

Cloud Performance Efficiency in Africa

by

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Dedication

This dissertation is dedicated to all my family and friends who provided support while I worked on this.

Acknowledgement

I will like to acknowledge my Supervisor, Dr. Josiah Chavula, for the guidance he provided during this research, which was very instrumental in putting me on the right path.

Table of Contents

Dedication.....	ii
Acknowledgement	iii
List of Tables	vi
List of Figures.....	vii
Abstract.....	viii
Chapter 1 Introduction	1
1.1 Aim and Objectives.....	2
1.2 Research Questions	3
Chapter 2 Background	4
2.1 Challenges to Public Cloud Adoption in Africa.....	4
2.2 Recent Cloud Deployments in Africa	5
2.3 Service Providers approach to improve performance	5
2.4 Internet Measurements	6
2.5 CDN Measurements	7
Chapter 3 Approach and Methods	10
3.1 RIPE Atlas Probes to CDN Servers	11
3.2 RIPE Atlas Probes to Public Cloud Datacenters/Cloud Regions	13
3.3 Public Cloud Datacenters/Cloud Regions to non-RIPE Atlas endpoints	14
3.4 Geolocation:	15

Chapter 4 Results and Discussion.....	16
4.1 Results	16
4.2 Discussion	24
Chapter 5 Conclusion.....	30
Bibliography	31
Appendix 1: Used RIPE Probes per Country to CDN Endpoints.....	34
Appendix 2: Used RIPE Probes per Country to the Cloud Regions.....	37
Appendix 3: Reverse Measurements to Africa	40
Appendix 4: Reverse Measurments to Europe.....	43
Appendix 5: Confirmed AWS African CDN Endpoints utilized by Reverse DNS with Airport Code Location.....	46
Appendix 6: Confirmed AWS European CDN Endpoints utilized by Reverse DNS with Airport Code Location.....	54
Appendix 7: Confirmed Azure African CDN Endpoints utilized by Reverse DNS with Airport Code Location.....	60
Appendix 8: Confirmed AWS European CDN Endpoints utilized by Reverse DNS with Airport Code Location.....	61

List of Tables

Table 1: Number of used RIPE Probes per Country to CDN Endpoints	12
Table 2: Number of used RIPE Probes per country to the Cloud Regions.....	13
Table 3: Median RIPE Latencies for selected African countries.....	22
Table 4: Median non-RIPE Latencies for selected African countries	23
Table 5: Median RIPE Latencies for selected European countries.....	23
Table 6: Median non-RIPE Latencies for selected European countries	23

List of Figures

Figure 1: Median Latency(ms) from selected African Countries to CDN Endpoints	16
Figure 2: Sorted Latency(ms) across selected African countries to CDN Endpoints by Mean....	17
Figure 3: Median Latency(ms) from selected African countries to AWS and Azure Cloud Regions	17
Figure 4: Sorted Latency(ms) for selected African countries to AWS and Azure Cloud Regions by Mean	18
Figure 5: Median Latency(ms) across selected European Countries to CDN Endpoints	19
Figure 6: Sorted Latency(ms) across selected European countries to CDN Endpoints by mean .	20
Figure 7: Median Latency(ms) for selected European countries to AWS and Azure Cloud Regions	20
Figure 8: Sorted Latency(ms) across selected European countries to AWS and Azure Cloud Regions by mean.....	21
Figure 9: Sorted Median Router Hop count by country	22
Figure 10: Median Latency(ms) of selected African CDN and Cloud Region measurements to AWS and Azure	26
Figure 11: Median Latency(ms) of selected European CDN and Cloud Region measurements to AWS and Azure	28

Abstract

Internet and Public Cloud adoption has been growing all over the world. An increasing amount of research has been conducted on Internet Performance across different continents. Major Cloud Providers have a growing presence in Africa, but little study has been conducted on Cloud Performance in Africa. This study undertakes to determine network performance from Africa to Public Cloud providers and compare this with what is achievable in a more developed continent like Europe. To achieve this, RIPE Atlas platform is used to run latency and traceroute measurements from RIPE Atlas endpoints in Africa and Europe to Public Cloud CDN endpoints and Virtual servers in Datacenters publicly available in both continents. Reverse measurements are also conducted from the Virtual servers to non-RIPE endpoints in both Africa and Europe. We find that countries with high network latencies in Africa are using CDN endpoints outside of Africa and, in some cases, make use of circuitous routes to Cloud destinations in Africa. In Europe, we found this to be different, as majority of CDN endpoints used were local to the continent, thereby leading to better CDN performance. While we see that using less expensive CDN PoPs in Africa could provide up to 87 percent performance improvement over relying on the Cloud Regions, Europe achieved up to 142 percent improvement.

Following the results of this study, we recommend that Cloud providers should continue to increase their CDN presence in Africa and work with local ISPs to improve routing to ensure that local Cloud infrastructure is optimized for network traffic within the continent.

Chapter 1 Introduction

Many organizations have struggled with the complexity and cost of managing their infrastructure of disparate information architectures and distributed data and software. This created a need for cloud computing to emerge which transformed the way technology services are invented, developed, deployed, scaled, updated, maintained and paid for. Cloud computing delivers managed technology services, drastically reducing the upfront costs that hindered organizations from innovating rapidly and making infrastructure management much easier [34]. Public and private organizations around the world run their technology operations on infrastructure managed by Cloud Providers like Microsoft, Amazon, Google, Huawei and so on [26]. These companies have made substantial investments into building public cloud environments across the world, and have frequently released many services to lead the way in technological innovation [25]. Their services are often delivered over the Internet or private dedicated network channels like fiber [27].

Public cloud adoption has kept growing, and there's been a growing demand for many organizations to deploy or migrate their applications to the Cloud. This trend has been adopted in major countries across Europe, North/South America and Asia, as well as in Africa [24]. For a while, most of the public Cloud infrastructure was in places like North America, Europe, and South-East Asia, among others, with no presence in Africa. So, African organizations using the Cloud have had to make use of the infrastructure in other continents. This means hosting data in these continents, thereby losing sovereignty of their data. In addition, they would have to incur additional latencies for their traffic traversing intercontinental fiber links [2].

Since the Cloud has been experiencing massive growth and attracting customers globally, including from Africa, Cloud providers have been making investments in expanding their presence in the continent. At the time of this research, the three major public cloud providers, Amazon Web Services (AWS), Microsoft Azure, and Google have some degree of presence in Africa, in the form of datacenters also known as Regions, or other forms of presence like Content Delivery Network Points of Presence (CDN PoP). We will reference the Regions as "Cloud

Regions” in this research. Amazon Web Services has its Cloud Region in Cape Town, South Africa and CDN Points of Presence in Cape Town and Johannesburg (South Africa) and Nairobi (Kenya)[11][12]. Azure has its Cloud Region in Cape Town and Johannesburg (South Africa) and CDN Points of presence in Cape town and Johannesburg (South Africa), Nairobi (Kenya) and Lagos (Nigeria)[7][8]. Finally, Google Cloud has no Cloud Region in Africa at the moment, but has CDN Points of presence (PoP) in Johannesburg (South Africa), Lagos (Nigeria) and Mombasa (Kenya) [9][10].

The Points of Presence (PoP) usually serve as locations where the Cloud providers host their Content Delivery Network (CDN) servers to act as a cache for users or clients accessing content hosted in a datacenter and provide an optimized network path to the datacenter. The farther clients are away from the datacenters, the higher the latency and poorer the performance. For example, if a client/user in Namibia is trying to access static website content hosted in a datacenter in the United States (US), they are likely to get far worse performance than clients in Canada, due to the geographic distance between Namibia and the US as compared to Canada and the US. To improve performance for Namibian clients, the content can be cached in local PoPs in Namibia whenever a client accesses those files, and the optimized network path between the PoP and the datacenter can accelerate connectivity to the origin when needed. Using CDN to bring content closer to users is a commonly used technique by Service Providers to reduce latency, thereby providing quality of performance [35]. Apart from these three providers who provide CDN services, there are other CDN operators like Cloudflare with PoPs across Africa. Cloudflare has the most points of presence in countries such as; Algeria, South Africa, Senegal, Morocco, Madagascar, Tanzania, Zimbabwe, Nigeria, Rwanda, Kenya, Liberia, Mauritius, Tunisia and Angola [21].

1.1 Aim and Objectives

Studies have revealed that there is need for Cloud infrastructure providers to deploy more infrastructure in Africa [2]. As Cloud providers have been expanding their presence in Africa, this research explores network performance within Africa to the major global Cloud Providers and CDN operator (AWS, Azure, Google and Cloudflare). As mentioned earlier, Cloud Providers have some presence already within Africa in the form of Cloud Regions and CDN

nodes to serve African Customers. This research measures network performance of current Cloud and CDN infrastructure of the major Providers in Africa aimed at serving African users. While its focus is on Africa, some comparison with Europe is explored in this study as well.

This research can help organizations and Internet Providers to devise the right Cloud strategies to ensure that they are getting maximum performance for their Cloud applications. A survey by a global leader in network/application performance monitoring, Riverbed [18], showed that business decision makers need quality network and application performance to avoid pitfalls that affect their business negatively. Some of the pitfalls identified included Customer dissatisfaction and attrition, negative impact on their brands, delays in contracts and deadlines, and more. On the other hand, optimal performance resulted in cost/time savings, improved employee productivity and customer satisfaction.

