwards, it started to announce its blocks through the European company.

For IPv4 we also highlight see China UNICOM - AS4837 (in lime green) gaining market in the last two years. This trend may indicates that the Chinese providers are intensifying the competition with US and Europe providers. In general, most

	2017	2018	2019	2020	2021
GoDaddy.com LLC (ASN26496)	25.49	25.17	24.80	0.02	0.01
Host Europe GmbH (ASN44273)	0.00	0.00	0.00	25.44	25.38
Cloudflare Inc (ASN13335)	3.59	4.08	4.65	5.44	8.37
1&1 IONOS SE (ASN8560)	3.34	2.97	2.76	3.29	3.17
Google LLC (ASN15169)	2.50	3.35	4.92	5.67	6.38
Amazon.com Inc (ASN16509)	0.00	0.83	3.03	3.31	3.75
Alibaba (US) Technology Ltd (ASN37963)	2.27	2.47	3.11	3.01	2.43
Zenlayer Inc (ASN21859)	0.00	0.83	3.03	3.31	3.75
China UNICOM (ASN4837)	0.29	0.26	1.36	3.75	3.18
China Telecom (ASN134763)	0.00	0.83	3.03	3.32	0.22
Rest	60.09	57.39	48.24	42.22	42.15

a) IPv4



	2017	2018	2019	2020	2021
GoDaddy.com LLC (ASN26496)	24.32	23.99	23.36	0.00	0.00
Host Europe GmbH (ASN44273)	0.00	0.00	0.00	24.03	23.99
Cloudflare, Inc (ASN13335)	1.75	2.32	2.86	3.61	5.02
1&1 IONOS SE (ASN8560)	2.88	2.58	2.38	2.94	2.86
Google LLC (ASN15169)	0.73	1.31	1.81	2.52	3.00
Dyn DNS (ASN33517)	2.15	0.62	0.65	0.08	0.07
VeriSign Global Registry Services (ASN36619)	1.67	1.69	0.00	0.00	0.00
VeriSign Global Registry Services (ASN396549)	0.00	0.00	2.22	0.00	0.00
Neustar Inc (ASN397239)	0.00	0.00	0.00	5.26	0.00
Neustar Inc (ASN397237)	0.00	0.00	0.00	0.00	6.29
Rest	66.45	67.36	66.70	61.53	58.75

b) IPv6

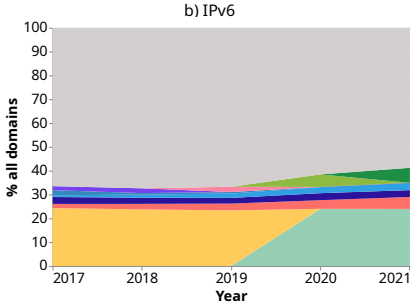


Figure 2: DNS Providers market share over the years. Better viewed in color.

providers have shown an increase in market share over the years. As a result, the concentration of the market in the hands of the Top 10 providers has increased by around 18% of the total, going from 40% in 2017 to 58% in 2021. However, for IPv6 we noticed a slightly slower growth behavior in relation to the market share by the Top 10 companies.

B. Top DNS Providers per TLD

We now examine the DNS infrastructure providers per TLD to determine if the concentration is similar or different across each TLDs. We begin by segmenting our dataset into TLDs and analyzing each one separately. Then, similarly to the previous analysis, we calculate the concentration of the Top 5, 10, 20, and 100 DNS provider ASes for each TLD.

Figure 3 illustrates the proportion of domain names for each top DNS provider AS, and for each TLD, from 2017 to 2021. We highlight a considerable concentration across all TLDs: the Top 1 to 5 DNS provider ASes resolve about from 25 to 81% of all IPv4 domains, depending on the TLD (Figure 3a). Estonia's `.ee` domains has the highest concentration increase over the analyzed 5 year span: from 77% in 2019 to 81% in 2021 on Top 1 - 5 providers. The United States ccTLD `.us` also has a high concentration of domains in the 5 providers, reaching around 67% of all domains.

