Shedding Light on the Adoption of Let’s Encrypt

Antonis Manousis, Roy Ragsdale, Ben Draffin, Adwiteeya Agrawal and Vyas Sekar
School of Electrical and Computer Engineering
Carnegie Mellon University
{antonis, bendraffin, adwiteeya, rragsdale,} @ cmu.edu

Abstract—Let’s Encrypt is a new entrant in the Certificate Authority ecosystem that offers free and automated certificate signing. It is visionary in its commitment to Certificate Transparency. In this paper, we shed light on the adoption patterns of Let’s Encrypt “in the wild” and inform the future design and deployment of this exciting development in the security landscape. We analyze acquisition patterns of certificates as well as their usage and deployment trends in the real world. To this end, we analyze data from Certificate Transparency Logs containing records of more then 18 million certificates. We also leverage other sources like Censys, Alexa’s historic records, Geolocation databases, and VirusTotal. We also perform active HTTPS measurements on the domains owning Let’s Encrypt certificates. Our analysis of certificate acquisition shows that (1) the impact of Let’s Encrypt is particularly visible in Western Europe; (2) Let’s Encrypt has the potential to democratize HTTPS adoption in countries that are recent entrants to Internet adoption; (3) there is anecdotal evidence of popular domains quitting their previously untrustworthy or expensive CAs in order to transition to Let’s Encrypt; and (4) there is a “heavy tailed” behavior where a small number of domains acquire a large number of certificates. With respect to usage, we find that: (1) only 54% of domains actually use the Let’s Encrypt certificates they have procured; (2) there are many non-trivial incidents of server misconfigurations; and (3) there is early evidence of use of Let’s Encrypt certificates for typosquatting and for malware-laden sites. Based on these results, we derive key security implications and recommendations for Let’s Encrypt, website administrators, browser vendors, and end users.

I. INTRODUCTION

Today’s web ecosystem critically relies on Certificate Authorities (CAs) in order to ensure that network connections are trusted and secure, as they vouch for the binding between a domain name and its public key by issuing digital cryptographic certificates. While CAs are a key part of this ecosystem, there are several known problems with them. First, the issuance of SSL/TLS certificates by traditional Certificate Authorities has historically been a manual and expensive process, with costs (per certificate) somewhere between $5 and $1000 a year [10], [29]. Second, Certificate Authorities have had little to no incentive for transparency so they rarely publish complete lists of the certificates they have signed; instead they serve as the sole entity to evaluate certificate requests. This has serious security ramifications in the event a compromised or malicious CAs issues fraudulent and untracked certificates. This threat is not hypothetical and has precedent: DigiNotar mis-issued SSL certificates that were later used to perform man-in-the-middle attacks against web users [13].

Certificate Transparency is a new effort that promises to combat the danger of compromised or malicious CAs issuing rogue certificates by adding all newly issued or revoked certificates to a public, verifiable, append-only log [43]. This ensures that if a certificate is not in the log, the client can take appropriate action and refuse to connect to a particular website. If certificates are in the log, the community can quickly determine if they are dangerous or fraudulent and act to revoke them. The development of Certificate Transparency has contributed to the emergence of (i) protocols that automatically sign minimally-validated certificates such as the Automated Certificate Management Environment (ACME) [3] and (ii) Certificate Authorities that utilize these protocols to automate the procedure of issuing certificates, like Let’s Encrypt [20]. Let’s Encrypt is currently the primary Certificate Authority leveraging the ACME protocol. Let’s Encrypt appears to be particularly popular as it is currently signing certificates at a rate of about 55,000 a day. A particularly interesting feature of Let’s Encrypt is that it is both free and automated.

Motivating Questions: The goal of this paper is to shed light on the adoption patterns of Let’s Encrypt certificates “in the wild”. Such an understanding can be immensely useful to multiple players in the end-to-end HTTPS ecosystem. For instance, this can shed light on: (1) how and where HTTPS adoption can be further stimulated; (2) expose potential sources of design optimizations and considerations for future deployments (e.g., are there flash crowds or heavy tailed behaviors); and (3) understand if/how the free and automated deployment can lead to potential sources of misconfigurations or abuse.

We divide our analysis into two high-level categories: (1) acquisition of certificates and (2) usage in the wild.

1) Acquisition: With respect to acquisition, we seek to analyze several natural questions with respect to:

- Geographic characteristics of issued certificates: Is Let’s Encrypt popular in countries with already high web/HTTPS penetration or is it more popular in countries with emerging Internet adoption?
- The ‘profile’ and motives of web domains that obtain them: Is adoption uniformly popular across different users or are some acquiring more certificates than others? Were sites previously using HTTPS with other CAs and then switching to Let’s Encrypt? How many of the certificates are first time HTTPS deployments? Are the early adopters popular websites or in the “tail” of the popularity distribution?
2) Usage: With respect to usage patterns in the wild, there are several natural questions regarding:

- Active deployment:
  Are users requesting Let's Encrypt certificates merely out of curiosity or are they being deployed in “production”? Are users using these certificates and renewal processes correctly?
- Malicious Intents:
  Does the free and automatic character of issuing trusted certificates become an enabler for malicious activities such as typosquatting and for delivering malware?

Methodology and Findings: Using a dataset of around 18 million certificate logs as well as Alexa’s records of the top 1 million web domains and services like Censys, VirusTotal and Geolocation databases we set out to answer questions on adoption and usage. We use the Certificate Transparency Logs in order to identify the domains certified by Let’s Encrypt and then we collect amplifying information from the aforementioned services.

Using this data, we perform our measurement experiments and our key findings are as follows:

- Geographical distribution of certificates: Let’s Encrypt has notably contributed to the democratization of adoption of TLS certificates. In countries like Argentina, Ukraine and South Africa, Let’s Encrypt certificates are over-represented in the whole population of HTTPS websites by a factor of 5. In western Europe, countries like Switzerland, France and the Netherlands issue the most certificates as a function of their active Internet population with an average ratio of 3.9 certificates per thousand active Internet users.
- Characteristics of adopting websites: We investigate the characteristics of websites that have adopted Let’s Encrypt as their CA. We observe that 1.2% of popular websites appearing in Alexa top million have transitioned from paid CAs to Let’s Encrypt.
- Bulk acquisition of certificates: We estimate that around 7% of all issued Let’s Encrypt certificates are used by companies for services that provide web-interfaces for secure communication between end-users and the company’s products (e.g., routers, Network Attached Storage Devices or dynamic DNS servers). We identify and discuss implications of this practice.
- Usage characteristics: The free nature of Let’s Encrypt has inadvertently created a pool of users that are interested in using the platform only out of curiosity. We estimated that the number of domains for which multiple redundant certificates have been issued is on average 9% of the number of domains using Let’s Encrypt. Further, we found that 15% of the total number of Let’s Encrypt domains opt out by not renewing their certificates. Finally, we observe that of the active domains that obtained a Let’s Encrypt certificate, only 50% replied with a valid Let’s Encrypt certificate on the standard HTTPS port.