1.2 Research Questions

In this research, we will attempt to measure and understand the performance characteristics from hosts in Africa to infrastructure provided by public cloud providers and these characteristics will be understood in terms of network latency and where necessary, their network paths. This research will aim to answer two questions;

- i) What are the performance characteristics for Internet traffic from specific African countries to CDN Points of Presence and Public Cloud Datacenters of the major Cloud Providers?
- ii) How do these characteristics differ for Cloud users in a more developed continent?

Chapter 2 Background

The Cloud has been advantageous to the global economy [36]. It democratizes access for people to different technologies across several domains like Compute, Networking, Security, Database, Analytics, Big Data, Artificial Intelligence and Machine Learning [37]. Access to these domains is now easily and quickly accessed. There are no more delays in getting the underlying technology infrastructure and software components together. Organizations can rapidly build and innovate, while paying for only what they use, with lower OPEX costs as opposed to high upfront CAPEX costs. Many companies are using Cloud hosted e-mail services, Sharepoint, storage services, SAP Enterprise resource planning applications and many other applications [17]. Whilst African countries had been disenfranchised from these benefits due to performance limitations in the past [2], new Cloud deployments look to increase access to African users. Performance issues could hinder the benefits that African companies can get from the use of the Cloud [17]. As the Public grows in Africa, and adoption continues to rise among organizations here, understanding the performance attributes for traffic originated within Africa to these Cloud endpoints can help Providers, Organizations and Governments strategize to ensure that Africa is not left behind in technological advancement.

2.1 Challenges to Public Cloud Adoption in Africa

The primary mode for organizations to consume Public Cloud services is through the Internet [23]. Africa has been experiencing massive growth in its broadband penetration rate. As at 2018, of all continents that are part of the International Telecommunication Union (ITU), Africa recorded the most robust growth in Internet usage, as the percentage of people using the Internet increased from 2.1 percent in 2005 to 24.4 percent in 2018 [16]. Despite the growth of broadband in Africa, several challenges pose a threat to Cloud adoption in the continent. For a while, most of the managed Cloud infrastructure were in North America, Europe and South-East Asia, among others, with no presence in Africa. Before Public Cloud companies moved to deploy some infrastructure within Africa, cloud consumers within Africa had to face

performance barriers due to high latencies to the Cloud destinations at high costs [2]. In addition to poor performance, making use of Cloud infrastructure outside of the African continent results in hosting data outside of the continent. When data is hosted overseas, it is subject to the law of the jurisdiction where it is held [25]. So, African Organizations using the Cloud had to make use of the infrastructure in other continents for hosting their data, could lose sovereignty of their data. The issue of data sovereignty is a major issue in Cloud adoption and usage, with many countries developing regulations to guide where companies can host their data [25].

2.2 Recent Cloud Deployments in Africa

With the growth of the Internet and digital penetration in Africa along with the growing demand for local Cloud infrastructure in Africa, Cloud providers have been making investments in expanding their presence into the continent. Companies like Amazon Web Services (AWS), Microsoft Azure and Google, the three major Public Cloud Providers now have a presence in different locations in South Africa, Nigeria (West Africa) as well as Kenya (East Africa). AWS has its Cloud Region/Datacenter in Cape Town, South Africa and Points of Presence in Cape Town and Johannesburg (South Africa) and Nairobi (Kenya) [11][12]. Azure has its Cloud Region/Datacenter in Cape Town and Johannesburg (South Africa) and CDN Points of presence in Cape Town and Johannesburg (South Africa), Nairobi (Kenya) and Lagos (Nigeria) [7][8]. Finally, Google Cloud has no Cloud Regions/Datacenters in Africa at the time of this research, but has CDN Points of presence in Johannesburg (South Africa), Lagos (Nigeria) and Mombasa (Kenya) [9][10]. The Points of Presence usually serve as locations where the Cloud providers host their Content Delivery Network (CDN) servers.

2.3 Service Providers approach to improve performance

Service Providers do not have complete control in delivering quality performance to users on the Internet. This is because they do not have control over how Internet providers route traffic towards their infrastructure. Most of the control they have is within their infrastructure. Hence, they take steps to optimize performance in the network environment. One example is Facebook's Edge Fabric System that was developed to augment BGP with measurement and control mechanisms to overcome BGP's lack of those mechanisms [29]. Also, while they may be able to

control where traffic egresses their infrastructure, ingress routing is at the discretion of BGP routing. Cloud providers keep exploring alternatives to improvements by expanding their points of presence and offering services like Google Cloud's Premium Network Tiers or AWS's Global Accelerator service as well as their CDN services which gives users access to nearer points of presence to access resources hosted in the datacenters [33]. This is provided for traffic to utilize their Wide Area Network (WAN) infrastructure thereby avoiding potential sub-optimal routing on the Internet. As was shown in a recent study on Private WAN Cloud Performance [28], the WAN infrastructure used by providers like Google and AWS for private connectivity between different geographical areas show improved performance when compared to the Internet. In addition, providers rely on creating private interconnections with network providers to optimize routing performance. Studies have shown that private connections provide better latency and throughput than best effort internet connections, and that Cloud based WANs are superior to both [32]. A measurement study of Amazon's interconnection fabric showed that it had 0.12k private peerings, 2.69k public peerings and 0.24k virtual private interconnections within the US to aid its performance goals [31].

Apart from using the Internet to access the WAN infrastructure of Cloud Providers, Customers also integrate using private dedicated network channels like fiber networks such as AWS Direct Connect, Azure ExpressRoute, and Google Dedicated Interconnect [24].

2.4 Internet Measurements

Research has shown that large scale Internet measurement studies conducted across multiple Internet paths and Clouds should be done from a measurement infrastructure that can scale to thousands of hosts across different countries, supports a wide range of measurements, strong authentication and security with simple configuration of such platforms [22]. An example of a platform with the required characteristics and has a large number of vantage points for carrying out these measurements is the Réseaux IP Européens Network Coordination Centre (RIPE) Atlas [6]. As of October 2021, RIPE Atlas had over 11,100 probes across 5000+ Autonomous System Numbers (ASNs) in 169 countries [38] and makes use of Application Programming Interface (API) keys with configured permissions for authentication in order to allow access to restricted data [39]. In measurements conducted with RIPE Atlas and similar tools, important metrics can

be captured such as network and web application latency, Domain Name System (DNS) latency and network paths gotten from traceroutes. There have been multiple Internet performance studies carried out to capture such performance information in Africa using reliable vantage points like RIPE Atlas. In such studies, it has been shown that interconnectivity and peering among Internet Service Providers (ISPs) isn't optimal to handle traffic within the continent. Many local ISPs are neither present at local exchanges, nor do they peer with one another at the local exchanges, which results in latency penalties of several hundred milliseconds [1] [29] [30]. The latency penalties are primarily driven by the circuitous nature of Internet paths for traffic within the continent. Chavula et al. [1] demonstrated that up to 75 percent of traces to African NRENs within Africa were re-routed outside of Africa through European hops in places like Amsterdam, London, Lisbon and Marseille, resulting in high latencies and poor performance. African Internet users would have to incur high latencies for their traffic traversing intercontinental fiber links. With the growth in Cloud infrastructure, Tier 1 ISPs globally are becoming less relevant, as there's a reduced need for cross-continental traffic going through major Internet backbones [23]. If there's low circuitousness for African Internet traffic directed to local public infrastructure, latency may be less and lengthy paths wouldn't be used, which may result in better performance. Since Cloud infrastructure in Africa is still new, there are not many studies that explore the performance characteristics for African users, to understand and benchmark against what is expected. Given the new Public Cloud Regions within Africa, carrying out more performance studies will help to quantify the effects of these problems.

2.5 CDN Measurements

Since there are more CDN edge caches present in countries like Kenya and Nigeria where Public Cloud Providers are yet to build Cloud Regions in, performance studies will have to consider CDN performance. In order to achieve adequate latencies to CDN Edge caches, providers employ approaches that redirect clients to the closest cache. These approaches could be either using DNS based redirection or Anycast based redirection to the closest cache [3].

DNS measurements are very vital for evaluating CDN performance. Computers have to use DNS results to determine which CDN servers to utilize. The DNS calculations to determine the results to be returned to a client may rely on the client's geolocation, the latency of the client to the edge

cache and other methods like geo-proximity, weighted based redirections, and more [27]. Three major Cloud providers in Africa, AWS, Microsoft and Google have different ways of utilizing DNS to direct users to the CDN, and they make references to this in their public documentation. AWS routes clients to CDN with least latency, Azure makes use of the geographic locations of the clients, and Google uses Anycast [13][14][15]. Just like with Google, Cloudflare relies on its Anycast network to route requests to the nearest Cloudflare datacenter. [21]

With DNS based directions to CDNs, computers make use of local DNS resolvers or external resolvers. The different approaches for determining the CDN server that a user should use has several advantages and disadvantages.

