# A First Look at Third-Party Service Dependencies of Web Services in Africa

Anonymous

No Institute Given

**Abstract.** Third-party dependencies expose websites to shared risks and cascading failures. The dependencies impact African websites as well *e.g.,* Afrihost outage in 2022 [19]. While the prevalence of third-party dependencies have been studied for the globally popular websites, Africa is largely underrepresented in those studies. Hence, in this work, we analyze the prevalence of third-party infrastructure dependencies in Africa-centric websites from 4 African vantage points. We consider websites that fall in one of the four categories: *Africa-visited* (popular in Africa) *Africa-hosted* (sites hosted in Africa), and *Africa-dominant* (sites targeted towards users in Africa), and *Africa-operated* (websites operated in Africa). Our key findings are: 1) 93% of the *Africa-visited* websites critically depend on a third-party DNS, CDN or CA. In perspective, *US-visited* websites are up to 25% less critically dependent. 2) 97% of *Africa-dominant*, 96% of *Africa-hosted*, and 95% of *Africa-operated* websites are critically dependent on a third-party DNS, CDN, or CA provider. 3) The use of third-party services is concentrated where only 3 providers can affect 60% of the Africa-centric websites. Our findings have key implications for the present usage and recommendations for the future evolution of Internet in Africa.

## 1 Introduction

The websites we use everyday offload critical services such as name resolution (DNS), content distribution (CDN) and certificate issuance/revocation (CA) to third parties for key services *e.g.,* AWS Route 53 for DNS, Akamai for CDN, DigiCert for CA. As a result, the availability and security of these websites, and thus of our data and operations, depend on the availability and security of those third parties. The effects of such dependencies are routinely observed in the Internet today. For example, a dependency on DNS, resulted into multiple websites (more than 100K) taken down for several hours together with their DNS provider (Dyn) which was attacked by a Mirai DDoS attack [26]. Similarly, users of multiple websites lost access to their accounts for weeks, because a single CA issued an incorrect revocation of a certificate in 2016 [24].

To gauge the security risk that such dependencies entail, one needs to understand the prevalence of third-party dependencies across the websites that are important for users all over the world. While such studies exist [29, 27, 28, 47, 53, 34], their target users/websites are particularly skewed towards North America and Europe.

The geographical bias of the datasets used in previous studies of third-party dependencies creates a critical gap as distinct regions exhibit unique characteristics, needs and opportunities that are effectively ignored. Naively assuming that observations generalize across regions, entails risks as it underestimates the practicality of certain attacks and creates false assurance of the security of critical region-specific websites (*e.g.,* those related to government or health insurance in those countries). This is also recognized by the Internet Society's Measuring Internet Resilience in Africa (MIRA) project [46].

To contribute towards bridging this gap, in this paper we study third-party dependencies of websites in Africa. Our study is motivated by the increasing number of DDoS attacks in Africa[4], the increasing popularity of third-party services, the low cyber readiness of African users and businesses [40]. These are exemplified by various recent attacks. For example, in July 2022, Afrihost, one of the major hosting and DNS providers in South Africa, went down for 30 hours due to load shedding which caused a cooling equipment failure in one of Afrihost's datacenters. Moreover, the relative scarcity of local providers urge website operators to rely often solely on global service providers such as Amazon, Akamai, Cloudflare whose outages also affect users, and websites from Africa.

Beyond raising awareness on the unique security challenges that African users and operators face, our study contributes to the resilience of the Internet in Africa. Concretely, we aim to provide stakeholders, and operators with more tailored insights, to help them avoid common pitfalls in using third-party dependencies, understand their attack surface, and optimize their defense strategies towards the most pressing needs.

To investigate third-party dependencies in African websites, we focus on websites which are *Africa-centric*, *i.e.,* websites that are popular in Africa (*Africa-visited*), or predominantly targeted towards Africans (*Africa-dominant*), or are hosted in Africa (*Africa-hosted*), or are operated in Africa (*Africa-operated*). We investigate their dependencies using four measurement vantage points in Africa (Nigeria, Rwanda, South Africa, Kenya). Specifically, our measurement study focuses on answering the following questions: First, how prevalent are third-party dependencies in the *Africa-visited*, *Africa-hosted*, *Africa-operated* and *Africa-dominant* websites? Second, how centralized are third-party dependencies among providers used in *Africa-visited*, *Africa-hosted*, *Africa-operated* and *Africa-dominant* websites? Finally, how does the dependence on third parties in Africa compare to the US?

Our main findings are as follows: First, third-party dependencies are 5% to 12% more prevalent in Africa as compared to the US. Moreover, for more popular sites, this gap increases up to 25%. Second, 93% of *Africa-visited*, 97% of *Africa-dominant*, 96% of *Africa-hosted*, and 95% of *Africa-operated* websites are critically dependent on a third-party DNS, CDN, or CA provider. Second, all vantage points in Africa are equally critically dependent on third-party DNS, CDN and CA providers. Third, the top-three DNS, CDN or CA providers for *Africa-centric* websites serve as sole providers up to 60% of the websites. Finally, the top providers for *Africa-visited* websites are mainly global providers (*e.g.,* Cloudflare, Amazon etc.). However, for the hosted, dominant and operated sets, we observe some local providers among the top providers.

Our findings have key implications for the present usage and recommendations for the future evolution of Internet in Africa. The high degree of centralization of providers and third-party dependencies make African websites vulnerable to various exploits, and availability attacks. While these dependencies mirror trends in other countries such as the US, there are some unique threats. First, Africa has unreliable Internet infrastructure which makes outages more commonplace [45, 15, 42] as observed in the Afrihost outage due to load-shedding [19]. Secondly, African website operators and service providers lack cyber expertise [40], due to which it can take longer for them to recover from an outage. By studying this issue in the African context, we highlight the need to build more resilient Internet infrastructure in Africa.

## 2 Preliminaries

Before we formally define our measurement goals, we define a set of actionable metrics that we use throughout our analysis. These metrics have been taken from Kashaf et al. [29]. We also articulate several research questions, that we aim to answer in this study.

### 2.1 Dependency Metrics

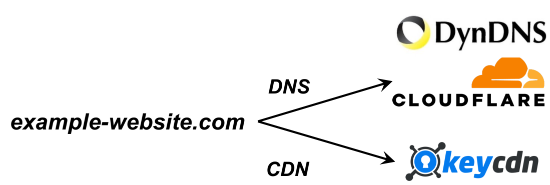



Fig. 1: *example-website.com* has a dependency on CloudFlare DNS and Dyn DNS. Moreover, it has a dependency on KeyCDN for CDN services. Since, it uses a single CDN provider, it has a critical dependency on KeyCDN. However, it is redundantly provisioned with respect to DNS as it is using two DNS providers.

When a website uses another entity for a particular service (*e.g.,* DNS), we say that the website has a **third-party dependency** on that service provider. We illustrate this in Figure 1. Here, *example-website.com* uses an entity other than itself for a particular service (here DNS and CDN). Therefore, *example-website.com* has a third party DNS dependency on Cloudflare and Dyn DNS, and it has a third party CDN dependency on KeyCDN. *example-website.com* in Figure 1 uses only a single CDN provider. Hence, it has a **critical dependency** on KeyCDN. However, since *example-website.com* uses two DNS providers, it is **redundantly provisioned** with respect to DNS and does not have a critical dependency on Cloudflare or Dyn DNS.

For DNS and CDN, we measure critical dependency by analyzing if a given website is redundantly provisioned or not. However, in case of CA dependency, a website is critically dependent on a CA if it does not support OCSP stapling. If OCSP stapling is enabled, the user accessing a given website does not have to contact the OCSP server to check the website certificate for revocation. Instead, an OCSP response signed by the certificate authority comes stapled from the website server itself, thus removing the dependence on OCSP server [10].

**Concentration of a service provider** The number of websites dependent on a service provider gives the concentration of that service provider.

**Impact of a service provider** This gives the number of websites critically dependent on a service provider.

### 2.2 Taxonomy of Websites

To systematically study third-party service dependencies in Africa-centric web services, we create a taxonomy of websites based on *(i)* who are their users; *(ii)* who operates them; *(iii)* where are they hosted; and *(iv)* who are their dominant users. In this section, we define those classes precisely at the granularity of a country.

**Users of a website** are the people who visit the website. A website may be used primarily by people from a single country (geolocation) or from multiple countries. We define $u_C$ as the Internet user, who is geographically located in country $C$.

**Owner/Operator of a website** is the entity or person that builds and manages the website, takes the security decisions, defines its privacy policy, etc. A website may have operators in a single country or in multiple countries. We define $o_C$ as the a website operator in country $C$.