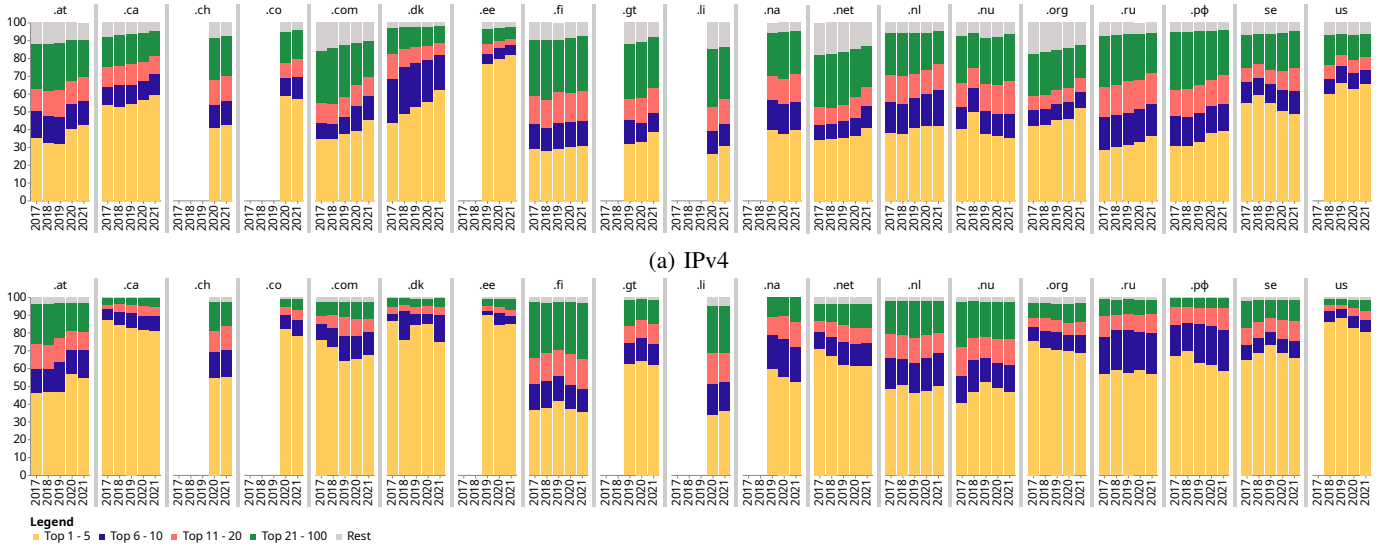
The market share concentration has remained rather constant for the majority of TLDs, both IPv4 (Figure 3a) and IPv6 (Figure 3b). Nonetheless, certain ccTLDs have seen an increase in concentration: Denmark's `.dk` domains were hosted by five providers in the previous five years, jumping from 43% to 61%. Similarly, Russia's `.ru` increased concentration from 28% to 36%. When we look at the aggregation of the Top 10 and 20 providers, we notice relative stability. However, it is worrying to note that for Denmark `.dk` the top 20 providers represent 82 to 88% of domains depending on the year. When we look at the top 100 providers in all TLDs, the concentration is even more worrying, where the percentage of domains resolved by these providers varies from 82 to 98%. In general terms, the number of providers in each country is getting smaller, which consequently causes a greater concentration of domains.

For IPv6 (Figure 3b), the concentration percentage is higher on the Top 1 - 5 DNS providers for all TLDs, presenting between 36 to 89% of analyzed domains. Furthermore, we see that in most TLDs, the Top 1 to 20 DNS ASes employ up to 95% of the entire domain scope, demonstrating the market concentration is mostly focused in the Top 20 DNS providers. Similar, but even worse, in some TLDs the Top 1 - 100 represents around 100% of the domain scope, such as Canada (`.ca`), Denmark (`.dk`) and Russia (`.p`ϕ).

C. DNS Top Providers per Location

Next, we analyze the location of the DNS providers per each ccTLD and gTLD. For this, we map the country of origin of each AS utilized for DNS servers and then the domain names to these countries. Note that our goal is only to map the country of origin for each company and not where the DNS servers of each AS are located geographically. For each TLD, we count the number of domains registered in each country and classify each of them into four categories, in order of priority:

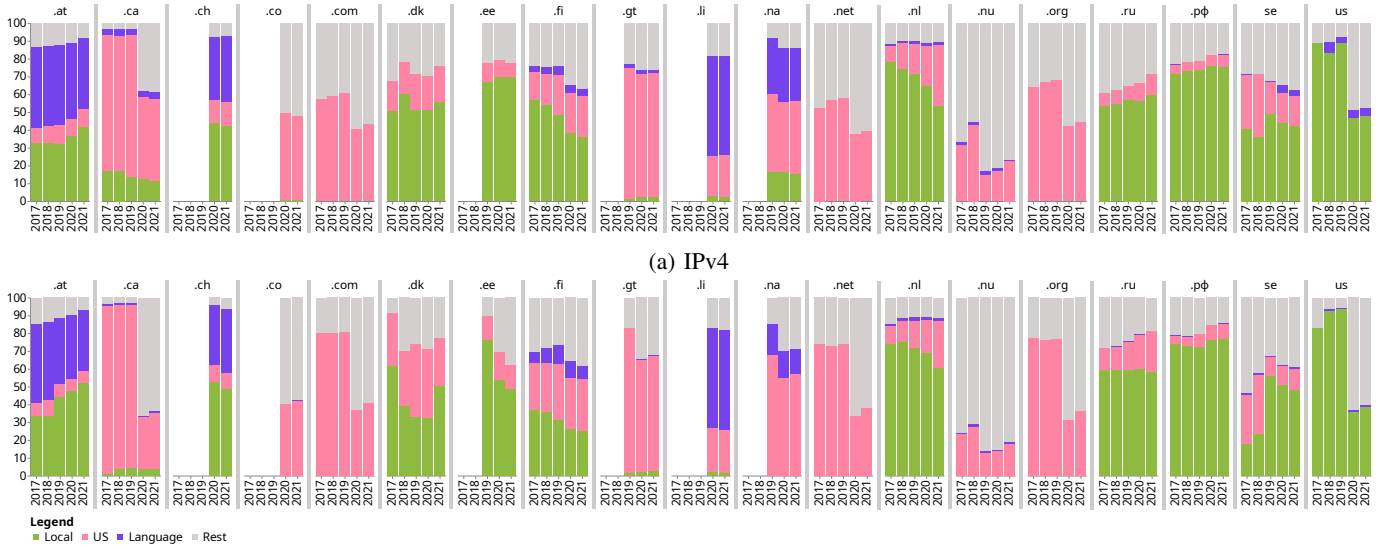
- **Local:** if the provider AS country is the same as the TLD.
- **US-based:** if the provider AS country is the US.
- **Same official language:** if the language of the provider AS is the same that the TLD. For example, Liechtenstein uses Deutsch as their official language and matches the ASes from countries that also use Deutsch as the official language, such as Germany.
- **Rest:** The rest of the domains do not match with any of the conditions above.



(a) IPv4

(b) IPv6

Figure 3: Top DNS Providers Concentration per TLD from 2017 to 2021. Better viewed in color.



(a) IPv4

(b) IPv6

Figure 4: Top DNS Providers Concentration per Location. Better viewed in color.

Importantly, each AS receives a single label, even if numerous apply. The assignment priority order for each label is the same as defined above.

Figure 4 shows the AS location classification per TLD from 2017 to 2021. This allows us to observe in which locations, each companies that dominate the DNS market in each TLD. We see a high dominance of local companies mainly in Europe, with emphasis on the Russian Federation TLDs (.**p**ϕ and `.ru`) and Estonia (`.ee`)

We also observe that the same official language can be a criterion for the dominance of certain TLDs. This can be seen in countries like Austria (`.at`), Switzerland (`.ch`) and Liechtenstein (`.li`) that use the Deutsche as the official language, and shows high use of companies which also have the Deutsche as the official language. This observation does not changes in the analyzed year span.

When we look at the US-based DNS companies, we can see that these companies are popular in Canada `.ca` (same language), Colombia (`.co`), Guatemala (`.gt`), and Namibia (`.na`) (which also has a portion of companies that have the same language: English like US companies). We were surprised to see US-based companies were not dominant for the most TLDs except for the gTLDs, which was expected.

Figure 4 also demonstrate the companies' location characteristics over the years. We see that for IPv4 in some TLDs, the presence of US-based companies has highly decreased,

such as `.ca` going from 76% to 45%, as well decreased the rate of presence in all gTLDs. Despite this, in some TLDs, we see an opposite trend for US-based provider, where their presence has increased, such as `.nl` going from 8% to 34% in five years. For IPv6, we see a repetition of the lows and highs in the same TLDs, with emphasis on the ccTLD `.ca` standing out from 94% to 31%.

VI. Conclusions and Future Work

In recent years we have seen the ascent of an Internet phenomenon referred to as *consolidation*, which regards the trend towards concentration of critical resources in the hands of a few market players. Such phenomenon raises multiple concerns over the concentration of *infrastructure*, *traffic*, *users*, and *services* in the hands of a small number of stakeholders. This leads to various risks to the Internet ecosystem, from both technical and sociopolitical perspectives, such as the recent DDoS attacks in 2016 [15] and 2019 [16] that exposed problems caused by shared resources from big DNS providers.

In this work, we studied the DNS industry's consolidation by looking at a collection of 16 ccTLDs and 3 gTLDs. We resolved and analyzed the authoritative NSes for all domains in each TLD in our dataset, mapping each NS AS to its parent organization, allowing us to assess DNS consolidation and estimate the market share of each DNS provider. By looking at the DNS market share of the top providers over a 5-year period, we also showed how such concentration has progressed over time. In our results, we showed that depending on the year the Top 1 to 5 DNS providers account for more than 40% of all domains and, most interestingly, the Top 1 to 100 providers account for about 80% of the total analyzed IPv4 domain namespace and about 96% for IPv6.

As future work we intend to address our work limitations, such a relying on sources of data from multiple vantage points. We also intend to analyze the state of centralization at other levels of the DNS infrastructure, as well as carry out studies for other services such as Email.

VII. Acknowledgements

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