Geolocation results rely on geolocation tools like Maxmind, and based on studies conducted, it is prone to errors and shouldn't be solely relied upon for getting the location of an Internet Protocol (IP) address [4]. When using geolocation for DNS calculations, the location of the DNS resolver's IP address is used to determine the closest CDN server. So, if the location of an IP address is incorrectly calculated, a client would have to make use of a distant CDN server. Also, if a client's computer makes use of an external DNS resolver outside of Africa, they could get directed to a distant CDN server outside of Africa, irrespective of where the client computer is located. This is because the DNS server would be responding based on the geographical location of the DNS resolver, and a distant CDN server would create performance problems. Another point to note is that even accurate geolocation information does not guarantee good performance, since a geographically close server may have high latency. The Internet Service Provider (ISP) may cause such high latency as the traffic path the ISP takes may be based on sub-optimal routing and peering policies [28].

In the case of latency-based DNS redirection, the latency between the DNS resolver and the available CDN servers will be used to determine the closest server [27]. For this to work, ISPs need to have good peering and routing policies, to route their traffic through the best and low latency paths to the available CDN servers. Research has shown that intra-African Internet traffic doesn't always take the most optimal path [1]. In addition to this, the assumption that the DNS results are always indicative of the actual client location and performance has been shown to be false [28]. Using the DNS resolver as a point of reference does not take the actual client's actual geolocation, or its latency to the CDN server into consideration. Rather, it uses the Name

Server's geolocation or latency to the CDN server as the case may be. This has been a well-known problem with DNS, and a specification known as Extension Mechanisms for DNS (EDNS) [19] which expands the size of some parameters of the DNS protocol is gaining popularity. In particular, it has an option known as EDNS Client Subnet (ECS) that allows a recursive DNS resolver to include the subnet of the client on whose behalf it is making the DNS query. However, DNS resolvers need to support this extension.

For Anycast based direction, it depends on the ISP in question. Anycast technology works such that prefixes are announced and advertised from multiple locations to the Internet hosting the edge servers. The edge server that a user would get directed to is based on the ISP, and it's BGP relationships with other service providers as well as its BGP routing policies. So, ISPs without rich peering and routing policies for prefixes may end up directing traffic from a user to a distant CDN server, thereby worsening performance [3].

Based on all of this, it is crucial to take DNS performance into consideration, and the location of the CDN servers it returns for the tests to be conducted. Since there's an apparent lack of studies on the implications of DNS and Anycast based redirections to CDNs in Africa, exploring the DNS performance characteristics would help improve understanding of Cloud performance generally in Africa.

Chapter 3 Approach and Methods

This research is a quantitative one based on the results of different tests that measure the network performance characteristics of Cloud infrastructure in Africa.

For the purpose of this research, the following measurements were carried out;

- a) Measurements between RIPE Atlas Probes and websites deployed on the different CDN infrastructure for the cloud providers. This is to measure the performance within Africa and Europe to the currently available CDN endpoints of the providers used for this study (AWS, Azure, Google and Cloudflare) for the purposes of comparison.
- b) Measurements between RIPE Atlas Probes and Public Cloud Datacenters/Regions. These measurements help to check the performance characteristics to the available Cloud regional endpoints of the providers used for this study (AWS and Azure) in Africa and Europe.
- c) Reverse Measurements from the Public Cloud Datacenters/Regions to non-RIPE Atlas Endpoints. The results obtained from these non-RIPE measurements are compared against the measurements from the RIPE probes to validate results of the RIPE-based measurements, which are the main results used for this study.

Measurements were conducted from a diverse number of African countries of which five of them will be major ones in the different parts of Africa. This includes Ghana (West Africa), Kenya (East Africa), South Africa (Southern Africa), Tunisia (North Africa) and Mauritius. Since this study focuses on Africa, other African countries included are; Morocco, Algeria, Botswana, Senegal, Tanzania, Mauritius, Namibia, Rwanda, Zambia, Togo, Burundi, Cameroun and Madagascar. The measurements from these countries are conducted against available CDN caches and datacenter locations. As discussed earlier, while there are multiple CDN locations in Africa, only AWS and Azure have a Cloud Region for Cloud services in Africa, and it's in South Africa. So, non-CDN measurements in Africa are used with the South African Cloud Region. In Europe, similar to Africa, six countries are used and compared to Africa. These are Russia (Eastern Europe), France (Western Europe), United Kingdom (North-Western Europe), Ireland (Northern Europe), Germany (Central Europe) and Italy (Southern Europe). Measurements are conducted against CDN caches in these countries and to an existing Cloud Region in Ireland.

Although Europe has more Cloud Regions than Africa, only Ireland is used to make the comparison between both continents as close as possible.

3.1 RIPE Atlas Probes to CDN Servers

These measurements rely on RIPE Atlas probes currently deployed in Africa and Europe to Web Destinations hosted on the CDN servers and on virtual servers in the destination public cloud environments. Of the available measurement platforms, RIPE Atlas has the largest number of vantage points making it an ideal measurement platform for this purpose [6]. Europe has a vast number of probes in different Autonomous systems across the continent. However, the current measurement infrastructure in Africa is limited, with many countries having very few probes except for South Africa and Kenya.

A simple custom web application was deployed to activate the CDN services on these Cloud platforms as well as in the Cloud Regions. These are;

1. AWS: <http://dbp4jx4vge93x.cloudfront.net/>
2. Azure: <http://uctmit.azureedge.net/>
3. Cloudflare: <http://afreenigeria.com>
4. Google Cloud: <http://google.victorbabs.com>

RIPE Atlas Measurements were created using a Python Script calling the RIPE APIs. These were ping and traceroute measurements, all of which were unidirectional from RIPE Atlas Probes to the above domains hosted on the CDN network of the cloud providers. For each Cloud provider, 4 measurements from the RIPE probes (two ping measurements, two traceroute measurements) to the respective domains ran every 8 hours for 30 days between September 1, 2021 and September 31, 2021.

Measurements collected relevant performance data from different countries to the hosted domains in the CDN server chosen by the Public Cloud operator. The performance data includes latency to the CDN server and the network paths. The AWS measurements returned 226 unique IP addresses belonging to CDN servers, Azure returned 81 unique destination IP addresses belong to CDN servers, Cloudflare and Google returned 2 unique Anycast IP addresses each. These IP addresses are shared by all of their CDN servers, made possible by their Anycast

implementation. Hence, there's no exposed visibility by the providers to determine the actual number of CDN servers that responded to the measurement requests.

To capture and analyze the data, RIPE Atlas APIs and User Interface (UI) were used to fetch the results, visually analyze these results using the RIPE provided UI along with run Python queries for data analysis using libraries like pandas and numpy, as well as seaborn and matplotlib for visualization.

Table 1: Number of used RIPE Probes per Country to CDN Endpoints

African Country	Number of Probes	European Country	Number of Probes
Algeria	2	Italy	9
Botswana	4	Russia	10
Burundi	3	United Kingdom	10
Cameroon	4	Ireland	8
Ghana	3	Germany	10
Kenya	10	France	10
Madagascar	3		
Mauritius	4		
Morocco	1		
Namibia	3		
Rwanda	2		
Senegal	2		
South Africa	10		
Tanzania	6		
Togo	3		
Tunisia	5		
Zambia	5		

More details on the used probes are provided in Appendix 1

3.2 RIPE Atlas Probes to Public Cloud Datacenters/Regions

Ping and traceroute measurements are done from the RIPE Atlas Probes to Public Cloud Regions in Africa and Europe. The Cloud Region used in Africa is in South Africa, as this is the only Cloud Region with AWS and Azure presence in the African continent. While Europe has multiple Cloud Regions for all providers, the Cloud Region in Ireland was chosen as a reference for these measurements. No other Cloud provider like Cloudflare or Google has a Cloud Region in Africa.

In each of these Cloud Regions, virtual servers were launched to be a target for the ping and traceroute measurements. The measurements were carried out from the RIPE probes to the South African Cloud Region, half of which were to the server in the AWS Cloud Region and the other half to the server in the Azure Cloud Region. The same also applies to the AWS and Azure Cloud Regions in Europe.

Just like with the CDN measurements, all measurements were created using a Python script calling the RIPE APIs for creating the ping and traceroute measurements. For each Cloud provider, 4 measurements from the RIPE probes (two ping measurements, two traceroute measurements) to the respective virtual servers steadily run every 8 hours capturing measurement information between September 1, 2021 and September 31, 2021.

For both measurements from RIPE probes to the CDN servers as well as to the Cloud Regions as described in 3.1 and 3.2 above, World bank Country API from its Data Help desk [30] (<http://api.worldbank.org/v2/country>) were used to request country data information in order to determine the country and part of their respective continents that the probes belong to, based on the 2 letter country code provided in the RIPE Atlas dataset.