**Host of a website** is the country (or countries) in which the the servers running the website are. We use the notation $h_C$ to specify that the hosting location of the website is in the country $C$.

**Dominant country for a website** is the country which has the majority traffic share for that website. We use $d_C$ to denote the dominant country for a website.

Using this taxonomy, we define the following website sets:

***Country-visited* websites $W_C^{visited}$:** This set comprises of websites which are used/visited by users $u_C$ of country $C$. In other words, this includes websites which are popular in country $C$.

***Country-dominant* websites $W_C^{dominant}$:** This set comprises of websites that have the majority of their users in country $C$. It may be operated or hosted by a single or multiple countries. This set contains websites which are specifically targeted towards a particular demographic. Studying this set is important because it includes websites that may not be very popular but are essential for African users such as government websites, hospital websites.

| Who uses it? | Who operates it? | Who hosts it? | Who is it for? | Website sets |
|---|---|---|---|---|
| $u_C$ | - | - | - | $W_C^{visited}$ |
| - | $h_C$ | - | - | $W_C^{hosted}$ |
| - | - | $o_C$ | - | $W_C^{operated}$ |
| - | - | - | $d_C$ | $W_C^{dominant}$ |

Table 1: We consider three sets (categories) of websites for our analysis which differ in the location of their users (usage), the location in which they are hosted (hosting) and their audience.

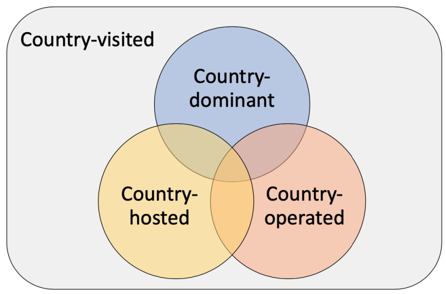



Fig. 2: The *country-dominant*, *country-hosted*, *country-operated* website sets overlap with each other, and they are all subsets of the *country-visited* set.

***Country-operated* websites $W_C^{operated}$:** This set comprises of websites operated by country $C$. These websites may have users from single or multiple countries and may be hosted by a single or multiple countries. Studying this set facilitates investigating the implications of third-party dependencies from the perspective of African website operators.

***Country-hosted* websites $W_C^{hosted}$:** This set comprises of websites that are hosted in country $C$. Each of these websites may have users from single or multiple countries and may be operated in a single or multiple countries. Studying this set is important because it often contains sensitive websites which need to remain local such as banking websites, hospital websites etc.

### 2.3 Research Questions

Given these definitions, we now define our main research questions that we answer in this paper.

- How prevalent are third-party critical CDN, DNS and CA dependencies in Africa-centric websites?
- How centralized are third-party dependencies among providers that serve Africa-centric websites?
- How does the state of third-party service dependencies in African countries compare to the US?

## 3 Dataset

We perform measurements from four vantage points through VPN servers located in Kenya (KE), Rwanda (RW), South Africa (ZA) and Nigeria (NG). We choose these vantage points as they provide us with a vantage point in each of South, East, West and Central Africa. We prepare country specific website sets for each country, and then use the same country as vantage point to carry out measurements. For example, we study *NG-visited* websites from NG. This section explains our methodology for collecting websites for each country and set of interest. We summarize our sets in Table 2.

One could looking at all existing websites that belong in the categories we defined in Section 2. To make the sets more tractable and focus on the most impactful websites we start from the websites that are popular in each African country which constitutes the *country-visited* set $W_C^{visited}$. This helps in identifying websites which can impact the African Internet users, website operators and the Internet economy of African countries the most.

We use the Chrome User Experience Report (CrUX) dataset [25] to get the top 10K popular websites in each selected African country. This dataset is curated monthly by aggregating browsing data of Chrome and Chromium users who have opted in for browser history and usage statistic reporting. These browsers constitute for more than 80% traffic in our countries of interest [54]. CrUX is ranked by the number of completed pageloads.

CrUX dataset is aggregated by web origin (e.g., https://google.com). For DNS analysis, we need domain names, and using web origin may result in multiple entries for the same domain. Hence, we normalize this dataset by grouping web origins by domain names, and choose the smallest rank value as the rank for each domain. This same normalization technique has been previously done in [52] and is shown to be accurate at capturing popular websites. [52] also shows that CrUX is better at capturing popular websites than other top lists as defined by visit and visitor metrics. In addition, most top lists only give popular websites in the world. However, for this analysis we need regional popular websites, and found that CrUX dataset is a good source for that. We build our websites sets based on the CrUX dataset, and the definition of website sets can be found in Table 1.

**Dataset for *country-visited* websites:** We use the CrUX dataset of top 10K websites, for NG, RW, KE, ZA and US. We normalize this dataset for each country, by grouping web origins by domain names as mentioned above. This gives us the *country-visited* $W_C^{visited}$ dataset for each country.

The *country-dominant*, *country-hosted* and *country-operated* website sets are built from this dataset with the relationship shown in Figure 2 by the following rules:

**Dataset for *country-dominant* websites:** As defined in Section 2, *country-dominant* websites are made for users located in corresponding African country. A naive approach to collecting such a list is to filter websites by their ccTLD[2]. However, this approach would result in many false positives because some domain registrar give .ccTLD domains to anyone. For example, `parse.ly` has the Libyan

| | dominant | hosted | operated | visited |
|---|---|---|---|---|
| Kenya | 1486 | 274 | 199 | 8433 |
| Nigeria | 1675 | 77 | 143 | 8440 |
| Rwanda | 698 | 208 | 20 | 7867 |
| South-Africa | 3000 | 1558 | 246 | 8434 |
| US | - | - | - | 7854 |

Table 2: Datasets sizes with respect to country

ccTLD, but the website is not made for or visited by Libyan users [1]. Therefore, we combine multiple heuristics to collect the *country-dominant* websites. Concretely, a website belongs to *country-dominant* if it belongs to *country-visited* set which is the top 10K visited websites and satisfies one of three requirements. First, we pick websites with African ccTLDs. Observe that this filtering is different from the previous heuristic as we require that the website is popular in that country as well. Second, the website hostname contains Africa or the name of an African country. Again, while this heuristic would alone cause false positives *e.g.,*`ancient-egypt.org`[2] intersecting it with the popular sites in Africa considerably decreases those cases. Finally, the website contains the phone number of that country. To conclude, we define *country-dominant* websites $W_{dom-afr}$as:

$$W_C^{dominant} = (W_C^{ccTLD} \cup W_C^{substr} \cup W_C^{phone}) \cap W_C^{visited}$$

**Dataset for *country-hosted* websites:** To find websites hosted in an African country, we perform an IP geolocation lookup using the Maxmind GeoLite database [39], and the `ipinfo.io` [1] database for IPs missing in the maxmind db. Instead of performing IP geolocation lookup on all existing websites, here also we only look at websites which are hosted in corresponding country, and are also popular in it *i.e.,* are in the $W_C^{visited}$ set.

**Dataset for *country-operated* websites:** To find websites operated in a given country, we look at the privacy policy and terms and conditions of websites to identify the country of interest. For example, in *murukali.com*, their terms and conditions page mentions, "These Terms of Service and any separate agreements whereby we provide you Services shall be governed by and construed in accordance with the laws of Rwanda." We use python geograpy library [49] to extract geolocation mentions in the privacy policy or terms. We include only those websites for which we get only a single country name, to decrease the number of false positives in classifying a website as being operated in a given country.

1 https://www.similarweb.com/website/parse.ly/#geography
2 https://www.similarweb.com/website/ancient-egypt.org/#geography

## 4 Methodology

We are interested in measuring the third-party dependencies of *Africa-centric* websites on authoritative Domain Name Servers, Content Delivery Networks, and Certificate Authorities for revocation information (OCSP servers and CRL distribution points).

To capture dependencies as observed by African users, we need to measure from multiple locations in Africa. Yet, accessing servers in various locations within Africa is challenging, due to the limited offered coverage from cloud service providers. To address this challenge, we combine the limited cloud presence with VPN services (PrivateVPN [48], ExpressVPN [23]) whose true location we diligently verified. We perform our measurements from four vantage points in Africa, scattered in East, West, South and Central Africa. Particularly, our vantage points are in South Africa, Nigeria, Kenya and Rwanda. For the South Africa vantage point, we use AWS, while all others are VPNs. To verify the location of the VPN server, we ping the server from different locations to identify the location with the smallest ping using online services like *ping.pe*, we also perform traceroute and we separately also reached out to the VPN provider to confirm the location of the VPN.