- Malicious usage: We see anecdotal cases where users have tried to provide legitimacy to malicious websites by ‘securing’ them with certificates provided by Let’s Encrypt. We experiment with typosquatted domains and discover that indeed malicious users have tried to leverage free TLS certificates to exploit users’ trust.

Implications: Based on the findings, we derive some key implications and recommendations for Let’s Encrypt, domain owners, users, and for browser vendors:

1) For Let’s Encrypt: First, the adoption patterns of Let’s Encrypt suggest that there is a number of domains requesting a large number of certificates for subdomains. This could both increase the load for renewals on Let’s Encrypt and needlessly bloat the audit logs. Therefore, Let’s Encrypt should maybe revisit the decision to not support wildcard certificates (e.g., *.foo.com), for cases where they would be a secure option (and provide guidance to domain owners on when wildcard certificates are not a suitable option). Second, the early signs of free certificates being used for malicious intent suggest that Let’s Encrypt can run checks for malicious indicators or for typosquatting intent as a proactive measure before issuing certificates.

2) For domain owners: Domain owners could benefit from some simple sanity checks to avoid common misconfiguration errors as we observed above. We also suggest that domain owners refrain from requesting certificates for inactive domains to avoid bloating up the audit logs. Finally, domain owners could benefit the community by providing more metadata and being more forthcoming in giving reasons or their intents while requesting certificates; e.g., why domains are inactive or why they transitioned.

3) For users and browser vendors: Given that there are a few common misconfiguration templates (e.g., default “toy” server configuration), users and browsers could proactively check for these when accessing HTTPS-enabled sites and potentially report them to a central “certificate health” repository.

Roadmap: Section 2 provides some background on Certificate Transparency, Let’s Encrypt and related measurement studies. Section 3 discusses the dataset and methodology used in our measurements. Sections 4 and 5 analyze the results of the adoption and usage patterns respectively. Section 6 presents implications of our analysis and finally Section 7 concludes this work.

II. BACKGROUND AND RELATED WORK

In this section we first provide background on Certificate Transparency and the mechanisms of Let’s Encrypt. Then, we discuss previous works that have provided preliminary measurements and insights on the adoption of Let’s Encrypt.

A. Certificate Transparency

The core idea behind Certificate Transparency is to create a public, verifiable, append-only certificate log. The log’s
integrity can be trusted because all of its entries are cryptographically verifiable. By checking the log, any client can verify the validity of a certificate before connecting to a particular website. If the certificate is not logged, then the client can reject the connection and avoid mistrusting the provided certificate. Appending certificates to the log does not add any extra latency as log-inclusion proofs are incorporated to the TLS handshake.

To avoid Certificate Transparency logs being wasteful in storage and bandwidth, current approaches leverage Merkle Trees. These are efficient data structures in which a leaf is an item in the log and each branch is a cryptographic hash of the nodes below the branch. The root of the tree, assembled by successive hashing, is therefore a summary of all its contents. A site may provide the signed root node of the transparency log’s Merkle Tree to prove that it has not changed the log or misbehaved. This allows for trusted and efficient log-inclusion proofs. The proliferation of an HTTPS ecosystem in which Certificate Transparency is an integral component makes scalability considerations important factors in the design of logs. As the web scales, they need to keep vast amounts of data and also to synchronize them between different replicas worldwide.

B. Let’s Encrypt

The principal goal of Let’s Encrypt and the ACME protocol is to make security accessible for everyone. The strategy for doing so is a service for websites to obtain a browser-trusted certificate without any human intervention by the Certificate Authority and minimal effort from the server’s administrator. This happens by running a certificate management agent on the web server. The procedure happens in two steps. First, the agent proves to the CA that the web server controls a domain and then the agent can request, renew, and revoke certificates for that domain.

Let’s Encrypt uses public key cryptography to identify the server. During the first communication between the server and Let’s Encrypt, a new public-private key pair is generated. This is similar to the process of creating an account at a traditional CA. The server administrator queries Let’s Encrypt in order to find out how the user should prove they own the domain. The CA then issues one or more challenges. The current options are: (1) check DNS records for the domain or (2) access a token on a specific URI on that domain. Additionally, Let’s Encrypt issues a nonce that the agent running on the web-server needs to sign with their newly-issued private key. Once the challenges have been satisfied, the domain has been validated, and the key pairs are authorized. The user can now issue requests for new certificates as well as renew or revoke existing certificates. They must simply send certificate management messages signed with the authorized key pair.

One interesting point about certificate issuance is choosing the log that will keep a record of the certificate. While Let’s Encrypt claims to submit all its certificates to Certificate Transparency Logs, there is no stated official log that they submit to. Information about published certificates can be found on domains specializing in certificate searches like https://crt.sh.

C. Related work

Early measurements of Let’s Encrypt: A parallel effort to quantify the impact of Let’s Encrypt has been performed by J.C. Jones, a Security Engineer at Mozilla who designed the infrastructure for Let’s Encrypt and currently serves on its Technical Advisory Board. This work utilized Certificate Transparency Logs as the primary lens to gain insight into the adoption and utilization of Let’s Encrypt as a Certificate Authority. It investigated the number of domains using Let’s Encrypt certificates that did not previously have a TLS certificate. Moreover, Jones addressed the utility of Certificate Transparency Logs as a data source by also examining the number of certificates that can be found in scans by Censys but not in Certificate Transparency Logs. Using this data, the post observes how Let’s Encrypt compares with other established Certificate Authorities, such as Comodo, Symantec or GoDaddy.

This concurrent work determined that 90.4% of the domains using Let’s Encrypt are new to Web PKI and Let’s Encrypt ranks fourth in the list of most observed unexpired certificates grouped by issuer. Also, it presented data showing that 55% of issued Let’s Encrypt Certificates are only found in Certificate Transparency Logs, 35% can be found in both Transparency Logs and Censys and 9% can only be found in Censys thus validating the largely comprehensive nature of Certificate Transparency Logs. Interestingly, the presence of sites with Let’s Encrypt certificates not listed in transparency logs seems counter to the goal that all Let’s Encrypt certificates are submitted to logs. Remedying this disconnect will be an important issue going forward.