Table 2: Number of used RIPE Probes per country to the Cloud Regions

African Country	Number of Probes
Algeria	2
Botswana	4
Burundi	3
Cameroon	6
Ghana	3

European Country	Number of Probes
Italy	9
Russia	10
United Kingdom	10
Ireland	8
Germany	10

Kenya	9
Madagascar	3
Mauritius	4
Morocco	1
Namibia	3
Rwanda	2
Senegal	2
South Africa	10
Tanzania	6
Togo	3
Tunisia	5
Zambia	5

France	10
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More details on the used probes are provided in Appendix 2

3.3 Public Cloud Datacenters/Regions to non-RIPE Atlas endpoints

In addition to the measurements described in Section 3.2, reverse measurements are also created from virtual servers created on the Public Cloud Providers' back to the RIPE Atlas probes in the different African and European countries. Using reverse probes serve as a healthy benchmark to compare the RIPE values to actual user values.

In order to determine non-RIPE Atlas measurement endpoints, the Center for Applied Internet Data Analysis (CAIDA) Python APIs were used to identify the top ASNs in six African countries. Based on the results, *ipinfo.io* was used to identify Public IP endpoints in those ASNs to run the measurements against. Just like with the other measurements, ping and traceroute measurements were conducted against the Public IP endpoints. The details of the selected African countries, ASNs used and Destination Public IP addresses are provided in Appendix 3 and 4.

During the measurements, it was discovered that none of traceroute probes from the RIPE software probes deployed on Azure returned results. It was then discovered that the Azure endpoints do not support the normal traceroute measurements. Further investigations showed that

while normal traceroutes are not allowed, Azure allows the use of “nmap” as an alternative. Hence, separate measurements were conducted to capture traceroute information for probes hosted in that Cloud Region. A bash script was created to spawn new nmap traceroutes to the non-RIPE endpoints using the following command “nmap -sn -Pn --traceroute "\$ip”” and saved in text files.

All tests were run for one month, three times daily. The reason for running the tests for that period was to balance out temporary network performance variabilities. This is because, it is possible that some Internet providers may re-route traffic or have momentary issues that they need to work on to resolve. So, taking a few measurements may capture those periods only and not the normal user experience. In order to capture normal behavior, the tests were run periodically every day for a period of a month, after which the captured data was analyzed.

3.4 Geolocation:

To verify the locations of the non-RIPE endpoints in Section 3.3, geolocation tools like ipinfo.io and Maxmind were used to check the countries that the IP addresses were used. However, geolocating CDN endpoint IP addresses did not yield correct results initially, as the geolocation tools reported the IP addresses as being in the United States. With the Anycast routing method, all CDN servers share the same set of IP addresses, so geolocating them using the IP address is impossible. To solve this problem, an alternative using reverse DNS lookup [5] was done for AWS and Azure which returns locations. This worked because AWS and Azure use latency and geographic based DNS routing respectively, unlike Google and Cloudflare, which use Anycast as previously discussed.

For the Reverse DNS lookup, a bulk tool, <https://www.infobyip.com/ipbulklookup.php>, was used for quick bulk lookups. Not all IP addresses had reverse DNS results, but the ones with results were captured. The DNS results use airport codes to represent the location of the CDN servers. See Appendix 5, 6, 7 and 8 for more information on the locations of the CDN servers.

Chapter 4 Results and Discussion

4.1 Results

The measurements carried showed the performance characteristics for Internet traffic from the selected African countries to the CDN points of presence and datacenters of the Cloud Providers used for the study.

For the African measurements, we find the following;

African RIPE Probes to CDN servers:

For the measurements carried out from the RIPE probes in Africa to the Public CDN endpoints, the median latency of all selected African countries (Ghana, Kenya, South Africa, Tunisia, Mauritius, Morocco, Algeria, Botswana, Senegal, Tanzania, Mauritius, Namibia, Rwanda, Zambia, Togo, Burundi, Cameroun and Madagascar) ranged from as low as 29ms to 65ms to the different CDN endpoints. The mean ranged from 58ms to 87ms.

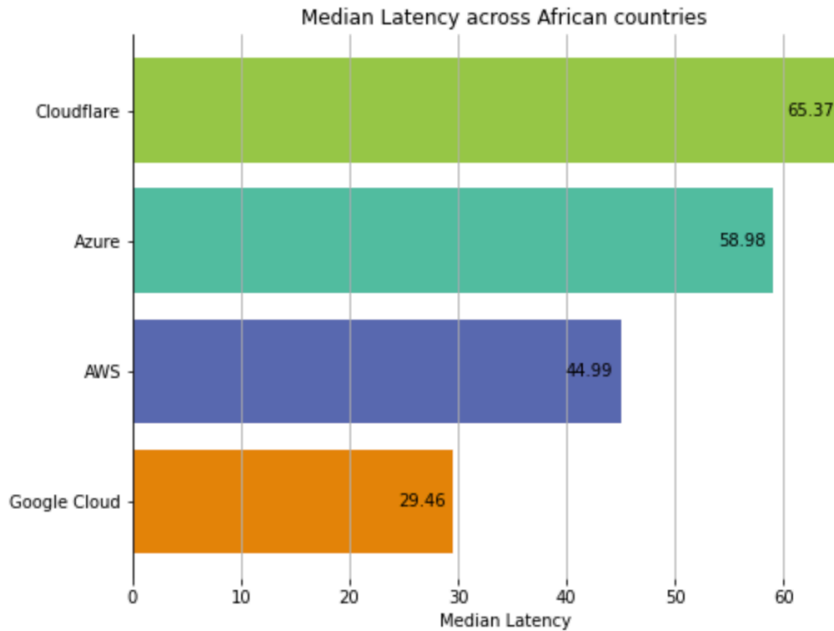


Figure 1: Median Latency(ms) from selected African Countries to CDN Endpoints

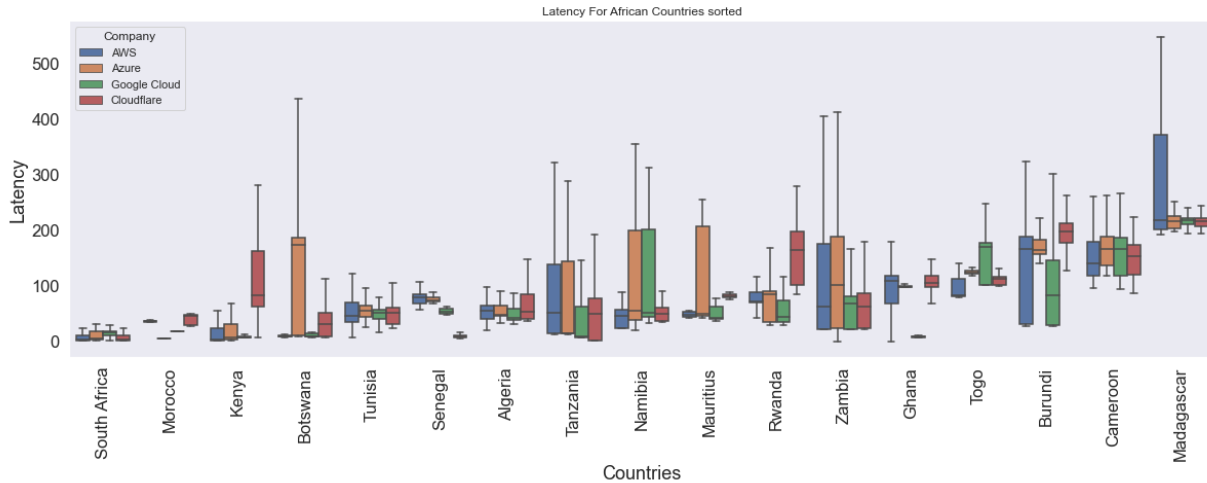


Figure 2: Sorted Latency(ms) across selected African countries to CDN Endpoints by Mean

South Africa, Morocco and Kenya had the least median latencies to the CDN servers, between 5ms to 10ms, while Burundi, Cameroon and Madagascar had the highest median latencies of the countries considered, ranging between 153 to 216ms.

African RIPE Probes to Cloud Cloud Regions/Datacenters:

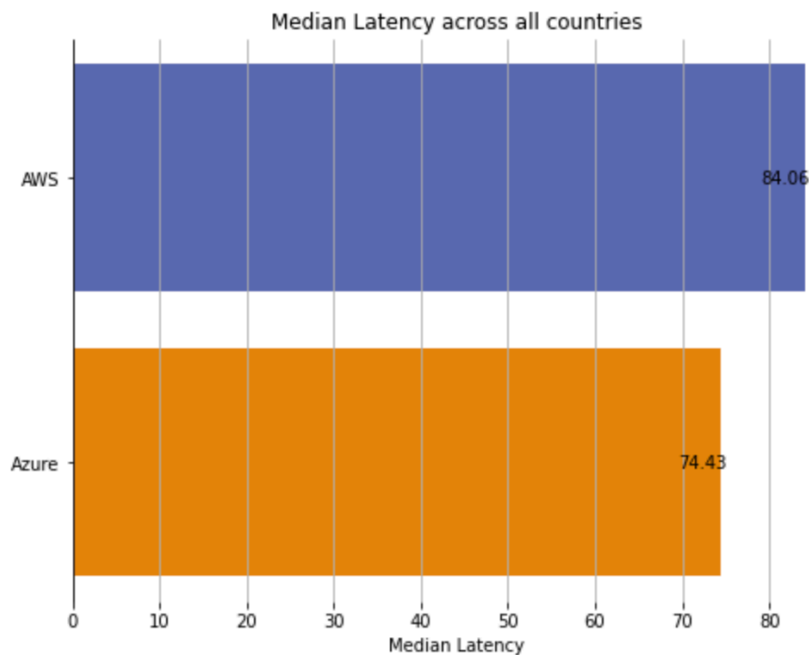


Figure 3: Median Latency(ms) from selected African countries to AWS and Azure Cloud Regions

The latency measurements to the CDN endpoints produced lower latencies than the measurements to the Cloud Region as expected. Looking at the latencies between the RIPE probes to the CDN endpoints and the same probes to the African Cloud Region, the median latency to AWS Cloud Region increased from 45ms (for CDN) to 84ms (for the Cloud Region). For Azure, it increased from 59ms (for CDN) to 74ms (for the Cloud Region). Similar observations were made in the mean latencies. The mean latency to AWS increased from 71ms (for CDN) to 136ms (for the Cloud Region) and for Azure, it increased from 87ms (for CDN) to 144ms (for the Cloud Region)

Figure 4 presents a box plot of latencies between RIPE Atlas Probes in African Countries to websites hosted on the CDN endpoints in AWS, Azure, Google Cloud and Cloudflare. These are sorted based on the mean of the aggregated results per country.