**DNS Measurements:** Given a website, we find out, 1)If the website has a dependency on a third-party DNS provider? If so, 2) Is the website critically dependent on that DNS provider, or is it redundant? To find out the authoritative name servers, we use dig [3] (Domain Information Groper) which is a command-line tool to fetch the NS (nameserver) records which give the records for authoritative nameservers of a given website. To identify third-party nameservers, we follow the methodology documented in Kashaf *et al.* [29]. Particularly, we use top-level domain (TLD) matching [33], subject alternate name (SAN) lists [5], and start-of-authority (SOA) DNS record [12] to classify a nameserver as a third-party. We get 12825 distinct (website, nameserver) pairs for *KE-visited*, 12287 pairs for *NG-visited* and 12792 pairs for *RW-visited*, and 14336 for *ZA-visited* websites of which 3% remain uncategorized as third-party or private for ZA, 4% for RW, 3% for NG and 2% for KE, and 3% from US. Hence, we conservatively exclude the websites involving them from our analysis. After identifying the third-party nameservers, we need to check if a website is redundantly provisioned. To do this, we group the nameservers of the websites by TLD, and SOA records as documented in Kashaf *et al.*. Nameservers in the same group are considered to belong to the same provider. We observe 1010 distinct nameservers for KE, 1170 for NG, 1078 for RW and 980 for the ZA, and 1274 for US.

**Certificate Revocation Measurements:** Given a website, we are interested in knowing, 1)If the website has a dependency on a third party CA provider? If yes, 2) Is the website critically dependent on that CA, or has it enabled OCSP Stapling? We extract the CRL distribution points (CDP) and OCSP server information from the SSL certificate of the website. To fetch certificates, we first send an SYN on TCP port 443 to see if the website supports HTTPS. If we receive a Connection Refused error, then it means the website does not support HTTPS. Next, we initiate an HTTPS connection with it and fetch the SSL certificates.

In the *NG-visited* websites, 94.0% support HTTPS, 95.7% support HTTPS in *KE-visited*, and 94.3% support HTTPS in the *RW-visited*, 95.2% in *ZA-visited* and 94.6% in *US-visited*. We observed 22 distinct CAs for NG, 26 distinct CAs RW, 24 distinct CAs for KE, 23 distinct CAs for ZA and 23 distinct CAs for US. We classify the CAs as third party, again using TLD matching, SAN list and SOA records [29].

Certain private CAs issue certificates and provide revocation checking for their own domains only, e.g., Microsoft, etc. Therefore, we use the same heuristics as mentioned for DNS to classify whether OCSP servers and CDPs are private or third parties as in [29]. Next, to see if a website has a critical dependency on OCSP servers and CDPs, we check if it has enabled OCSP Stapling using OpenSSL [58]. If enabled, the certificate's revocation status comes stapled from the webserver when a user visits the website, requiring no online revocation check from the OCSP server. To measure OCSP stapling, we obtain the certificate for each website using OpenSSL [58]. An OCSP response stapled with the certificate implies support for OCSP stapling.

**CDN Measurements:** To find CDNs that a website uses, we look at CNAME redirects for the internal resources of a webpage. If the website is using a CDN for a particular resource, the CNAME of that resource will point to the CDN as done by [29]. First, we render the landing page of the website using puppeteer [6], and record the URL of all the resources retrieved by a website. Then we use TLD matching and SAN lists to identify the internal resources [29]. Then we query the CNAME for all internal resources of the webpage, and use CNAME-to-CDN map from the prior work [29], which we verified and extended to include African CDNs. Then we classify a CDN as private or third party by using the same TLD matching, SAN Lists and SOA records as done in [29]. We find that 18.5%, 23.9%, 19.6%, 22.0%, and 40.4% use CDN for *NG-visited*, *RW-visited*,*KE-visited*, *ZA-visited* and *US-visited*. We observe 56 distinct CDNs for NG, 59 CDNs for RW, 59 CDNs for KE, 55 CDNs for ZA and 60 CDNs for US.

### 4.1 Limitations

- Our analysis considers only four vantage points in Africa. It is possible that the dependencies in countries for which we do not have more vantage points vary greatly. While we accept this limitation, however, getting vantage points in some of African countries is extremely hard due to the lack of mature Internet infrastructure, including VPN server presence.
- We only look at popular websites. While this may overlook certain websites, studying for all possible websites is not feasible. We argue that this is a reasonable compromise as popular websites will be the ones which impact African users, and businesses the most.
- Our heuristics for *Africa-dominant* websites may have false positives and negatives. However, the correct way to find *Africa-dominant* websites would be to check the total traffic share of different countries for each website and then choose those that have the largest traffic share from Africa. We had to

use this heuristics because the data for per country traffic share of a website is not available.
- We also inherit the limitations of the Kashaf *et al.* [29] as we replicate their methodology.

## 5 Findings

In this section, we first analyze third-party dependencies in *Africa-centric* websites, and use US as a baseline. Next, we analyze provider concentration to identify single points of failure in the African web ecosystem.

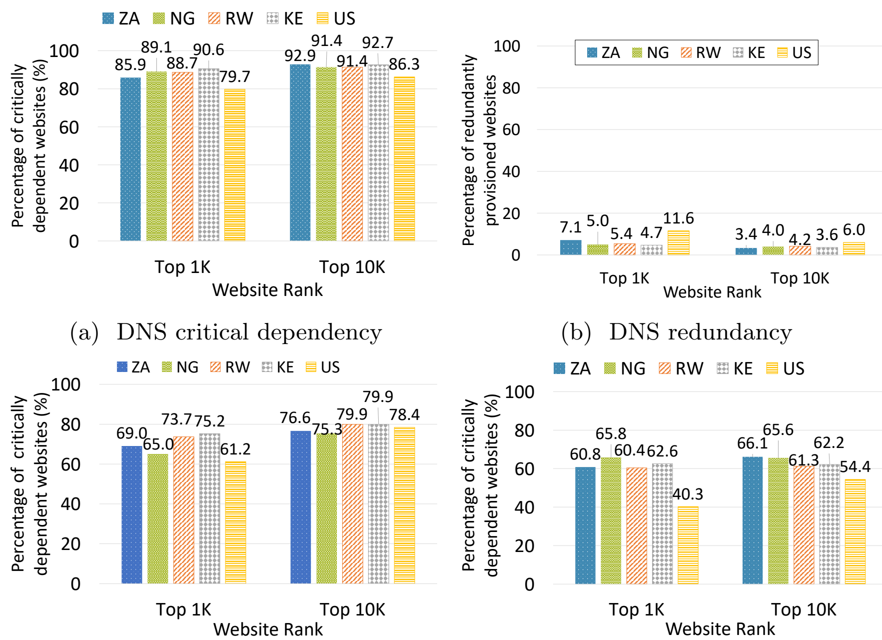
### 5.1 Third-party dependencies

**Observation 1**: ***93% of Africa-visited websites are critically dependent on third party CAs, CDNs and DNS. In perspective, US-visited websites are up to 25% less critically dependent.***

Figure 3 illustrates the portion of portion of *US-visited ZA-visited*, *NG-visited*, *RW-visited* and *KE-visited* websites that are critically dependent or redundantly provisioned as a function of the particular service and as measured by vantage points that are in the corresponding region. Concretely, Figure 3a shows the percentage of critically dependent websites on DNS in African countries, and the US. We observe that for DNS, critical dependency in *US-visited* is 5% to 7% less as compared to the African countries. Interestingly, when we look at more popular websites (top 1K), this gap further increases (6% to 10%) as shown in Figure 3a. This means that web users from US are comparatively less vulnerable, especially if they are using particularly popular websites, as compared to African users. This result is intuitive, as more popular websites in US (*e.g.,* top 1K) care more about availability as compared to local African websites.

Figure 3b illustrates the percentage of redundantly provisioned websites in DNS. We observe that there is not much difference (2%) between *US-visited* websites and *Africa-visited* websites. However, when we look at more popular websites (top 1K), the gap increases by 5% to 7% from 2%. At the same time, we find that the use of private DNS is only 3% to 4% higher in *US-visited* websites (not shown) and becomes 2% to 5% when we look at more popular websites (also not shown). This means that critical dependency in more popular *US-visited* websites is reduced because of increase in redundancy instead of use of Private DNS. However, for *Africa-visited*, there is not much significant increase in redundancy for more popular websites, except South Africa.