While this parallel effort tackled high level questions concerning the scale of Let’s Encrypt’s operations, and demonstrated how a commitment to Certificate Transparency makes these logs an invaluable lens into an otherwise opaque ecosystem, it did not attempt to link certificate issuance to actual usage. We observe that the unprecedented low barriers to entry in the automated and free nature of Let’s Encrypt causes this simplifying assumption to not hold. It is invalid to assume that just because a certificate was issued that it is actively, or correctly, securing a domain. In this work we start from the same foundation of Certificate Transparency Logs but go further by leveraging other sources such as Geolocation databases, Alexa’s historical records, VirusTotal, and active HTTPS scans to shed light on specifically measurable aspects of the adoption and utilization of Let’s Encrypt.

Related measurement efforts: Our work follows in the line of a rich history of measurements of security-related aspects of the web ecosystem. There are several orthogonal efforts analyzing other aspects of the HTTPS ecosystem. Liu et al., study the frequency and accuracy of certificate revocation and checking; they paint a less-than-optimistic picture of the effectiveness of revocation. Durumeric et al., analyze the prevalence of the Heartbleed vulnerability in web servers.
and assess the impact on the web certificate ecosystem \[39\]. Zhang et al, more specifically look at the issue of revocation behavior in the aftermath of Heartbleed \[50\]. Bates et al., analyze the adoption of the Convergence CA extension to the “crowdsourced” approach for certificate verification named Perspective \[49\]; they measure how effective it will be at scale and suggest that simple caching strategies can improve scalability \[34\]. Naylor et al, have analyzed the costs of websites moving to HTTPS \[46\] and Varvello et al, analyze the adoption of the HTTP/2 standard \[48\]. In terms of measurement infrastructures, Zmap \[38\] and Censys \[37\] provide novel capabilities for Internet-scale scanning and provide useful datasets that enable the kinds of analysis we perform in this paper. A recent work by Lever et al., looks at the notion of residual trust when domain registrations expire and are repurposed with a different use \[44\]. We observe that a small but non-trivial fraction of certificates were not renewed. Given the automated nature of certificate renewals, an interesting direction for future analysis is measuring scenarios if these certificate renewals failed because domain registrations lapsed.

**Other related work in web certificates:** Let’s Encrypt leverages new ideas like Certificate Transparency and the ACME protocol. It promises to revolutionize the tedious, human-in-the-loop procedure of issuing trusted certificates. It is the first organization to automate such a procedure, yet will likely not be the last. The following subsection focuses on recent articles that showcase the early impacts of Let’s Encrypt \[14\]. For the interested reader, related research in the broader area of certificates and web-trust includes but is not limited to works that: evaluate the Certificate Trust Model \[36\], discuss efficient ‘gossip’ protocols to ensure consistency of certificate logs \[35\], develop methods for enhanced certificate transparency and end-to-end encrypted mail \[47\], and discuss common SSL errors or cases of forged certificates \[33, 41\].

### III. Dataset and Methodology

In this section we describe our datasets, the methodology by which we collected and processed them, as well as the limitations of our approach. Our decisions were guided by our overarching goal which is to evaluate the adoption and usage patterns of Let’s Encrypt certificates. Specifically, our methodology should allow us to investigate the rate of adoption of Let’s Encrypt certificates, the motives of adopting users, their geographic distribution as well as the HTTPS history of Let’s Encrypt-certified domains. We also needed be able to identify patterns of misuse or abuse on behalf of users as well as indications for malicious activities.

**A. Sources of Data**

Our first goal was to collect a complete list of domains that have used Let’s Encrypt as their Certificate Authority. The source of these domains was Certificate Transparency logs, which collectively contain a complete record of virtually all the signed certificates issued by Certificate Authorities complying with Certificate Transparency rules, including Let’s Encrypt. We evaluated two primary options for obtaining certificate transparency logs; a full log mirror solution and a simpler log downloader. As a major supporter of Certificate Transparency, Google provides an open source log server solution that can also be used in mirror mode \[18\]. We first examined this option as it would be the most full-featured solution. However, community members have built more streamlined tools for batch downloads, leading us to a second method, a simple log downloader. We utilized the code provided by James ‘J.C.’ Jones \[11\] as well as the original ct-sync tool from Adam Langley as described in his efforts to establish Certificate Transparency \[9\].

Using this method we downloaded the full set of Certificate Transparency Logs from the Certly Log Server \[7\] which includes certificates issued by Let’s Encrypt up to March 31st. In this batch, we obtained certificate logs for 1,331,781 unique certificates to analyze. This includes 1,156,266 certificates issued by Let’s Encrypt. This full mirror was the first dataset which we used for analysis and further amplification. On April 15th 2016, Google announced that Certly failed to comply with Certificate Transparency regulations, specifically the requirement about 99% uptime \[12\] and therefore was no longer considered a trusted CT log by the community. We proceeded by scaling our measurements up by downloading Google’s most recent Aviator CT log of around 17 million entries. As mentioned in Section II there is no official Certificate Transparency log for Let’s Encrypt certificates. A comparison between the official announcements from the Let’s Encrypt organization \[22\] about issued certificates with the number of Let’s Encrypt certificates appearing in Certly showed that Certly contained 90% of the issued certificates up until March 30th and therefore at the time we evaluated that this would be an adequate preliminary data set. After Certly was no longer considered a trusted Transparency log, the Aviator log was determined to be a satisfactory replacement.

The information stored in Certificate Transparency logs was the starting point for most of our experiments. This allowed us to bootstrap our measurements related with the geographical characteristics of Let’s Encrypt, typosquatting analyses and also enabled the collection of auxiliary information from services like VirusTotal \[31\] and Alexa \[4\]. The validity period of each certificate allowed us to investigate certificate usage patterns and user behavior, including determining the existence of duplicate certificates for a particular domain. A caveat of this method, however, is that since many traditional Certificate Authorities do not make their certificate records public, the knowledge about HTTPS history of domains would have to come from other sources.

To collect additional information about each domain found in the Certificate Transparency logs, we had to leverage other services that could provide us with useful amplifying information and metadata. This information came from the following datasets and allowed us to gain clearer insights into the Let’s Encrypt ecosystem.

1. **VirusTotal** \[31\]: an online service which can be used to scan a URL, domain name, IP or a file against various ‘malicious activity detection’ services. Specifically, VirusTotal scans each
URL with 67 different antivirus solutions and reports how many reported that a domain is suspicious or infected.

2. **Censys** [5]: provides internet-wide scan data capturing how devices, websites, and certificates are configured and deployed. It contains a collection of historic data for most domains of interest and provides a SQL like interface for users to make queries to these sources of data.

3. **Alexa** [4]: a service that provides commercial web traffic data and analytics in order to benchmark and compare web domains.