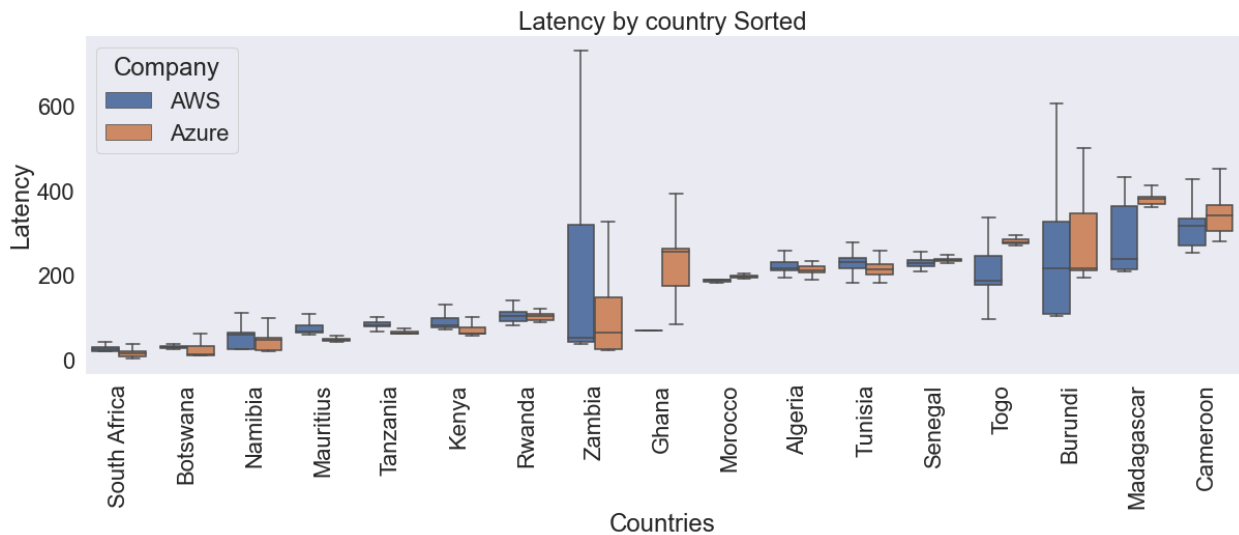


Figure 4: Sorted Latency(ms) for selected African countries to AWS and Azure Cloud Regions by Mean

To put the results gotten from the African countries in context, it is necessary to answer the second research questions to see what the results look like in a more developed continent.

European RIPE Probes to CDN servers

For European countries measured (Russia, France, United Kingdom, Ireland, Germany and Italy), the median latency to CDN endpoints was much lower. The median ranged from 13ms to 17ms, while the mean ranged from 17ms to 24ms

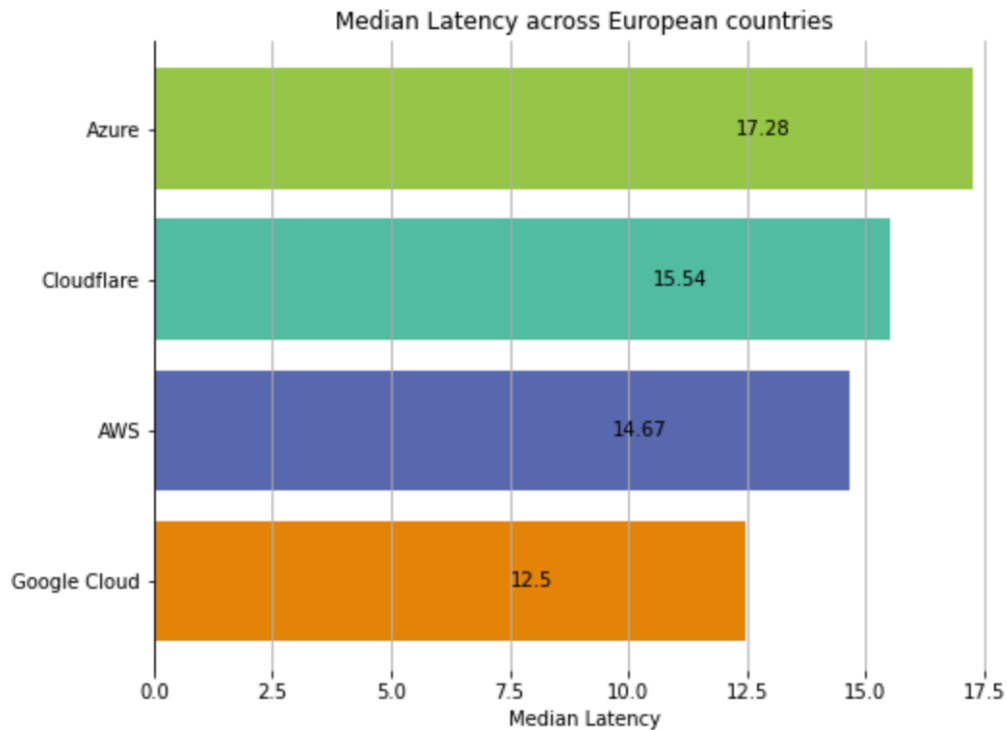


Figure 5: Median Latency(ms) across selected European Countries to CDN Endpoints

In Europe, the countries with the lowest median latencies to the CDNs were France, Germany and the United Kingdom (UK), with values ranging from 11.99ms to 14.71ms with Russia having the highest latencies of the countries measured with 33.5ms.

Figure 6 presents a box plot of latencies between RIPE Atlas Probes in different European Countries to websites hosted on the CDN endpoints in AWS, Azure, Google Cloud and Cloudflare. These are sorted based on the mean of the aggregated results per country.

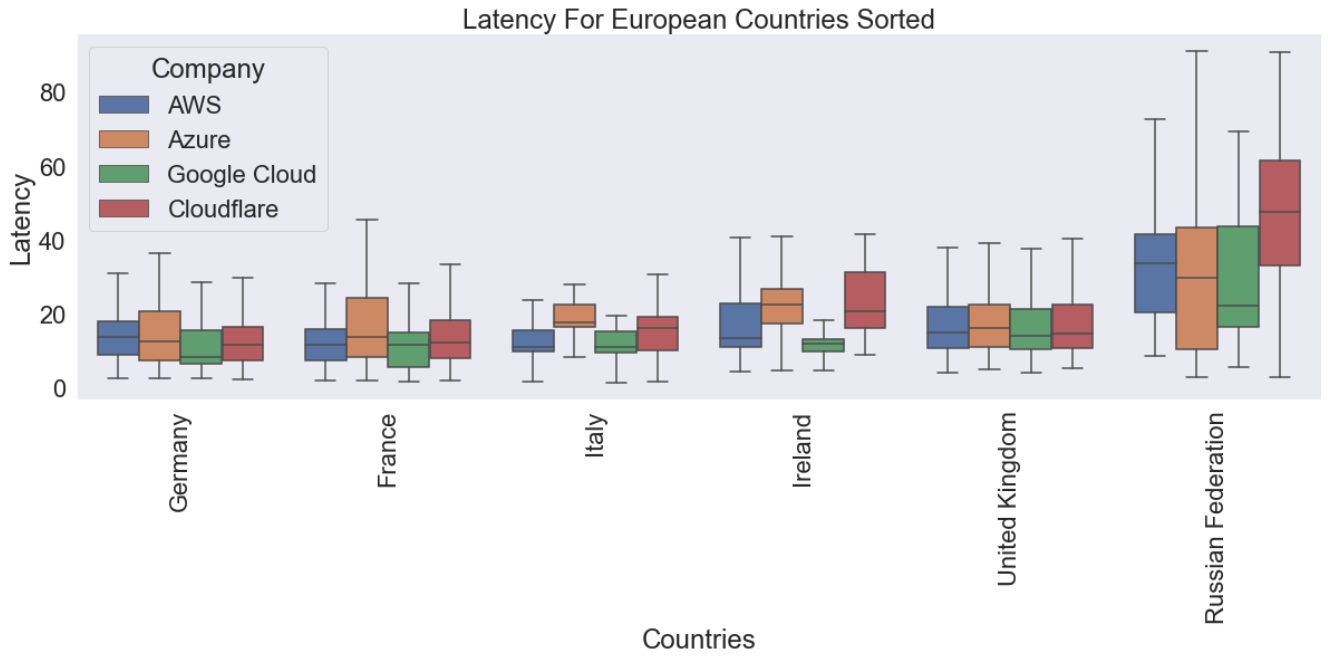


Figure 6: Sorted Latency(ms) across selected European countries to CDN Endpoints by mean