Figure 3c compares the critical CDN dependency in *US-visited* with *Africa-visited* websites. Overall, we found that 22%, 18%, 23% and 19% websites use a CDN in *ZA-visited*, *NG-visited*,*RW-visited* and *KE-visited* websites, while in *US-visited*, 40% websites use CDN. In the top 10K, critical CDN dependency in

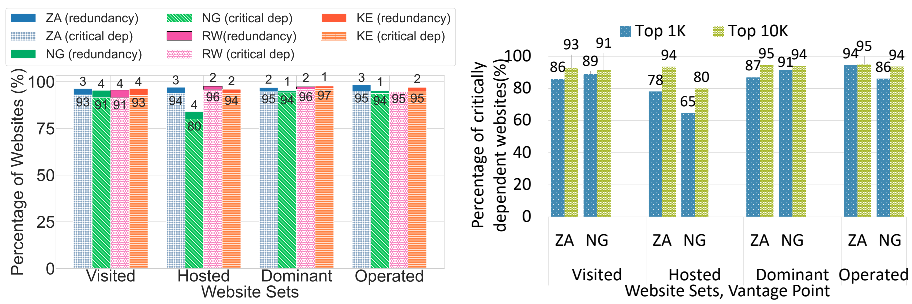



(a) DNS critical dependency (b) DNS redundancy

(c) CDN critical dependency (d) CA critical dependency

Fig. 3: (a) Critical dependency in DNS for top 10K US-visited sites when measured from a US vantage point is 5% to 7% less than the top 10K Africa-visited websites. This gap in critical dependency increases to 6% to 10% in the more popular (top 1K) websites. (b) Percentage of websites which are redundantly provisioned is slightly higher (2%) in the *US-visited* websites as compared to the *Africa-visited* websites. However, when we look at more popular websites (top 1K), for *US-visited*, the percentage of redundantly provisioned websites is 5% to 7% higher than the *Africa-visited* websites. (c) Critical dependency in CDN for top 10K US-visited sites is similar to the top 10K Africa-visited websites. However, for more popular websites, US-visited sites are 4% to 15% less critically dependent than Africa-visited sites. (d) Critical dependency in CA for top 10K US-visited sites when measured from a US vantage point is 7% to 12% less than the top 10K Africa-visited websites. This gap in critical dependency increases to 20% to 25% in the more popular (top 1K) websites.

*US-visited* is comparable to the *Africa-visited* websites. We find the number of redundantly provisioned websites is also similar (not shown here). When we look at more popular websites (top 1K), the critical CDN dependency in *US-visited* is 4% to 14% less than *Africa-visited* websites. The use of private CDN remains negligible in *US-visited* and *Africa-visited* websites (not shown here). Moreover, the percentage of redundantly provisioned websites in top 1K is 5% to 15% higher for *US-visited* as compared to *Africa-visited* websites. So the reduced critical dependency as we move towards more popular websites in *US-visited* websites, is because of increase in redundancy.




(a) (b)

Fig. 4: (a) Third-party critical DNS dependency is highly prevalent (more than 90%) in Africa-centric websites when measured from all the four vantage points. In the case of Nigeria, the critical dependency in the NG-hosted websites is less. However, NG-hosted websites only constitutes 1% of the total websites for Nigeria in our dataset. (b) Across all website sets, we found that as we move from more popular websites (top 1K) to less popular websites (top 10K), the percentage of critically dependent websites increases. This means that more popular websites are more resilient in our African vantage points.

Figure 3d shows the percentage of websites critically dependent on CA in the *US-visited* and *Africa-visited* websites. We find that the number of websites that support HTTPS is similar in *US-visited* and *Africa-visited* websites (not shown). Recall that for CAs, critical dependency is measured in terms of whether a website supports OCSP stapling or not. We find that *US-visited* websites are 6% to 12% less critically dependent on CAs compared to *Africa-visited*. Moreover, as we move to more popular websites (top 1K), we find that the gap in critical dependency between *US-visited* and *Africa-visited* websites further increases to 20%-25%. This low adoption of OCSP stapling can be attributed to low cyber readiness in Africa. Furthermore, in US there have been many efforts to promote OCSP stapling, particularly by popular CDN providers such as Cloudflare, Amazon Cloudfront and Akamai. Since the adoption of CDNs in *Africa-visited* websites is low, this could explain the lower adoption of OCSP stapling.

---

**Observation 2**: ***Critical DNS dependency in Africa-centric websites is extremely prevalent (92% to 97%), leaving users highly exposed. Third-party critical DNS dependencies are higher in more popular websites compared to less popular ones.***

---

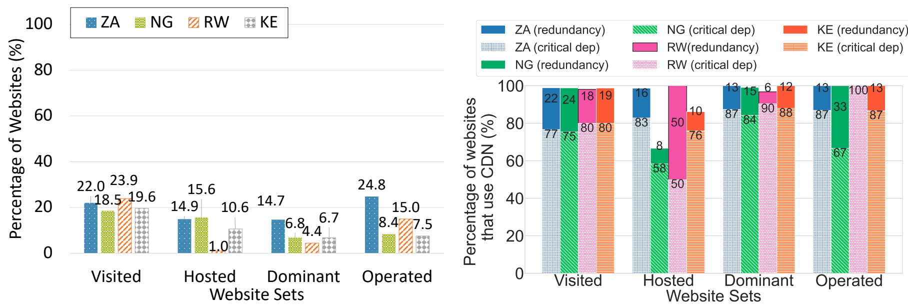
To further investigate the result of Figure 3a and Figure 3b, Figure 4a also shows critical dependency and redundancy of websites in a third-party DNS provider, but distinguishes them between visited, hosted, dominant and operated website sets. For the set of visited websites, the critical DNS dependency is very high 91% to 93% and stable across countries. This shows that users in Africa from these countries are equally vulnerable to the side effects of DNS third-party dependencies. If we look at the hosted websites, we find that *NG-hosted* websites have less critical dependence compared to other African countries. Concretely, the third-party DNS dependency is only 84% in *NG-hosted* websites. We find that this is due to two key reasons. First, many websites belonging to Meta (*e.g.,* facebook.com, freebasics.com, whatsapp.com etc.) are locally hosted in Nigera, and these websites use private DNS. Indeed, we confirmed their hosting by pinging them from Nigeria. Second, the *NG-hosted* sets contain only a small number of websites 2 making the Meta associated domains statistically significant.

For dominant website sets, we find that the critical dependency in all African websites is very high, concretely 94% to 97%. In fact, the websites that predominantly target African Internet users are more vulnerable than *Africa-visited* websites, with a difference of 2% to 5%. There is almost negligible redundant provisioning in this set. For operated websites, again the critical dependency is 94% to 95% with negligible redundant provisioning. This trend in general shows that no matter where in Africa users are, or what they visit, they are highly vulnerable to the side-effects of third-party DNS dependencies. Moreover, the fact that the trend persists across all African countries that we studied shows that the situation is dire for the entire continent. In fact, the countries for which we have results have relatively more developed Internet infrastructure.

Figure 4b shows the critical dependency for the top 1K and top 10K websites for ZA and NG. In general, we observe that as we move towards more popular websites (top 1K), the critical dependency decreases across all website sets for both ZA and NG. This is partly because of increase in the number of websites using Private DNS (not shown). For example, for ZA, third-party dependency decreases by 4% for *ZA-visited*, and *ZA-dominant*. For *ZA-hosted* it decreases by 8%, while for *ZA-operated* it remains the same. In addition to the increase in private DNS, we also observe an increase in redundantly provisioned websites. For example, in the case of ZA, redundantly provisioned websites increase from up to 4% in top 10K, to 6%-12% in the top 1K. We observe similar trend in NG, KE and RW. While the increase in redundancy for more popular websites is encouraging, it is still far from ideal. Even for more popular websites, third-party dependencies are highly prevalent. Across different website sets, we see more encouraging trends. For example, the hosted websites in the top 1K are far less critically dependent than the other website sets. However, this trend is only for ZA and NG and does not appear in KE and RW where it is more similar to the other sets. In NG, this decrease in critical dependence is primarily because of the use of Private DNS. For ZA, however, this is because some of the websites using global providers are using multiple providers, and also because all the websites using TENET South Africa as DNS, are redundantly provisioned.