4. **Geolite2 Geolocation Database** [17]: This service allowed us to get geographic information about domains of interest.

**IV. ANALYSIS OF CERTIFICATE ACQUISITION**

In this section we present results pertaining to the acquisition patterns of Let’s Encrypt certificates. First, we evaluate the rate of acquisition of Let’s Encrypt and then we proceed by characterizing the geographic distribution of certificates. We then explore the prevalence of certificates among popular websites and finally, we investigate the ‘profiles’ and motives of adopting users, especially those who obtain certificates in large quantities.

**A. Rate of Adoption**

To analyze the acquisition of Let’s Encrypt as a Certificate Authority, we downloaded Certificate Transparency logs from 17 September 2015 up to 15 May 2016. Figure 1 confirms the popular perception that adoption is on the rise and shows the total number of certificates issued by Let’s Encrypt over time. We can clearly see that acquisition is on the rise with close to 4M certificates issued as of May 14, 2016.

We also analyzed if there were interesting temporal patterns in the issuance of these certificates. To this end, we looked at the number of certificates issued per day as well as the number of unique effective TLDs (e.g., xyz.com or foo.co.uk rather than .com or .co.uk) that acquired certificates on a daily basis in Figure 2. Figure 2a shows the aggregate number of issued certificates per day, while Figure 2b shows the unique effective TLDs (eTLDs) requesting Let’s Encrypt certificates on a daily basis. This result is generally consistent with our general acquisition graph but it also reveals an interesting observation that there are certain abnormal peaks in early May.

We further investigated the root causes of these spikes and found two types of explanations. The first observation was that a set of providers were issuing certificates for many of the subdomains they controlled. That is either because Let’s Encrypt does not support wildcards; e.g., xyz.com requests certificates for a.xyz.com and b.xyz.com or because each subdomain represents a different user account requiring its own dedicated certificate. These providers generally obtain a very large number of certificates at once. An example of one such user is automattic.com, a web development company that between May 4th and May 7th, 2016 issued 850 certificate for its clients. Table I depicts Let’s Encrypt users that issued the highest number of certificates for the peaks of figure 2a. Interestingly, the same user is responsible for acquiring certificates in bulk on a regular basis.

| Date    | eTLD     | Issued certificates |
|---------|----------|---------------------|
| May 4th | freeboxos| 5419                |
| May 5th | freeboxos| 2159                |
| May 6th | freeboxos| 1652                |
| May 7th | freeboxos| 1426                |
| May 10th| freeboxos| 1199                |

**TABLE I: eTLD with most certificates issued**

However, that does not tell the full story and cannot fully explain the spikes. In fact, if we look closely at Figures 2a and 2b what we actually see is that the number of unique domains issuing certificates is comparable to the numbers of certificates issued per day. Using DNS resolution and whois lookups on the set of domains that were issued certificates on these specific days revealed that many of them in fact had the same authoritative name server or the same NS entry in the WHOIS record. A specific example was a French provider ovh.com that seemed to have obtained certificates for many unique eTLDs that do not share a common suffix; i.e., these were domains of the form xyz.com rather than xyz.ovh.com. In particular, during the days with the highest spikes on adoption, we observed that OVH was responsible for 30-35% of the total number of certificates issued and that up to the end of our measurement period, it had acquired around 650,000 Let’s Encrypt certificates.

**B. Analysis of Top Users**

The insight that particular users consistently acquire large numbers of certificates led us to proceed with our investigation of the websites using Let’s Encrypt clustered by the effective TLD (eTLD). For example, domains a.example.com and b.example.com were clustered under example.com. Similarly, domains such as a.example.co.uk and b.example.co.uk were clustered under example.co.uk. The goal was to pinpoint cases of domains with a surprisingly high number of issued certificates. We excluded cases of domains where the Second Level Domain represents a geographic location (for example domains in Ukraine are clustered at a city level so a domain in Kiev will end in kiev.ua), as we wanted to identify unique entities obtaining Let’s Encrypt certificates in bulk.
Table II contains the 6 highest e-TLDs and the number of certificates issued. For the specific entries in Table II, what we observe anecdotally is that companies often obtain large numbers of Let’s Encrypt certificates in order to provide secure connections between the end-user and the web interfaces of services they sell. For example, ‘FreeboxOS’ is a service offered by the popular low-cost French ISP ‘Free’ that combines telephony, satellite TV and WiFi [16]. FreeboxOS provides a web interface so that users can connect to their local modem and safely manage their account, therefore they issue a TLS certificate per userID. Similar patterns are observed by other companies in the table above like ‘duckDNS’ and ‘Synology’. (The one exception is Jacob Hoffman-Andrews who is a programmer, tech blogger and contributor to Let’s Encrypt which explains the high number of Let’s Encrypt certificates issued for his personal website.)

The certificates acquired by the domains in Table II account for almost 7% of the total number of certificates issued by Let’s Encrypt. Their purpose is to provide secure access to individual client-owned devices (e.g freeboxos cable boxes), as well as to user profiles managed by the certificate-acquiring organizations. The service for which these certificates are issued requires individual, per-user certificates, rather than wildcard certificates (*.domain.com) which would make users susceptible to Man-In-The-Middle attacks. However, the observation that companies request very high numbers of certificates also draws attention to the fact that Let’s Encrypt does not currently support wildcard certificates.

Supporting wildcard certificates is, in our opinion, a feature that would be useful for specific applications. For example, libraries around the world use a product called EZproxy to connect library patrons to licensed resources. In order for the connection between the patron and EZproxy to be encrypted, EZproxy requires the use of a large number of nonstandard ports or wildcard certs [23]. We also believe that the absence of wildcard certificates can potentially lead to 2 major scalability issues in the Certificate Transparency logs. First, it can create an excessive storage overhead and also as Certificate Transparency Logs are often distributed and replicated around the world, the lack of wildcard certificates can harm the performance of log synchronization when new certificates are added.

C. Geographical Analysis

In order to answer the question of whether Let’s Encrypt has facilitated the democratization of TLS, we characterize the geographic distribution of Let’s Encrypt certificates. We focused on two key questions: (i) finding the countries where certificates issued by Let’s Encrypt are most popular and (ii) finding those countries in which Let’s Encrypt certificates have been disproportionately popular compared to the overall number of websites (HTTPS enabled or not).

**Analysis approach:** To determine and visualize the geographical distribution of encrypted certificates we use the following steps:

1) Collect Let’s Encrypt domain names.
2) Resolve the domain names into valid IP addresses.
3) Determine Autonomous Systems for each of the demands, in order to identify when many websites might be using the same cloud hosting providers.
4) Look up each IP address and a geolocation database to get the latitude, longitude, city, state and country.
5) Cluster data by country and visualize using a Choropleth map.