European RIPE Probes to Cloud Regions/Datacenters:

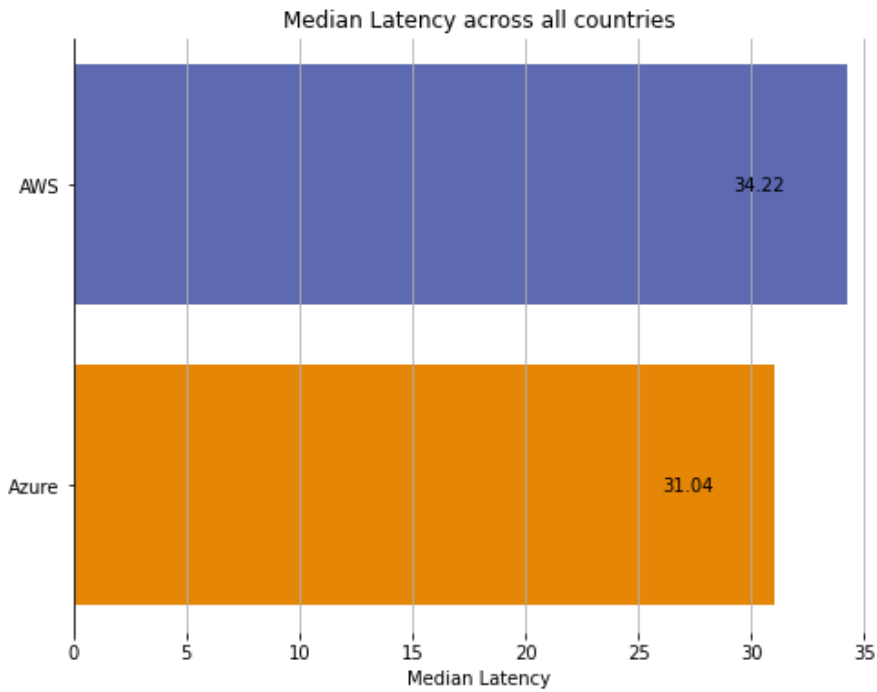


Figure 7: Median Latency(ms) for selected European countries to AWS and Azure Cloud Regions

Similar to Africa, the latency measurements to the CDN endpoints were much lower than the measurements to the Cloud Region as expected. Looking at the latencies between the RIPE probes and the CDN endpoints, and from the same probes to the African Cloud Region, the median latency to AWS Cloud Region grew from 14ms (for CDN) to 34ms (for the Cloud Region). For Azure, it grew from 17ms (for CDN) to 31ms (for the Cloud Region). Similar growth was also observed in the mean latencies. The mean latency to AWS grew from 21ms (for CDN) to 37ms (for the Cloud Region) and for Azure, it also grew from 21ms (for CDN) to 35ms (for the Cloud Region).

Figure 8 presents a box plot of latencies between RIPE Atlas Probes in European Countries to websites hosted on the CDN endpoints in AWS, Azure, Google Cloud and Cloudflare. These are sorted based on the mean of the aggregated results per country.

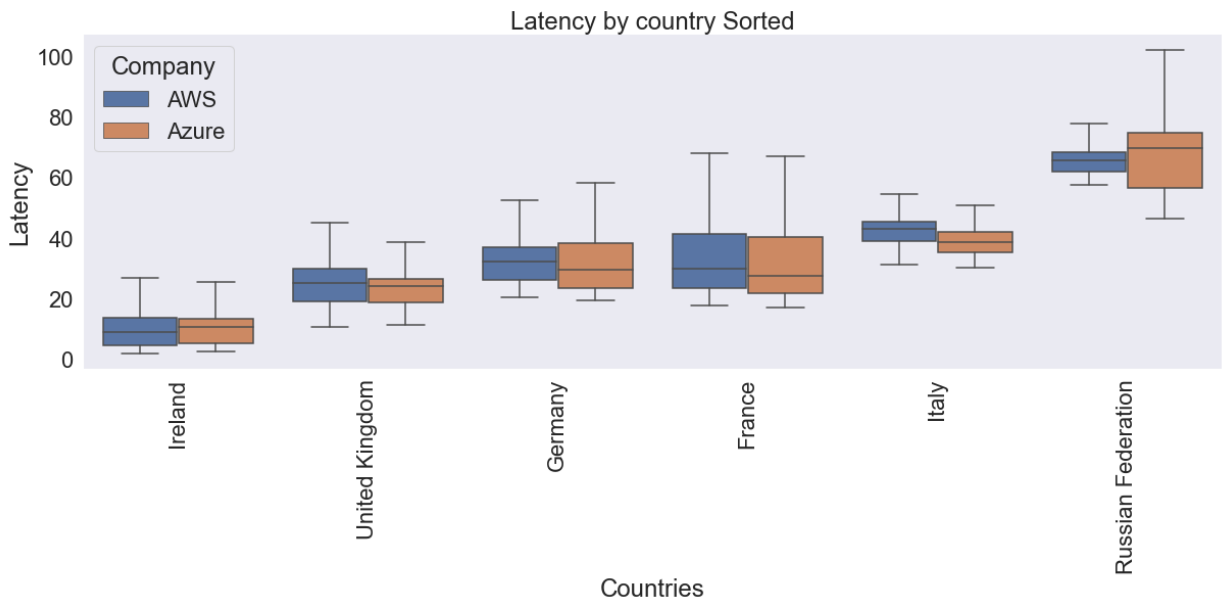


Figure 8: Sorted Latency(ms) across selected European countries to AWS and Azure Cloud Regions by mean

In terms of the router hop count seen from the traceroutes, the countries with the highest hop count values were African countries, with Senegal having a median hop count value of 14, while Madagascar and Burundi had a median hop count of 16.

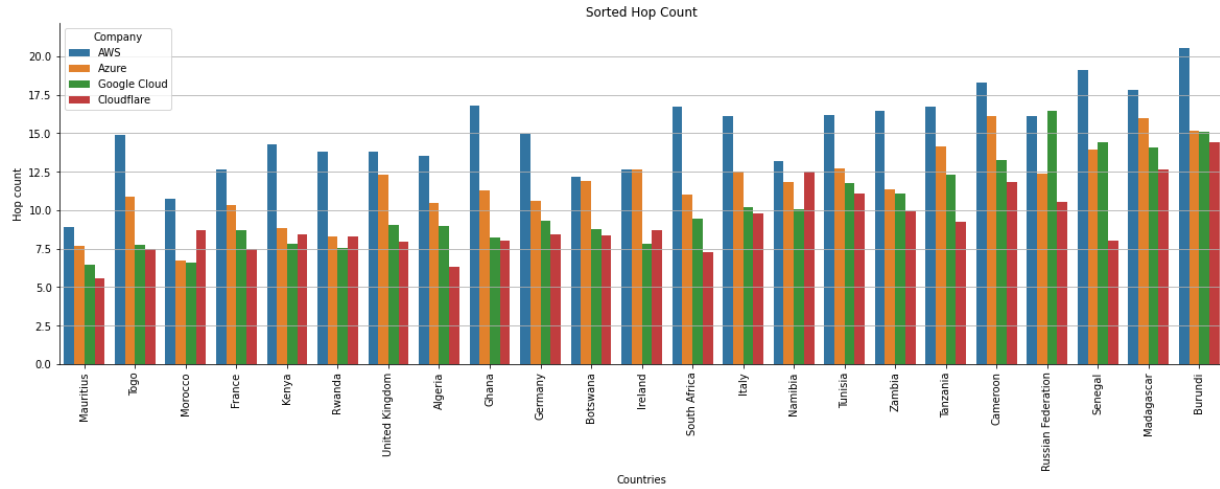


Figure 9: Sorted Median Router Hop count by country

Reverse Measurements:

As earlier mentioned, Reverse measurements were conducted from the AWS and Azure Cloud Region to public non-RIPE endpoints to serve as a benchmark in comparing the RIPE values to actual user values.

For the selected countries, we see that differences between RIPE and non-RIPE measurements are low, between 1 to 30ms, confirming that the RIPE results used for the study are a good indication of results that actual user experience.