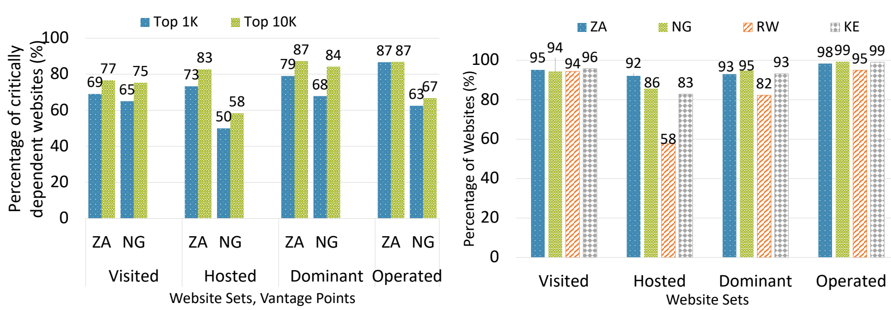
---

**Observation 3**: ***Among the websites that use CDN, critical dependency is prevalent (75% to 80%); although less compared to DNS. Third-party critical dependencies in CDN are higher in more popular web-***




(a) (b)

Fig. 5: (a) The percentage of websites that use CDN is less in the specialized sets such as hosted, dominant and operated as compared to the visited set except for ZA. (b) Critical dependency on CDNs for Africa-centric websites is less prevalent as compared to critical DNS dependency. For the dominant website set, this dependency is much higher.




(a) (b)

Fig. 6: (a) Critical CDN dependency is lower for more popular websites, as compared to less popular websites. (b) Support for HTTPS is very high in Africa-centric websites, with the exception of hosted website sets.

***sites compared to less popular ones.***

Figure 5b shows the critical dependency and redundancy in websites that use CDN for different website sets. Here, the sum of critical dependency and redundancy gives the total third-party dependency. The number of websites that actually use a CDN in each set is shown in Figure 5a. In the visited sites, 18.5% to 23.9% use a CDN. In general, we observe a decrease in critical dependency as compared to DNS. In case of visited websites, *ZA-visited* and *NG-visited* are slightly less critically dependent and are slightly more redundantly provisioned as compared to *RW-visited* and *KE-visited* websites. The use of Private CDN in across all vantage points of the visited set is less than 1%, which is not surprising. For the hosted set, *NG-hosted* has a higher percentage of websites with private

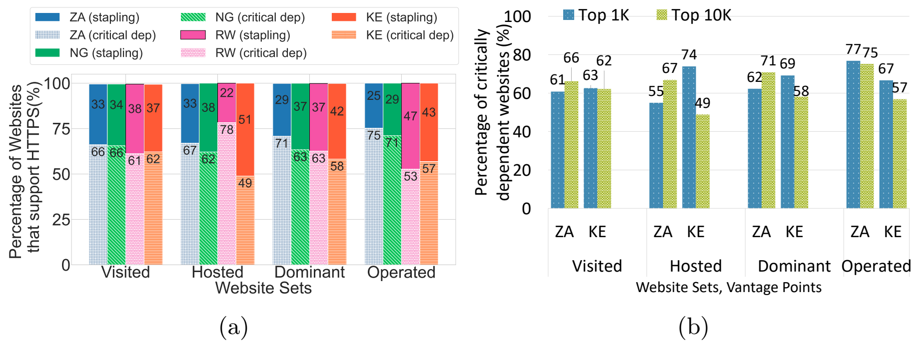



Fig. 7: (a) Third party CA critical dependency is less prevalent in Africa-centric websites as compared to DNS dependency. Moreover, Kenya and Rwanda are less critically dependent in the hosted, dominant and operated sets as compared to South Africa and Nigeria. (b) Increase in popularity does not change the prevalence of critical CA dependencies in Africa-centric websites. In fact, for Kenya (and also Nigeria and Rwanda), critical CA dependency increases as we move towards more popular websites.

CDN (100-58+8). This is also because of the websites affiliated with Meta use their own private CDN. We ignore the trend in *RW-hosted* websites, as only 1% (2 websites) use CDN. *KE-hosted* websites are less critically dependent than *KE-visited* websites; this is also because of the private CDN using Meta domains, which becomes statistically significant because not many *KE-hosted* websites use CDN. For *ZA-hosted* websites, the critical dependence is higher than *ZA-visited* websites. It is unclear why this is the case as the CDN providers for both sets are similar. For the dominant website set, we find that all the countries have more critical dependences compared to the visited set. This means that websites which predominantly target African users are more vulnerable. However, as shown in Figure 5a, only a very small number of websites in the dominant website set use CDN.

In the case of operated websites, the critical dependency is high for *ZA-operated*, *KE-operated* and *RW-operated* websites. We do not see a specific reason for which the *NG-operated* are less critically dependent. The adoption of CDN in the specialized sets of hosted, operated and dominant is very less to have any significant impact.

Figure 6a shows the change in CDN critical dependency as we move from more popular (top 1K) websites to less popular websites (top 10K). For example, for ZA, the critical dependency for more popular websites is 8% to 10% lower than less popular websites (except the operated set). We observe a similar trend for RW and KE. This reduction in critical dependency for more popular websites is because more popular websites are more redundantly provisioned. The use of private CDN remains negligible for top 1K and top 10K websites (not shown here).

---

**Observation 4**: ***In the case of CA critical dependency, 40% to 75% of the Africa-centric websites are critically dependent. For the hosted, dominant and operated website sets, more popular websites are more critically dependent.***

---

Figure 6b shows the number of websites that support HTTPS. HTTPS adoption is in general very high in Africa-centric websites, which is encouraging. However, there are a few notable exceptions. For example, HTTPS adoption is low particularly in the *RW-hosted* websites. It is also low for *NG-hosted* and *KE-hosted* when compared to the visited websites. For RW, the *RW-dominant* website set also has lower HTTPS adoption as compared to other countries.

Figure 7a shows the percentage of websites that are critically dependent among the total HTTPS supporting websites. In general, we find that critical dependency on CAs is less compared to DNS. In the visited website set, 33% to 38% of the websites that support HTTPS, also support OCSP stapling. In case of hosted websites, the trend remains largely similar for ZA and NG. For RW, which already has only 58% HTTPS (Fig 6b supported websites in *RW-hosted* website set, for the remaining websites, only 22% support OCSP stapling. This means that *RW-hosted* websites leave the African users particularly vulnerable. More alarming is the fact that more than half of these websites that are critically dependent are government websites ending with *.gov.rw*. For KE, 51% of the *KE-hosted* websites support OCSP stapling, which is encouraging. OCSP stapling support in Kenya is in general better for all website sets as compared to other countries. In case of RW, OCSP stapling support is also good except for the *RW-hosted* websites. OCSP Stapling support for ZA is not very encouraging compared to other African countries. The *ZA-operated* and *ZA-dominant* websites are particularly more vulnerable than the respective sets in other countries. This means that ZA Internet users are vulnerable to side-effects of third-party CA dependency. In the case of NG, the *NG-operated* websites are more vulnerable compared to other website sets for NG.

Figure 7b shows the change in critical dependency as we move from more popular (top 1K) websites to less popular (top 10K) websites. For ZA, the critical CA dependency follows the same trend as in the case of DNS and CDN, where more popular websites are less critically dependent (except for *ZA-operated* websites. However, for Kenya, we observe that critical dependency actually increases in more popular websites (top 1K). We observe a similar trend for NG and RW. It is unclear why this is the case. Nevertheless, it is not encouraging and implies that more popular hosted, dominant and operated websites are more vulnerable to the side-effects of third-party CA dependency including outages, performance degradation, etc.

## 6 Provider Concentration

In this section, we first compare the concentration among providers for *Africa-visited* websites and *US-visited* websites. Then we closely look at Africa, for different website sets.

---

**Observation 5**: ***Concentration of providers in Africa-visited websites is slightly higher than US-visited websites for DNS and CA.***

---

Figure 8 shows the fraction of websites for a given number of DNS, CDN and CA providers. To compare the degree of concentration between *Africa-visited* and *US-visited* websites, we plot the fraction of websites served by a given number of providers. We label the number of providers that cover 85% of the websites for each country. In general, we observe similar degree of concentration in *US-visited* and *Africa-visited* websites. Figure 8a shows the fraction of websites served by a given number of DNS providers. For *ZA-visited* and *KE-visited* websites, the concentration is slightly higher than *US-visited* websites. In general, a single DNS provider critically serves more than 40% of *Africa-visited* websites, while in the case of *US-visited*, a single provider critically serves 34% of the websites. Interestingly, the top 5 providers for *US-visited*, *NG-visited*, *RW-visited* and *KE-visited* websites are the same global DNS providers. However, for *ZA-visited*, which includes local providers like Xneelo and Afrihost.

Figure 8b shows the fraction of websites served by a given number of CDN providers. In general, we observe a great degree of concentration in *Africa-visited* as well as *US-visited* websites. Moreover, top CDN providers in *Africa-visited* and *US-visited* websites are also same, and are all global providers. Figure 8c shows the fraction of websites served by a given number of CA providers. In general, CA providers are more concentrated for *Africa-visited* as compared to *US-visited* websites. While the top providers in *US-visited* and *Africa-visited* websites are similar. We observe some minor differences, like Let's Encrypt and Sectigo are more popular in *Africa-visited* websites as compared to *US-visited* websites where Amazon is more popular. In general, DigiCert is the major provider in all.