As an aside, we observed that the process for resolving around 2 million domain names into IP addresses pushes the limits of Domain name resolution as DNS for end-users is a relatively slow process that suffers in reliability when querying at high speeds. To address this problem, we created a DNS query script written in Go-lang that manually crafted DNS packets to hardcoded domain name servers. Since each domain name server put query rate limiters on the program, the system had to be designed to request DNS resolutions from many DNS servers at a time, including multiple DNS resolvers from
Amazon Web Services and Google. Ultimately, the system was able to achieve over 500 DNS resolutions per second. This enabled us to resolve 2 million domain names in one hour on a well-connected server.

The method described above showed that 29,372 domains or 1.5% of the domains queried did not resolve to any IP addresses because the servers had been taken down or are not publicly accessible. We consider 1.5% of the total number of domains to be a small fraction that does not skew the results of the geographic distribution and exclude these from the analysis. However, of the websites that did not resolve, it was interesting to see how many of them had issued more than one Let’s Encrypt certificate. We found that 20% of these domains had more than one Let’s Encrypt certificate.

![Fig. 3: Raw Count of Let’s Encrypt certificates](image)

**Results:** As Figure 3 shows, Let’s Encrypt certificates are most commonly used in countries with high Internet penetration. This is a seemingly obvious result but we delved deeper in order to find out in which countries Let’s Encrypt certificates are most popular. We compared the number of active Let’s Encrypt certificates with the active Internet population of each country [19]. The results can be seen in Table III. Table IV shows the 20 countries with the highest number of issued certificates as a percentage of the total number of Let’s Encrypt certificates. We observe that Let’s Encrypt certificate penetration is predominant in Central and Western Europe and for countries like Switzerland, the Netherlands, France or Germany the percentage of active usage and acquisition is 4 times higher compared to the United States. The ratio is 8 times for Canada. We postulate that this fact is because a large number of Western European countries have solid awareness about the importance of privacy on the Internet. Is a longstanding priority for the citizens of these countries and those considering hosting personal or business sites seek out getting certificates from authorities like Let’s Encrypt.

| Country            | certificates/1000 users |
|--------------------|-------------------------|
| Switzerland        | 5.0                     |
| France             | 3.887                   |
| Netherlands        | 3.703                   |
| Germany            | 3.061                   |
| Singapore          | 2.941                   |
| Ireland            | 2.338                   |
| Czech Republic     | 1.633                   |
| Ukraine            | 1.622                   |
| Iceland            | 1.489                   |
| Luxemburg          | 1.445                   |
| Estonia            | 1.172                   |
| USA                | 1.094                   |
| Austria            | 0.881                   |
| Sweden             | 0.828                   |
| Saint Kitts and Nevis | 0.699               |
| Denmark            | 0.635                   |
| Norway             | 0.535                   |
| Canada             | 0.525                   |
| Slovenia           | 0.523                   |
| Latvia             | 0.523                   |

**TABLE III: Top 20 countries with highest number of Let’s Encrypt certificates as a function of the active Internet population**

| Country               | % certificates/all LE certs |
|-----------------------|-----------------------------|
| United States         | 28.14%                      |
| Germany               | 19.48%                      |
| France                | 19.41%                      |
| Netherlands           | 5.3%                        |
| United Kingdom        | 4.3%                        |
| Switzerland           | 3.27%                       |
| Ukraine               | 2.86%                       |
| Slovak Republic       | 2.22%                       |
| Canada                | 1.51%                       |
| Japan                 | 1.39%                       |
| Czech Republic        | 1.36%                       |
| Singapore             | 1.24%                       |
| Russia                | 1.14%                       |
| Ireland               | 0.78%                       |
| Sweden                | 0.6%                        |
| Australia             | 0.63%                       |
| Poland                | 0.58%                       |
| Austria               | 0.55%                       |
| Spain                 | 0.52%                       |
| Italy                 | 0.33%                       |

**TABLE IV: Top 20 countries with highest percentage of Let’s Encrypt certificates as a function of total number of Let’s Encrypt certificates**

Figure 3 also indicates that the number of Let’s Encrypt certificates in smaller or less well connected countries is blooming and will likely continue into the future. Notable countries with surprising high rates of use are Ukraine, South Africa, Argentina and Brazil.

Another interesting question about geographic distribution is where Let’s Encrypt certificates are disproportionately popular compared to all website hosting or all certificates. By
For every domain with Let’s Encrypt certificate, we set out to identify the first date of issuance of the Let’s Encrypt certificate and then compare with previous records. Specifically we: (1) collect a list of all domains with certificates issued by Let’s Encrypt; (2) Find the earliest Let’s Encrypt certificate issuance day for each of the domains, which can be found in the Certificate Transparency Log; and (3) Search the Certificate Transparency Logs for the aforementioned domains looking for certificates issued before Let’s Encrypt certificates were adopted.

We observe that in total, 503 domains transitioned from known CAs to Let’s Encrypt. Table V shows the top 5 Certificate Authorities that clients left for Let’s Encrypt. An interesting insight is that most of the CAs that users ‘abandoned’ according to Alexa in order to transition to Let’s Encrypt, (not limited to CAs mentioned in the tables above) are CAs that have one or more of the following characteristics: (1) Have received poor reviews from users in SSL reviews websites such as sslshopper [27] and spiceworks [26]; (2) Are among the Certificate Authorities that provide ‘affordable’ certificates [30]; (3) Are not (or no longer) trusted by popular browsers; or (4) Have been involved in security breaches [9]. This suggests that Let’s Encrypt has become an attractive alternative for users who value the trust and privacy provided by HTTPS but they are currently using untrusted CAs or are reluctant to pay large amounts of money in order to obtain a certificate from one of the more expensive Certificate Authorities.

| CA                | % Transitioned to LE |
|------------------|----------------------|
| COMODO RSA CA    | 31.21%               |
| StartCom CA      | 12.3%                |
| RapidSSL SHA256 CA | 9.7%          |
| Go Daddy         | 7.4%                 |
| GlobalSign SHA256 CA | 2.7%       |

TABLE V: Certificate Authorities popular domains left to transition to Let’s Encrypt