Table 3: Median RIPE Latencies for selected African countries

Country	min	max	avg
Ghana	175.0549	176.1101	175.4724
Kenya	75.7495	76.63796	76.17744
Mauritius	60.01893	61.87172	60.8538
South Africa	18.63832	20.42662	20.08086
Tanzania	77.11225	77.5839	77.38252
Tunisia	218.8078	225.7894	222.9739

Table 4: Median non-RIPE Latencies for selected African countries

Country	min	max	avg
Ghana	169.0859	169.5421	169.1751
Kenya	74.5096	75.90981	75.8643
Mauritius	88.7495	91.7382	90.23563
South Africa	18.0712	18.4306	18.3045
Tanzania	77.47436	77.94744	77.79558
Tunisia	203.1596	203.7328	203.5426

Table 5: Median RIPE Latencies for selected European countries

Country	min	max	avg
France	27.47796	30.33052	28.4505
Germany	29.83515	30.42052	30.0306
Ireland	8.404585	11.9544	10.91928
Italy	40.49507	41.41346	40.95305
Russia	65.76589	66.18371	65.90031
UK	23.5529	25.24398	24.48598

Table 6: Median non-RIPE Latencies for selected European countries

Country	min	max	avg
France	26.53102	27.15718	26.75443
Germany	24.90906	25.54637	25.33402
Ireland	2.127008	2.375658	2.256461
Italy	39.8915	40.8807	40.6225
Russia	60.58156	61.3879	61.1135
UK	23.35508	24.0512	23.81877

4.2 Discussion

This study was conducted to understand the performance characteristics of accessing Cloud Services in Africa from different African countries. Network Latency was the key metric used in understanding this. Active measurements were conducted from probes in Africa and Europe to CDN endpoints hosted by major Cloud providers, as well as to Cloud providers who have established Cloud Regions/Datacenters in Africa for accessing various Cloud services.

Cloud Performance in African Countries:

The results showed low median latency for African countries with Cloud infrastructure presence or close proximity to the countries with such infrastructure. Also, we observed that the higher latencies were experienced in countries without any infrastructure presence or in farther proximity from countries with such infrastructure. The African countries with the highest latencies – Madagascar, Burundi, Cameroon - had higher median hop counts, with double the hop count of the country with the least hop count – Mauritius.

Looking at the instances where we saw consistently highest latency values in the CDN measurements, we observe two behaviours;

- i) Traffic gets routed to CDN locations in a different continent. With AWS, of all the returned 226 DNS results for the unique destination IP addresses resolved by DNS, four of them were CDN endpoints in Cape Town, four in Johannesburg and four in Nairobi. The remaining belong to endpoints in United States, Europe and Asia resulting in higher latency.

With Azure, of all the returned 21 DNS results for the 81 unique destination IP addresses resolved by DNS, one was an endpoint in Lagos and another in Cairo. The remaining 60 IP addresses had no DNS results. This implies that Azure hasn't created pointer (PTR) records to map those IP addresses to DNS names with the airport code location. Hence, they could not be used to confirm the CDN servers in Cape Town, Johannesburg, Lagos, Kenya or Morocco. However, the same behaviour as observed

with AWS is seen here. With the exception of 154.0.171.154 with a PTR record pointing to poof.aserv.co.za, the remaining 18 IP addresses were for CDN endpoints in Europe, incurring high latencies.

- ii) Circuitous routing behaviour is present in some situations. Traffic gets routed through Europe before returning to the CDN location in Africa. An example of this is with traffic from probe in Botswana (168.167.100.14) to an AWS CDN endpoint. The returned DNS response is for a cache in Cape Town (52.85.24.38). Even though Botswana and South Africa and neighbouring countries, traffic goes through the United Kingdom (168.167.100.42, 168.167.100.41, 168.167.254.113, 168.167.3.99, 41.191.216.57, 154.54.73.229, 154.54.57.161, 130.117.51.138, 149.11.173.122) before returning back to South Africa. This is observable with a combination of reverse DNS lookups and Maxmind.

These observations emphasize the need to have more CDN points of presence available in countries to prevent sub-optimal routing or routing to/through distant continents in order to improve performance and keep traffic local within the continent. In addition, there's room for both Internet and Cloud providers in Africa to deepen their relationships with other network providers and IXPs in Africa in order to avoid routing through other continents for destinations within African, thereby improving performance. Cloudflare's situation emphasizes why a combination of both of this is important: while it has the greatest number of points of presence in Africa, it relies on Anycast routing that requires optimal routing to deliver good performance. However, in Africa, other providers with lesser number of points of presence had better performance due to better routing and peering with network providers.

The African countries with the least latencies didn't necessarily have the least number of router hop counts. South African had a median latency of 5.3ms with a median hop count of 11, Kenya had a median latency of 8.3ms with a median hop count of 9, and Botswana had a median latency of 10.2ms with a median hop count of 10. The African country with the least median hop count of 7 was Mauritius, but with a median latency of 50ms. In the case of South Africa for example, the vast majority of CDN traffic was local. Hop count makes no difference if the router

hops are within the same provider and are in very close proximity of themselves. The traffic from Mauritius on the other hand went to destinations in South Africa and global cities like Berlin, Hong Kong, Zurich, Dubai and so on. Hence, hop count isn't a good measure of performance.

Using AWS as a reference overall, the African countries with the best performance made more use of nearby CDN endpoints with good routing to those endpoints. For example, with South Africa to AWS, all the CDN endpoints that were returned using DNS were within the country, either in Cape Town or Johannesburg. For the other providers, that information was difficult to ascertain. Azure doesn't have reverse DNS set up for all of its CDN endpoint IP addresses. Google and Cloudflare on the other hand make use of anycast routing. With Anycast routing, multiple CDN servers around the world share the same IP address. Hence, reverse DNS will not be feasible for any of them to implement, thereby making it difficult to ascertain the location of the CDN server.

Nevertheless, we observed that the African countries with CDN presence had good network latency, even better than what was observed in Europe. With South Africa and Botswana making use of the South Africa CDN endpoints and Kenya making use of Kenyan CDN endpoints, median latency were between 5.3ms and 10.3ms. European countries like France, Germany, United Kingdom using their CDN endpoints had latencies between 11.99ms and 14.7ms.

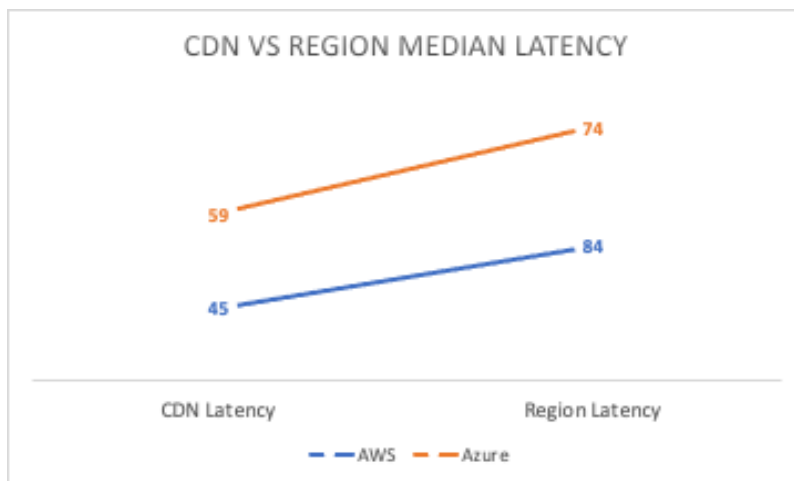


Figure 10: Median Latency(ms) of selected African CDN and Cloud Region measurements to AWS and Azure

Figure 10 shows a comparison of the median latency for measurements conducted to the CDN endpoints and Cloud Regional endpoints of both AWS and Azure in Africa, which are the only two providers with a Cloud Region presence in Africa. Looking at the results, we observed that the existing CDNs in Africa are a great way to optimize performance. Our results show that the latencies observed from African probes to the CDN endpoints were much lower than that of the same probes to the African Cloud Region in South Africa. Based on these results, it's evident that African users can achieve a good level of performance improvement by adopting CDNs for suitable applications.

Comparison Performance in Europe to Africa:

Overall, the probes in Europe to the CDN endpoints showed better performance than African countries. Of the countries measured, the European country with the highest median latency was Russian, with a mean latency of 34ms, which was higher than 75 percent of the African countries measured.

With AWS, of all the returned 226 unique destination IP addresses resolved by DNS, most of them were in Europe, except for 34 of them that were in the US. Hence, there were fewer destinations outside of Europe that would have incurred higher latency values.

With Azure, of all the returned 21 DNS results for the 81 unique destination IP addresses resolved by DNS, only three were from outside Europe. One was an endpoint in Lagos, one in Dubai and another in Cairo. The remaining 60 IP addresses had no DNS results. Hence, they could not be used to confirm the number of IP addresses belonging to CDN endpoints in Europe. This behavior is the inverse of what was observed in Africa, with a vast majority of the returned CDN endpoints from Europe. The results make it clear that unlike in Africa, CDN traffic mostly stays within Europe, destined for endpoints in the continent.