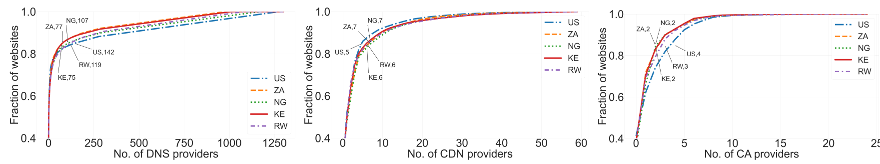
Overall, we observe that African users are as vulnerable to the side effects of third party dependencies as the US users. Note that this is not encouraging or alleviating because Africa faces more challenges with respect to cyber security expertise, reliable infrastructure etc., and hence single-points-of-failure in Africa can have more severe consequences.

---

**Observation 6**: ***Approximately 60% of the total African-visited sites are critically dependent on top 3 DNS, CDN or CA providers.***

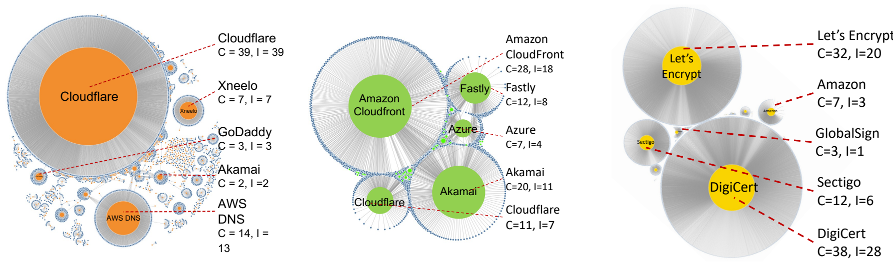
---

Figure 9 shows the dependency graph for *Africa-visited* websites. The size of a node is proportional to its indegree which is the number of websites dependent on it. We also label the concentration and impact of each provider as



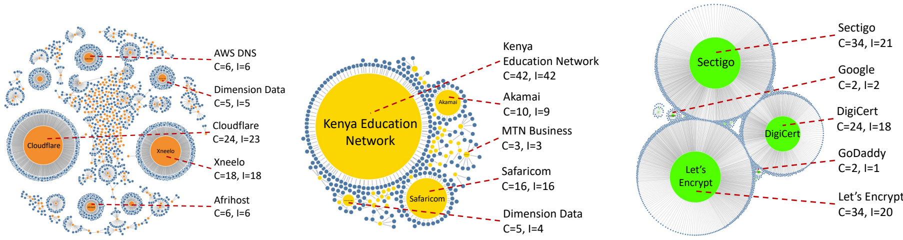

(a) DNS (b) CDN (c) CA

Fig. 8: (a) Concentration of DNS providers in *ZA-visited* and *KE-visited* is slightly higher than *RW-visited*, *NG-visited* and *US-visited* websites. (b) Concentration of CDN providers in *Africa-visited* and *US-visited* websites is largely similar, with concentration in *US-visited* websites being slightly higher. (c) Concentration of CA providers in *Africa-visited* websites is slightly higher than the *US-visited* websites.




(a) DNS (b) CDN (c) CA

Fig. 9: (a) Cloudflare and Amazon serve most of *ZA-visited* websites and have higher concentration and impact than other third-party DNS providers. (b) Amazon Cloudfront and Akamai have slightly higher concentration and impact as CDN providers for *NG-visited*. (c) DigiCert and Let's Encrypt serve the largest number of *KE-visited* websites and have much higher concentration and impact than other CA providers.




(a) DNS Dominant (b) DNS Hosted (c) CA Dominant

Fig. 10: (a) Africa local providers like Afrihost and Xneelo show up in the top 5 DNS providers for *ZA-dominant* websites. (b) Kenya Education Network provides DNS service for the largest number of *KE-hosted* websites. (c) Sectigo, Let's Encrypt, and DigiCert provide CA services to almost the same number of *NG-dominant* websites. The three providers also have similar concentration and impact.

described in Section 2 in terms of the percentage of websites. Figure 9a shows the dependency graph for DNS providers for *ZA-visited* websites. We find that Cloudflare alone critically serves 39% of the *ZA-visited* websites. In general, top 3 DNS providers critically server 59% of the websites. We observe the same trends for other countries. For example, for *RW-visited* websites, top 3 DNS providers critically serve 60% of the websites, 62% for *NG-visited* and 58% for *KE-visited* websites. Moreover, the top 2 providers in all the countries are same, namely Cloudflare and AWS DNS. For NG, we do not observe any local DNS provider in the top 10 DNS providers. For Kenya, we observe the Kenya Education Network (KENET) as one of the major DNS providers. For Rwanda, we observe AOS.rw as one of the major local providers. For ZA, we observe many local DNS providers in the top 10, namely Xneelo, Dimension Data, DiaMatrix and Afrihost. For more popular websites (top 1K), the local DNS providers also come in the top 3 provider, for example Kenya Education Network (KENET) for top 1K *KE-visited* websites, AOS.rw for top 1K *RW-visited* websites, and Dimension Data for top 1K *NG-visited* websites.

In the case of CDN providers, Figure 9b shows the CDN dependency graph for *NG-visited* websites. Top 3 providers in *NG-visited* websites critically serve 37% of the websites that use CDN. We observe similar trends for other countries. For example, for *RW-visited* websites, top 3 CDN providers critically serve 47% of the websites, 39% for *ZA-visited* and 44% for *KE-visited* websites. Importantly, none of the countries, have a local CDN provider that is used. Moreover, the top CDN providers remain similar for all African countries, even for more popular websites (top 1K).

In the case of CA providers, Figure 9c shows the CA dependency graph for *KE-visited* websites. Top 3 CA providers critically serve 54% of the *KE-visited* websites. We observe similar trends for other countries. For example, for *NG-visited* and *ZA-visited* websites, top 3 CDN providers critically serve 57% of the websites that support HTTPS, and 51% for *RW-visited* websites that support HTTPS. The top CA providers across all countries remain the same. There are again no local providers.

For the *Africa-dominant* websites, we observe that many local providers dominate. For example, Figure 10a shows the DNS dependency graph for *ZA-dominant* websites. Concentration of DNS providers is evident: top 3 DNS providers critically server 47% of the *ZA-dominant* websites. More importantly, the top providers include many local providers such as Afrihost, Xneelo, Dimension Data. We observe similar trends in DNS dependency of *KE-dominant* websites, where we see KENET, safaricom, and Kenya Web Experts among the top providers. Similarly, for RW, we see local providers such as AOS.rw, Kaneza, Afriregister among the top providers. For *NG-dominant*, we do not see any DNS local provider.

Overall, there is concentration in *Africa-dominant* websites across all services. For example, in top 3 DNS providers for *Africa-dominant*, concentration remains between 48% to 58%. In case of CDN dependency, the concentration of top 3 CDN providers for *Africa-dominant* websites remains around approximately 50% to 63%. Similarly, for CA dependency in *Africa-dominant* websites, the concentration of top 3 CA providers for *Africa-dominant* websites remains around approximately 52% to 62%. In case of CDN and CA dependency, we do not see any local providers across all website sets. For example, Figure 10c shows the CA dependency graph for *NG-dominant* websites.

In the case of *Africa-hosted* websites as well, there is concentration across all services. Figure 10b shows the DNS dependency graph for *KE-hosted* websites. A large number 42% of these websites are served by Kenyan Education Network (KENET), which is a not-for-profit service provider that primarily serves universities, research institutes, government websites and hospitals. Overall, top 3 DNS in *Africa-hosted* websites critically serve 42% for ZA, 44% for NG, 68% for KE, and 91% for RW. For Rwanda, only a single DNS provider AOS.rw critically serves 87% of the *RW-hosted* websites. In case of CDN, only 3 CDN providers critically server 56% to 58% of *Africa-hosted* websites. Similarly, in case of CA, only 3 CA providers critically serve 45% for KE, 49% for NG, 75% for RW and 60% for ZA in the hosted websites. For Rwanda, Digicert alone serves 63% of the *RW-hosted* websites, and for ZA, Let's Encrypt alone serves 42% of the *ZA-hosted* websites.

In addition to this, the providers for *Africa-operated* websites are also highly concentrated. For example, for *NG-operated* websites, Cloudflare servers as a DNS provider for more than half of the websites. We observe similar trends in CDN and CA providers and across countries.