E. Adoption by popular domains

For this analysis, we focus only on domains listed on Alexa top 1 million domains and our goal is to investigate how popular Let’s Encrypt is among them. Figure 5 shows how many Let’s Encrypt websites are in Alexa’s top 1M list of websites. We observe that even though there is a slight increase in the total number of high profile websites that use Let’s Encrypt, the rate of acquisition is lower compared to the overall rate of acquisition of Let’s Encrypt as a CA. Clustering those domains in groups based on their ranking in May showed that 0.4% are in positions between 1000 and 10,000. 7.7% are in positions between 10,001 and 100,000 and finally 92% of these domains rank below 100,000. The low rate of acquisition can be attributed to the fact that, a website with high visibility on the web is most likely already certified by a CA; until its current certificate expires, its administrators would not be particularly motivated to switch from their current CA to Let’s

D. Domain History of using HTTPS

Next, we investigate the HTTPS characteristics of domains currently using Let’s Encrypt certificates. Specifically, we examine how many websites have used Let’s Encrypt as their first Certificate Authority and how many have transitioned from a traditional Certificate Authority to Let’s Encrypt. To that end, we leverage one main source of data, Alexa records of the top 1 million domains. We acknowledge that this is a small subset of all domains however, given that many Certificate Authorities did not comply with Certificate Transparency until very recently, the number of domains for which we could extrapolate information was extremely limited. On the contrary, Alexa historic records contain information about the certificate chains of the most popular domains and therefore they constitute a more credible source of data, even if the sample of domains is smaller.

Fig. 4: Relative popularity of Let’s Encrypt certificates

comparing the number of websites in a particular country to the number of Let’s Encrypt certificates in that country, we can determine the degree of market penetration of Let’s Encrypt certificates. For each country, determine the number of any type of website and the number of Let’s Encrypt websites hosted there. We compute the ratio of the number of Let’s Encrypt sites compared to the number of sites in that country, to indicate the relative popularity of Let’s Encrypt there. For instance, If one country had 1,000 sites in a sample of 1 million global sites, one would probably expect the number of Let’s Encrypt certificates in that country to be 1,000 since they should be representing the same population (all websites). If, however, had over 5,000 certificates in the same sample size, one would be surprised about how common Let’s Encrypt certificates had been deployed. This would be a positive sign for Let’s Encrypt’s value to people in those countries. If, alternatively, the country had only a handful of Let’s Encrypt certificates, then it could raise the question of why are users there not using Let’s Encrypt as much as one would expect. This could be due to language barriers on the Let’s Encrypt site, appealing solutions offered by traditional Certificate Authorities, or poor awareness and marketing of Let’s Encrypt in those countries. Figure 4 showcases the aforementioned distribution of Let’s Encrypt certificates worldwide. Notable countries where Let’s Encrypt is popular are Ukraine, Austria, Turkmenistan, Kazakhstan, Australia and South Africa.

### Table V: Certificate Authorities popular domains left to transition to Let’s Encrypt

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Encrypt.

![LE Domains in Alexa top 1M](image)

**Fig. 5: Number of Let’s Encrypt certified domains in Alexa top 1M**

**F. Summary of key observations**

To summarize, the key observations on the acquisition are:

1) 7% of all Let’s Encrypt certificates are requested by companies providing their clients with appliances like routers, modems, NAS or dynamic DNS servers. Companies like Synology, Free and DuckDNS take advantage of the free automated Let’s Encrypt certificates and acquire them in bulk in order to guarantee a secure channel between the client and the web interface of the client-owned device.

2) More than 55% of all Let’s Encrypt certificates have been issued in Western Europe. Countries like Switzerland, France and the Netherlands have an average of 3.9 certificates per 1000 Internet users. Furthermore, Let’s Encrypt has democratized the procedure of obtaining TLS certificates worldwide and therefore in countries like Argentina or Ukraine Let’s Encrypt certificates are over-represented in the population of HTTPS websites by a factor of 5.

3) Anecdotal evidence from Certificate Transparency logs suggests that Let’s Encrypt has become an attractive alternative for users who value the trust and privacy provided by HTTPS but are using either untrusted CAs or are reluctant to pay large amounts of money in order to obtain certificates from one of the more expensive Certificate Authorities.

**V. Analysis of Usage Characteristics**

In this section, we explore how domain owners are using certificates issued by Let’s Encrypt “in the wild”. We estimate the percentage of domains that have obtained multiple, redundant Let’s Encrypt certificates as well as the percentage of domains that obtained but never renewed their Let’s Encrypt certificates. We then run active tests in order to inspect how many domains actually use their Let’s Encrypt certificates during the HTTPS handshake. Additionally, in an effort to detect malice in domains certified by Let’s Encrypt, we leverage the VirusTotal service. Finally, investigate cases of typosquatting domains that are trying to exploit end-users’ trust to HTTPS certified domains.

**A. Active usage analysis**

While Let’s Encrypt’s commitment to certificate transparency [20] provides an unprecedented and valuable view into the TLS ecosystem, it can only serve as an upper bound for expectations. The mere issuance of a signed certificate implies nothing about the certificate’s deployment or utilization over time. One data source that provides useful information about real world deployment is the Censys.io search engine which is powered by regular Internet-wide scans [40]. Censys not only performed full IPv4 scans but also conducts service discovery and follow on protocol handshakes to collect amplifying information which can be used to validate the live deployment of issued certificates.

To this end, we leveraged Censys in order to figure out the gap between issuance of Let’s Encrypt certificates and their actual deployment. The resulting discrepancy between these two values, encouraged us to investigate the case of end users/early adopters that deploy Let’s Encrypt certificates out of curiosity. We measure cases of duplicate certificates issued, and we also measure the percentage of certificates that were issued and never renewed. This information comes exclusively from Certificate Transparency Logs and Alexa records. As a final step, we perform our own active testing on the domains that claim to be using a certificate issued by Let’s Encrypt in order to actually verify our results.

Our results, shown in Figure 6, show that the highest observed total number of certificates does not exceed 253,892 on May 3rd 2016. This is an order of magnitude lower than the naive upper bound discerned from Certificate Transparency logs of 2,799,771 and the more realistic bound of 1,932,242 unexpired certificates as reported by Let’s Encrypt.

![LE Certificates](image)

**Fig. 6: Let’s Encrypt certificates observed by Censys**

Now, some of these may reflect potential gaps in Censys scans. To this end, we also conducted our own active HTTPS scanning. By actually attempting to resolve a domain from the Certificate Transparency Logs and making an active HTTPS request we can safely assert which certificates are active. This addresses the overcounting problem of Certificate

Transparency logs and potential undercounting by Censys. We collected all the unique names from the transparency logs and then ran the sslyze tool, a full featured SSL scanner written in Python, against each of them.

The results of this test are summarized in Figures 7—11. We observe that 90.2% of our domains successfully completed a HTTPS handshake, whereas 9.8% failed. If we take a closer look at the reasons behind the failures we will observe that 16.8% of them can be attributed to DNS failures whereas the majority of failures is due to timeout errors, rejected or incomplete handshakes.