The high degree of concentration in the specialized sets also points towards the vulnerability of African users to single-points-of-failure. Moreover, in the existence of local providers in the specialized sets while encouraging also raises questions about the resilience of these websites. The high concentration among these local providers makes them single-points-of-failure, where their expertise to defend against attacks and security incidents is not determined as compared to global providers like Amazon.

## 7 Discussion

In light of our findings, now we present some implications and recommendations for the African users, website operators, and service providers.

**High Concentration:** We find that there is a great degree of concentration in the use of third-party DNS, CDNs, and CAs in the Africa-centric websites. This high concentration creates even more single-points-of-failure which are already prevalent in Africa [45]. Naturally, the third-party dependencies in combination with the problematic intermittent connectivity [19, 45, 42] hinders the growth of the digital economy in Africa, which would require reliable communication among users and businesses. Hence, it is of paramount importance that the websites are redundantly provisioned so that the outage of service providers does not affect the websites and that the website operators are trained to effectively handle outages and recover from failures.

**Highly prevalent third-party dependencies:** While the concentration of third-party dependency in Africa-centric websites risks their availability, it also creates opportunities. Indeed, third-party providers have certain benefits such as better quality of service, higher capacity, better security expertise, etc. which small websites cannot afford on their own.

**Sparse local providers:** We find that on all Africa-centric websites, the number of local providers is very small, except for South Africa. This is problematic in two ways. First, the lack of local providers questions the cyber-autonomy of Africa-centric websites and reduces the diversity of providers available to the Africa-centric websites. Indeed, governments could and have tried to rectify that. For example, in Rwanda, with the help of Korea Telecom, the Government of Rwanda created a service provider AOS.rw that serves many Rwanda-centric websites. Even, not-for-profit initiatives like KENET, and South Africa TENET which provide DNS, and web hosting services among others to websites often belong to the government.Second, the use of non-local providers in some cases can also increase the cost of Internet access in Africa, if it implies content loading from outside Africa. Africa has one of the highest transit cost [50], hence accessing remote content also makes Internet access expensive for Africans. In our data, we find that most websites are hosted outside of Africa. Therefore, there is an incentive for policy makers to promote local hosting of content so that local providers and infrastructure are promoted.

## 8 Related Work

A huge body of work exists that performs dependency analysis. Some of those analyze dependencies on country, or/and ISP. For example Simeonovski *et al.* analyzes dependencies with respect to global scale threats where bad actors can by a country, an autonomous system or a service provider like Email server, DNS *etc.* [53]. Similarly, NSDMiner discovers network service dependencies such as ISPs, from passively observed network traffic [43]. Zembruzki *et al.* [59] looks at centralization among hosting providers. Hsiao *et al.* [27] analyzes the cyber-autonomy of government websites of the G7 countries. Dell *et al.* [20] studies third-party DNS dependency using a passive DNS dataset. WebProphet measures the internal backend infrastructure of websites for performance [36]. Simailrly, Ikran *et al.* studies dependency chains in third party web content [28]

Many studies try to understand CDNs and hosting infrastructure [32, 55, 16, 7, 38]. These are complementary to our work. Other work analyzes the critical paths to understand how content affects the page load time (e.g., [57]), or focuses on the privacy implications of the tracking services (e.g., [51, 35, 31]). However, our work is orthogonal as it focuses on the infrastructure services at a higher level than individual websites. Kumar et al. [33] study HTTPS adoption and Podins et al., [47] measure the implementation of Content Security Policy, among third-party web content. Other efforts (e.g., [44, 41]) analyze third-party web content for attacks. Ager *et al.* identifies and classifies content hosting and delivery infrastructures across the world [7]. Zmap [22] and Censys [21] present tools to scan the Internet at scale to find vulnerabilities like heartbleed. Our focus on web infrastructure is complementary to this work. Other work has analyzed the use of TLS, the certificate ecosystem, and the use of Certificate Revocation in the wild (e.g., [17, 56, 37, 18, 60, 30, 33]). These suggest potential attacks that could be executed via the third party services we analyze here.

There have been many efforts to understand the African Internet Ecosystem. For exmaple, Akanho *et al.* measures the EDNS and TCP compliance in the nameservers for African websites [8]. Chavula *et al.* analyzes the location of cloud hosting providers in Africa for latency [14]. Calandro *et al.* analyzes the hosting of African news websites [13] to determine the fraction of local content. Similalry Brinkman *et al.* [11] discusses the interweaving connection in the Internet due to dependencies and tries to seek what constitutes of "African websites", which we provided definition for in our work. Arouns *et al.* looks at the DNS landscape for African ccTLDs [9]. Our work is complementary to these efforts as we also try to understand the resilience of Internet in Africa.

## 9 Conclusion

In this work, we analyze third-party DNS, CDN and CA dependencies in Africa-centric websites in an effort to bridge the gap of previous works, and offer region-specific actionable insights to African users and operators. Particularly, we study the prevalence of third-party dependencies on *Africa-visited*, *Africa-dominant*, *Africa-operated* and *Africa-hosted* websites. We find that *Africa-centric* websites are highly vulnerable to the side-affects of third-party dependencies. In addition, we find that there is a high degree of concentration in the use of third-party service providers, meaning that a handful of providers serve a large portion of the websites. Our findings have implications for the current usage and recommendations for the future evolution of the Internet in Africa.

## References

1. Comprehensive IP address data, IP geolocation API and database - IPinfo.io. https://ipinfo.io/
2. Country domains: A comprehensive ccTLD list. https://www.ionos.com/digitalguide/domains/domain-extensions/cctlds-a-list-of-every-country-domain/
3. dig: dns lookup utility. https://linux.die.net/man/1/dig
4. Latest research shows DDoS attacks up by 300% in Africa since 2019. https://seacom.com/media-centre/latest-research-shows-ddos-attacks-300-africa-2019/
5. SAN Certificates: Subject Alternative Name – Multi-Domain (SAN). https://www.digicert.com/faq/subject-alternative-name.htm
6. Puppeteer. Puppeteer (May 2022)
7. Ager, B., Mühlbauer, W., Smaragdakis, G., Uhlig, S.: Web content cartography. In: Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference. pp. 585–600 (2011)

8. Akanho, Y., Alassane, M., Houngbadji, M., Phokeer, A.: African nameservers revealed: Characterizing dns authoritative nameservers. In: International Conference on e-Infrastructure and e-Services for Developing Countries. pp. 327–344. Springer (2020)
9. Arouna, A., Phokeer, A., Elmokashfi, A.: A first look at the african's cctlds technical environment. In: International Conference on e-Infrastructure and e-Services for Developing Countries. pp. 305–326. Springer (2020)
10. Bock, H.: The problem with ocsp stapling and must staple and why certificate revocation is still broken, 2017. URL https://blog. hboeck. de/archives/886-The-Problem-with-OCSP-Stapling-and-Must-Staple-and-why-Certificate-Revocation-is-still-broken. html (2017)
11. Brinkman, I., Merolla, D.: Space, time, and culture on african/diaspora websites: a tangled web we weave. Journal of African Cultural Studies **32**(1), 1–6 (2020)
12. Butkiewicz, M., Madhyastha, H.V., Sekar, V.: Understanding website complexity: measurements, metrics, and implications. In: Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference. pp. 313–328 (2011)
13. Calandro, E., Chavula, J., Phokeer, A.: Internet development in africa: a content use, hosting and distribution perspective. In: International Conference on e-Infrastructure and e-Services for Developing Countries. pp. 131–141. Springer (2018)
14. Chavula, J., Phokeer, A., Calandro, E.: Performance barriers to cloud services in africa's public sector: A latency perspective. In: International Conference on e-Infrastructure and e-Services for Developing Countries. pp. 152–163. Springer (2018)
15. Chege, K.G.: Measuring internet resilience in africa (Nov 2020), https://www.internetsociety.org/blog/2020/11/measuring-internet-resilience-in-africa/
16. Choffnes, D., Wang, J., et al.: Cdns meet cn an empirical study of cdn deployments in china. IEEE Access **5**, 5292–5305 (2017)
17. Chung, T., Liu, Y., Choffnes, D., Levin, D., Maggs, B.M., Mislove, A., Wilson, C.: Measuring and applying invalid ssl certificates: The silent majority. In: Proceedings of the 2016 Internet Measurement Conference. pp. 527–541 (2016)
18. Chung, T., Lok, J., Chandrasekaran, B., Choffnes, D., Levin, D., Maggs, B.M., Mislove, A., Rula, J., Sullivan, N., Wilson, C.: Is the web ready for ocsp must-staple? In: Proceedings of the Internet Measurement Conference 2018. pp. 105–118 (2018)
19. Comment, D.S.: Load shedding in south africa causes cooling system failure at mtn data center (Jul 2022), https://www.datacenterdynamics.com/en/news/load-shedding-in-south-africa-causes-cooling-system-failure-at-mtn-data-center/
20. Dell'Amico, M., Bilge, L., Kayyoor, A., Efstathopoulos, P., Vervier, P.A.: Lean on me: Mining internet service dependencies from large-scale dns data. In: Proceedings of the 33rd Annual Computer Security Applications Conference. pp. 449–460 (2017)
21. Durumeric, Z., Adrian, D., Mirian, A., Bailey, M., Halderman, J.A.: A search engine backed by internet-wide scanning. In: Proceedings of the 22nd ACM SIGSAC Conference on Computer and Communications Security. pp. 542–553 (2015)
22. Durumeric, Z., Wustrow, E., Halderman, J.A.: Zmap: Fast internet-wide scanning and its security applications. In: Presented as part of the 22nd {USENIX} Security Symposium ({USENIX} Security 13). pp. 605–620 (2013)
23. ExpressVPN: High-speed, secure and anonymous vpn service | expressvpn (2016), https://www.expressvpn.com/

24. Globalsign certificate revocation issue. https://www.globalsign.com/en/status (October 13, 2016), accessed: May 23, 2020
25. Google: Chrome ux report, https://developer.chrome.com/docs/crux/
26. Hilton, S.: Dyn analysis summary of friday october 21 attack. http://dyn.com/blog/dyn-analysis-summary-of-friday-october-21-attack/ (Oct 26, 2016), accessed: May 23, 2020
27. Hsiao, H.C., Kim, T.H.J., Ku, Y.M., Chang, C.M., Chen, H.F., Chen, Y.J., Wang, C.W., Jeng, W.: An investigation of cyber autonomy on government websites. In: The World Wide Web Conference. pp. 2814–2821 (2019)
28. Ikram, M., Masood, R., Tyson, G., Kaafar, M.A., Loizon, N., Ensafi, R.: The chain of implicit trust: An analysis of the web third-party resources loading. In: The World Wide Web Conference. pp. 2851–2857 (2019)
29. Kashaf, A., Sekar, V., Agarwal, Y.: Analyzing third party service dependencies in modern web services: Have we learned from the mirai-dyn incident? In: Proceedings of the ACM Internet Measurement Conference. pp. 634–647 (2020)
30. Kotzias, P., Razaghpanah, A., Amann, J., Paterson, K.G., Vallina-Rodriguez, N., Caballero, J.: Coming of age: A longitudinal study of tls deployment. In: Proceedings of the Internet Measurement Conference 2018. pp. 415–428 (2018)
31. Krishnamurthy, B., Wills, C.: Privacy diffusion on the web: a longitudinal perspective. In: Proceedings of the 18th international conference on World wide web. pp. 541–550 (2009)
32. Krishnamurthy, B., Wills, C., Zhang, Y.: On the use and performance of content distribution networks. In: Proceedings of the 1st ACM SIGCOMM Workshop on Internet Measurement. pp. 169–182 (2001)
33. Kumar, D., Ma, Z., Durumeric, Z., Mirian, A., Mason, J., Halderman, J.A., Bailey, M.: Security challenges in an increasingly tangled web. In: Proceedings of the 26th International Conference on World Wide Web. pp. 677–684 (2017)
34. Kumar, R., Asif, S., Lee, E., Bustamante, F.E.: Third-party service dependencies and centralization around the world (2021). https://doi.org/10.48550/ARXIV.2111.12253, https://arxiv.org/abs/2111.12253
35. Lerner, A., Simpson, A.K., Kohno, T., Roesner, F.: Internet jones and the raiders of the lost trackers: An archaeological study of web tracking from 1996 to 2016. In: 25th {USENIX} Security Symposium ({USENIX} Security 16) (2016)
36. Li, Z., Zhang, M., Zhu, Z., Chen, Y., Greenberg, A.G., Wang, Y.M.: Webprophet: Automating performance prediction for web services. In: NSDI. vol. 10, pp. 143–158 (2010)
37. Liu, Y., Tome, W., Zhang, L., Choffnes, D., Levin, D., Maggs, B., Mislove, A., Schulman, A., Wilson, C.: An end-to-end measurement of certificate revocation in the web's pki. In: Proceedings of the 2015 Internet Measurement Conference. pp. 183–196 (2015)
38. Matic, S., Tyson, G., Stringhini, G.: Pythia: a framework for the automated analysis of web hosting environments. In: The World Wide Web Conference. pp. 3072–3078 (2019)
39. Maxmind, L.: Geoip country database
40. Moyo, A.: Africa found wanting on cyber crime preparedness. https://www.itweb.co.za/content/4r1lyMRoaVAqpmda (Dec 2019)
41. Mueller, T., Klotzsche, D., Herrmann, D., Federrath, H.: Dangers and prevalence of unprotected web fonts. In: 2019 International Conference on Software, Telecommunications and Computer Networks (SoftCOM). pp. 1–5. IEEE (2019)
42. Mutiso, R., Hill, K.: Why hasn't africa gone digital? Scientific American (Aug 2020), https://www.scientificamerican.com/article/why-hasnt-africa-gone-digital/

43. Natarajan, A., Ning, P., Liu, Y., Jajodia, S., Hutchinson, S.E.: NSDMiner: Automated discovery of network service dependencies. IEEE (2012)
44. Nikiforakis, N., Invernizzi, L., Kapravelos, A., Van Acker, S., Joosen, W., Kruegel, C., Piessens, F., Vigna, G.: You are what you include: large-scale evaluation of remote javascript inclusions. In: Proceedings of the 2012 ACM conference on Computer and communications security. pp. 736–747 (2012)
45. Phokeer, A.: The gambia's internet outage through an internet resilience lens (Jan 2022), https://pulse.internetsociety.org/blog/the-gambias-internet-outage-through-an-internet-resilience-lens
46. Phokeer, A., Chege, K., Chavula, J., Elmokashfi, A., Gueye, A.: Measuring internet resilience in africa (mira)
47. Podins, K., Lavrenovs, A.: Security implications of using third-party resources in the world wide web. In: 2018 IEEE 6th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE). pp. 1–6. IEEE (2018)
48. PrivateVPN: Privatevpn: The world's most-trusted private vpn provider, https://privatevpn.com/
49. Rakshit, S.: geograpy3: Extract countries, regions and cities from a url or text (Oct 2022), https://pypi.org/project/geograpy3/
50. Rao, N.: Bandwidth costs around the world (Aug 2016), https://blog.cloudflare.com/bandwidth-costs-around-the-world/
51. Roesner, F., Kohno, T., Wetherall, D.: Detecting and defending against third-party tracking on the web. In: Presented as part of the 9th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 12). pp. 155–168 (2012)
52. Ruth, K., Kumar, D., Wang, B., Valenta, L., Durumeric, Z.: Toppling top lists: Evaluating the accuracy of popular website lists. In: Proceedings of the 22nd ACM Internet Measurement Conference. pp. 374–387 (2022)
53. Simeonovski, M., Pellegrino, G., Rossow, C., Backes, M.: Who controls the internet? analyzing global threats using property graph traversals. In: Proceedings of the 26th International Conference on World Wide Web. pp. 647–656 (2017)
54. SimilarWeb: Top browsers market share - most popular browsers in august 2022 | similarweb, https://www.similarweb.com/browsers/
55. Singh, R., Dunna, A., Gill, P.: Characterizing the deployment and performance of multi-cdns. In: Proceedings of the Internet Measurement Conference 2018. pp. 168–174 (2018)
56. VanderSloot, B., Amann, J., Bernhard, M., Durumeric, Z., Bailey, M., Halderman, J.A.: Towards a complete view of the certificate ecosystem. In: Proceedings of the 2016 Internet Measurement Conference. pp. 543–549 (2016)
57. Wang, X.S., Balasubramanian, A., Krishnamurthy, A., Wetherall, D.: Demystifying page load performance with wprof. In: Presented as part of the 10th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 13). pp. 473–485 (2013)
58. Young, E.A., Hudson, T.J., Engelschall, R.: Openssl: The open source toolkit for ssl/tls (2011)
59. Zembruzki, L., Sommese, R., Granville, L.Z., Jacobs, A.S., Jonker, M., Moura, G.C.: Hosting industry centralization and consolidation. In: NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium. pp. 1–9. IEEE (2022)
60. Zhu, L., Amann, J., Heidemann, J.: Measuring the latency and pervasiveness of tls certificate revocation. In: International Conference on Passive and Active Network Measurement. pp. 16–29. Springer (2016)