The most interesting observation however is that of the active domains owning a certificate by Let’s Encrypt, only 54% are using that certificate during the TLS handshake. We delved deeper in order to inspect what domains were serving different certificates and what Certificate Authority those certificates were issued from. Table VI shows the results for the top 20 eTLDs that had acquired but were not using Let’s Encrypt certificates.

Interestingly, we find that most of these are hosting services which were acquiring a large number of certificates figures prominently in this list. The most interesting example is again the one of ovh, a France based cloud and web hosting provider, also a platinum sponsor of Let’s Encrypt. ovh promises to provide standard encryption for his services and to use Let’s Encrypt to that end. The fact that they are using AlphaSSL shows that either they have misconfigured their deployment (a rather probable result after manual inspection of selected ovh hosted websites) or they are still in the process of transitioning from AlphaSSL to Let’s Encrypt. Another interesting observation is that many of them were using self-signed certificates; e.g., elbiahosting returns self-signed certificates even though on their website they claim that they have started supporting Let’s Encrypt certificates. At this time, we cannot speculate on their motives for not using the acquired Let’s Encrypt certificates despite their publicly stated intent to do so.

### B. Miscellaneous Characteristics of User Behavior

Next, we shed light on three categories of anecdotal but non-trivial characteristics of user behavior that we observed during our analysis.

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1 One caveat is that sslyze does not take into account SAN domains and only attempts to connect to port 443.

2 The reason behind the high number of timeouts is that SSLyzer only attempts connections to port 443 and does not follow URL redirects. That adds some inaccuracy to the results because as we observed, when we tried to access freeboxos domains, they generated a 302 HTTPS redirect message and thus we categorized them as failures.

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| eTLD      | CA               | #domains |
|-----------|------------------|----------|
| ovh.net   | AlphaSSL-SHA256  | 359757   |
| ovh.net   | AlphaSSL         | 307565   |
| cloudflare.com | COMODO ECC     | 49932    |
| elbiahosting.sk | *elbiahosting.sk | 8549     |
| hosting-admin.net | ssl.hosting-admin.net | 4503 |
| synology.com | Synology Inc.    | 1354     |
| dreamhost.com | smi.dremhost.com | 1287     |
| kasserver.com | COMODO RSA      | 797      |
| planroomcheckout.com | COMODO RSA | 711      |
| pagekite.me | StartCom Class 2 | 406      |

**TABLE VI: top 10 eTLDs and number of domains owning Let’s Encrypt Certificates but not serving them**
Redundant certificates: To originally explain the discrepancy between the Censys results and the number of certificates, we posited that many domains might be issuing redundant certificates. This led us to examine the amount of redundancy. The results showed that on average, 9% of the exact domains in the Transparency Log had issued more than one certificate at the same day, with that percentage reaching around 30% during the months of December 2015 and January 2016 when Let’s Encrypt was still at its first days as a stable product. This shows that to some extent the free nature of Let’s Encrypt certificates triggers the curiosity of users who experiment with the platform and issue more certificates than they need. Even though this has no implications to the actual website as it is up to the webmaster to choose which certificate will be served, a potential implication of that is the unnecessary bloating of Certificate Transparency Logs that now have to keep track of unused certificates.

Non renewal of certificates: To explore further the ‘curiosity’ of end users and their willingness to adopt certificates issued by Let’s Encrypt we also calculated the number of certificates that were issued but never renewed (even though Let’s Encrypt has a policy for automatic certificate renewal every 90 days). We observed that around 15% of all issued certificates were never renewed. We believe that this number describes potential adopters who were willing to experiment with Let’s Encrypt but decided not to continue using its services.

Toy/fake CA: A low-scale but still interesting observation about potential misconfiguration of Let’s Encrypt certificates came from a search in the list of Certificate Authorities that popular domains had obtain Certificates from. One of the CAs that appeared in that list was Happy Hacker Fake CA. We investigated that CA further and discovered that it is managed by the staging server of Let’s Encrypt. This means that some end users during their experimentation with Let’s Encrypt successfully managed to obtain a certificate, only to realize later (if at all) that this certificate was issued by a fake CA. Even though browsers would mark this certificate as untrusted, we believe that for an inexperienced user it would take time until he realized that his website was insecure and untrusted despite his belief about the opposite.

C. Potential use for Malice

Traditionally end users have been ‘trained’ to trust a website if it has the verified certificate symbol against its domain name. However, now with the existence of Let’s Encrypt, an adversary can easily obtain a valid certificate for a malicious or typosquatting domain making an end user fall prey to phishing and drive by download category of attacks.

1) Hosting malware

We make use of the VirusTotal API to detect malicious activity on Let’s Encrypt-signed websites. The VirusTotal API provides a detection ratio depending on how many of these services classified a particular domain as malicious. We were able to obtain a private API key to conduct this measurement and made use of the URL report API to scan a sample of 100,000 domains from the unique domains in our Certificate Transparency database. The reason why we only chose a small (but random) sample of domains was our limited quotas on VirusTotal along with the high latency of executing URL scans. Virus Total allowed us to inspect domain names using 67 different antivirus solutions and reported how many out of the 67 solutions classify the website as malicious.

An interesting first result of our VirusTotal measurements is that 82,524 of the 100,000 sampled domains were scanned for the very first time. This implies that end users, web administrators and even certificate transparency monitors fail to run safety checks on websites to ensure protection from malicious actors. A second scan was therefore conducted to gather the results for all the domains that were scanned for the first time.

\[ \text{Figure 10: Number of websites with Let’s Encrypt certificates that triggered one or more antivirus alerts through Virus Total} \]

Figure 10 shows that around 1% of the websites inspected were found to be malicious by one or more antivirus solutions. Although the total number of domains identified is a very small component of the total number of domains scanned (and of the broader HTTPS ecosystem), we believe that this finding constitutes an indication that malicious adversaries have started to take the ease of issuing TLS certificates as an opportunity to exploit end users’ notion of trust.

2) Typosquatting

As a next step we focused on domains that were most likely being typosquatting \[42\], \[32\]. To determine which of the Let’s Encrypt sites are likely typosquatting, we leveraged a technique based on the Levenshtein distance\[24\], which measures how similar two strings of characters are, where the measure is defined in terms of an ‘edit distance’. Edit distance describes the number of modifications to one string that you need to get the other. By using this technique in a generative fashion, we can create sets of domain names that are a low edit distance away from popular brand names. We searched for domains with close matches (strings with an edit distance of maximum one).

Specifically, we take the Alexa top 250 domain names. We remove those that are less than 6 characters or too common (for example ‘apple’ as the word is too common). Then, we ran a Levenshtein distance generator with a maximum
edit distance of one and removed anything that ended up as a real word (e.g. flickr -> flicker). Thus, we determined a list of domain name misspellings that are similar to other common domains. Then, performed a lookup of this large list of possible misspellings to determine which of them actually appear in the set of Let's Encrypt signed certificates. We ignored changes in the tld level domain. We were careful to remove sites that were obviously not typosquatting, in case they were included in the list due to spelling similarities.

Out of the 105 eligible popular domain names sampled, we discovered 203 likely typosquatting domain matches (e.g. domain within an edit distance of one from the original). We also had to be careful to remove sites that were obviously not typosquatting, in case they were included in the list due to spelling similarities. A sample of the most commonly targeted domains are shown in Table VII along with example URLs.

| Domain Name | Number matches | Example Domain |
|-------------|----------------|----------------|
| Google      | 14             | googlez.fr     |
| Facebook    | 12             | facebook.fr    |
| Reddit      | 12             | reddit.com     |
| Blogger     | 8              | blogges.de     |
| Forbes      | 7              | dorbes.com     |
| Allegro     | 7              | allegu.com     |
| Netflix     | 6              | netflix.desi   |
| Booking     | 6              | booking.com    |

TABLE VII: Sample of top typosquatted target and example typosquatting domains

D. Observations

To summarize, the key observations are:

1) We investigated the actual usage patterns of Let’s Encrypt certificates in order to assess how users interact with the service. We observed that on average 9% of Let’s Encrypt domains have obtained multiple, redundant certificates and 15% of all the certificates obtained have not been renewed.

2) We ran active HTTPS tests to evaluate how many of the domains with an unexpired certificate are actually serving their clients with that certificate. Surprisingly enough, only 54% of the active domains use their Let’s Encrypt certificate whereas 46% use either self-signed certificates or certificates issued by other CAs.

3) To detect malice in the domains we leveraged the VirusTotal service which examines each domain against 67 antivirus solutions and found that 1% of the domains, tested positive for some threat.

4) Further analysis showed that malicious actors are attempting to exploit end users’ trust by using certificates issued by Let’s Encrypt for domains that are either typosquatting.

VI. IMPLICATIONS

In this section, we discuss the potential implications of our observations for different players in the HTTPS ecosystem: Let’s Encrypt, web domains, and end-users and browsers.

Let’s Encrypt: We identify a few key opportunities for Let’s Encrypt to improve adoption and also improve overall efficiency and scalability. Specifically,

- Revisit the need for wildcards: With more and more companies issuing individual Let’s Encrypt certificates for their clients, and with more and more users issuing multiple certificates out of curiosity or need, Let’s Encrypt should consider the option of allowing its users to choose whether they want to issue wildcard certificates or not. The benefit of these actions is clear: Certificate Transparency logs will remain manageable in size as with the current trends, adding around a million certificates on a monthly basis can potentially lead to scalability issues for these logs and performance issues for monitors that want to inspect them or a regular basis.

- Check intent before issuing certificates: Being free and automated lowers the barrier not only for less popular websites but also for abusive purposes. We already see early evidence of the use of Let’s Encrypt for malware-laden websites and typosquatting. One option is that Let’s Encrypt can use well-known tools and approaches from the security community to check if the website has potentially abusive intent before issuing a new certificate; e.g., look at the Google SafeBrowsing history of the site or initiate an active scan on a new certificate request. While this does not offer perfect protection against users (e.g., a newly created domain can be dormant and turn malicious later), this does raise the bar for websites that are already known to exhibit malicious intents.

For Users and Client Browsers: In terms of users and user-facing browsers, we identify two key implications:

- Protect the User through Website Analysis The increasing adoption of HTTPS definitely leads to a safer and more
trusted browsing environment for users who share more and more of their private data online. However, the ease of deployment of Let’s Encrypt certificates has shown that it becomes easier for attackers to exploit that notion of trust in order to deploy ‘trusted’ malicious domains. Specifically, Let’s Encrypt as it lacks supervision in the domains that it signs; it can contribute to the creation of seemingly secure malware-hosting and typosquatting domains. For instance, given that we observe many popular websites are not using Let’s Encrypt, it might be easy to distinguish typosquatting behaviors against popular domains by simply looking at the certificates.

- **Proactively check for configuration errors:** Our observations suggest that there are serious misconfigurations among many website owners who use Let’s Encrypt. Additional documentation, training materials, and native language support could educate these users on proper deployments. Additionally, scanning sites for misconfigurations and alerting the user could provide valuable encouragement for site owners to improve. From the users side, additional transparency about deployment quality can allow users and browsers to proactively check for dangerous connections when accessing newly HTTPS-enabled sites.

- **Use active measurements to complement Certificate Transparency:** We observe that nearly half of all issued certificates are never used, including by domains that are purportedly sponsors of the the Let’s Encrypt effort. This suggests that looking at the transparency log by itself may not be sufficient proof of the “active” status of a certificate and thus we will still need some active measurement system [28, 29] to complement transparency logs.

VII. CONCLUSIONS

The emergence of Let’s Encrypt and Certificate Transparency are promising and potentially revolutionary trends in the HTTPS ecosystem. To fully unleash the potential of these opportunities, however, we need to have a systematic understanding of how users are acquiring and actually using these capabilities. This measurement study is a first look at the adoption characteristics of this emerging ecosystem.

In particular, we find that Let’s Encrypt is being acquired more by less-popular domains and in countries with traditionally lower Internet penetration, which suggests the potential to democratize the benefits of HTTPS. At the same time, however, we do observe a certain degree of “lack of seriousness” in adoption; many certificates are inactive and there are obvious sources of misconfigurations and inefficiencies in how deployed certificates are being used. Finally, we also make a cautionary note that ease of acquisition and low cost can be a double-edged sword. As it improves accessibility, it also lowers the barriers for malicious uses. We see early evidence of potential sources of abuse of Let’s Encrypt by malicious websites hosting malware and/or typosquatting.

We discussed key implications for different players in this ecosystem and how they can use these findings to take actionable measures. For instance, Let’s Encrypt could offer new capabilities to offer wildcard certificates to reduce load. There may also be a need to check for abusive intent through a community-run warning system. Finally, browser vendors and users can take easy precautions to detect misconfigured deployments to avoid privacy violations.

As with any study looking at an emerging phenomenon, our datasets invariably have some limitations and biases. Despite these, we believe that our analysis has shed light on some key observations on the adoption. These have important implications that can inform the future of these technologies. We hope that our analysis and results inspire future measurements and can translate into action items for various parties involved.

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