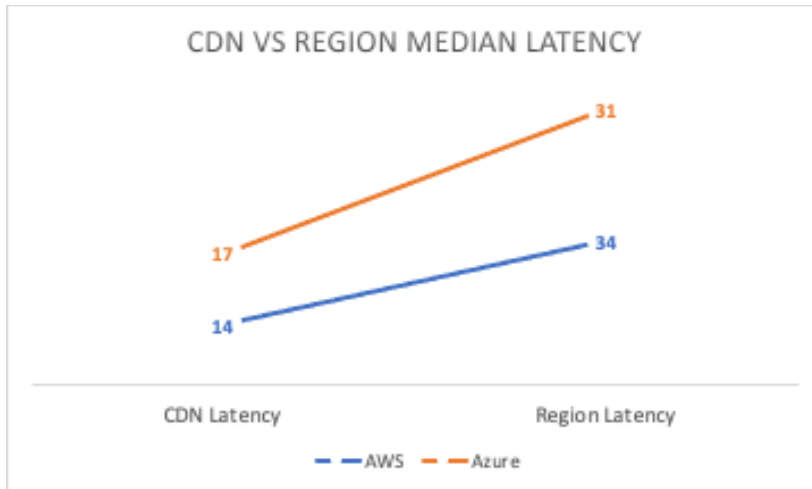


Figure 11: Median Latency(ms) of selected European CDN and Cloud Region measurements to AWS and Azure

We see similar superior performance with lower latencies in Europe. However the performance advantage we see in Europe is higher than what we see in Africa. AWS had 142 percent improvement in median latency for measurements to CDN and the European Cloud Region and Azure having 82 percent improvement for similar measurements, as compared to Africa where we saw 87 percent improvement with AWS and 25 percent improvement with Azure for the same measurements to the CDN and African Cloud Region. This points to the earlier discussion on how majority of CDN endpoints used in Africa were non-African, which is the inverse in the case of Europe. This creates room to optimize performance for African users.

Cloud Provider Performance Comparison:

Finally, for comparing the latencies between the providers who use different mechanisms for routing clients to their CDN points of presence, there was no clear winning strategy. While Google Cloud showed the least latency consistently with its Anycast routing method, Cloudflare, which also uses Anycast had higher median latency than AWS which uses latency based routing and Azure which makes use of its Geographic based routing [13][14][15][21]. Google CDN had the least latency in Africa and Cloudflare had the highest which suggests that Google has better routing to its CDN servers. Despite AWS having CDN locations in South Africa and Kenya, its latency based routing system returned caches outside of Africa for probes in Africa. Azure showed similar behaviour by returning non-African endpoints for African probes. For Google and Cloudflare, similar behaviour was observed with Anycast routing traffic outside of the

continent as well in a sub-optimal manner. However, in a continent with more CDN points of presence and more optimal routing among all four providers, we see that all of them have very similar latencies. So, while they both have the advantages and disadvantages, it appears like there isn't a clear way to predict performance based on the CDN routing method employed by the different providers. Having optimal routing with more relationships with providers and IXPs is important as well. Further research will be needed to examine this in more detail.

Chapter 5 Conclusion

In this study, we looked at the efficiency of Cloud Performance in Africa. We saw that there had been challenges to Cloud adoption and that Providers had been making steady progress in expanding Cloud infrastructure on the continent and making investments in improving performance.

To understand the performance characteristics, we ran measurements for Internet traffic from selected African countries to CDN points of presence and Public Cloud Datacenters also known as Cloud Regions. We also compared this with data obtained from measurements in selected European countries.

We saw that African countries had much higher median and mean latencies than their European counterparts. The two reasons identified for this behaviour were – traffic being routed to a CDN location in a different continent, and sub-optimal routing of traffic within the continent. In comparing the data, the study also showed that while it is important to have datacenter presence in Africa, providers can achieve up to 87 percent better performance using CDNs to establish more points of presence in Africa, which are less expensive than having full Cloud Regional presence. This can go up to even 142 percent as seen in Europe, for which the majority of the CDN endpoints used are local to the continent, reducing the chances of incurring high cross-continental latencies.

From analysing the results, there was no clear way to predict performance based on the routing methods applied by the different CDN providers. Future work can be done to examine this, not just to explain the behaviour but examine options to improve this, given the little CDN presence currently in Africa.

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Appendix 1: Used RIPE Probes per Country to CDN Endpoints

African Country	Probe ID
Algeria	16604
	1001421
Botswana	596
	13269
	19526
	19550
Burundi	12975
	16780
	21610
Cameroon	1001183
	17901
	17889
	2456
Ghana	4274
	33031
	1002595
Kenya	52443
	50022
	22218
	13771
	13705
	13114
	13218
	13121
	13100
	13299
	Madagascar
15313	

European Country	Probe ID
France	13486
	32041
	35691
	50649
	50672
	52786
	52792
	53415
	54004
54194	
Germany	1001404
	52811
	34458
	29386
	27110
	24977
	20130
19822	
Ireland	14892
	26358
	16930
	10749
	10813
	16063
	26869
	27252
34957	
53795	

	19592
Mauritius	19414
	23580
	50085
	1001317
Morocco	12344
Namibia	1000327
	12803
	14465
Rwanda	14955
	21607
Senegal	22522
	52931
South Africa	54246
	51813
	50139
	33175
	33127
	16438
	14384
	13711
	13503
	22458
Tanzania	50463
	24798
	20772
	13887
	10243
	19925
Togo	10203

Italy	54863
	50898
	55060
	50542
	12280
	23265
	21932
Russian Federation	15458
	28347
	55553
	55392
	55193
	54229
	55333
	51054
United Kingdom	35506
	21451
	19166
	53878
	55136
	14328
	21336
	21461
	32496
	51136
53150	
54226	
54427	
55279	

	19591
	32641
Tunisia	1001944
	567
	23112
	25034
	27411
Zambia	21673
	54325
	13758
	21026
	1001195

Appendix 2: Used RIPE Probes per Country to the Cloud Regions

African Country	Probe ID
Algeria	16604
	1001421
Botswana	596
	13269
	19526
	19550
Burundi	12975
	16780
	21610
Cameroon	2456
	17889
	17901
	32459
	33985
	1001183
Ghana	33031
	1002595
	4274
Kenya	52443
	22218
	13779
	13771
	33752
	13218
	13114
	4078
	13705
Madagascar	14712

European Country	Probe ID
France	27379
	30451
	30964
	31408
	33475
	33649
	35691
	52770
	53813
	54684
Germany	1001404
	55143
	54714
	52811
	54621
	51022
	50907
	33814
Ireland	20605
	51643
	54649
	53795
	21359
	21263
	16930
	10881
10633	
13339	

	15313
	19592
Mauritius	50085
	19414
	23580
	1001317
Morocco	12344
Namibia	1000327
	12803
	14465
Rwanda	14955
	21607
Senegal	22522
	52931
South Africa	55130
	51813
	50139
	33273
	33127
	27571
	16438
	13711
	12956
	33083
Tanzania	50463
	24798
	20772
	13887
	10243
	19925

Italy	30376
	55647
	53289
	50542
	28538
	13640
	24070
	23218
	16019
	28483
Russian Federation	55392
	55193
	54229
	53800
	54590
	50717
	21451
	11992
United Kingdom	3763
	51065
	54971
	12174
	13077
	14328
	15022
	22062
	32496
	51089
54548	
55023	

Togo	10203
	19591
	32641
Tunisia	1001944
	567
	23112
	25034
	27411
Zambia	21673
	54325
	13758
	21026
	1001195

Appendix 3: Reverse Measurements to Africa

	Nigeria Targets	https://bgp.he.net/country/NG	
	ISP	ipinfo	IP address
1	MainOne	https://ipinfo.io/AS37282	154.113.0.174
2	Glo	https://ipinfo.io/AS37148	41.203.93.154
3	Airtel	https://ipinfo.io/AS36873	105.112.93.147
4	MTN	https://ipinfo.io/AS29465	102.90.6.222
5	Inq Digita	https://ipinfo.io/AS16284	217.117.9.193
	South Africa Targets	https://bgp.he.net/country/ZA	
	ISP	ipinfo	IP address
1	Dimension Data	https://ipinfo.io/AS3741	196.38.88.224
2	MTN SA	https://ipinfo.io/AS16637	41.204.200.11
3	Workonline Communications	https://ipinfo.io/AS37271	197.157.95.70
4	Telkom SA	https://ipinfo.io/AS5713	196.25.211.127
5	Vodacom	https://ipinfo.io/AS36994	41.0.5.48
	Kenya Targets	https://bgp.he.net/country/KE	
	ISP	ipinfo	IP address
1	Wananchi Group	https://ipinfo.io/AS15399	197.211.1.26
2	Safaricom Limited	https://ipinfo.io/AS33771	41.90.125.11
3	AccessKenya	https://ipinfo.io/AS15808	196.200.16.88
4	Airtel Networks Kenya Limited	https://ipinfo.io/AS36926	154.79.242.182
5	Frontier Optical Networks	https://ipinfo.io/AS37305	41.79.8.79
	Tunisia Targets	https://bgp.he.net/country/TN	

	ISP	ipinfo	IP address
1	Tunisia Backbone AS	https://ipinfo.io/AS2609	193.95.66.40
2	Ooredoo Tunisie SA	https://ipinfo.io/AS37693	196.179.244.65
3	Topnet	https://ipinfo.io/AS37705	41.226.27.1
4	ORANGE	AS37492	196.235.58.72
5	SOCIETE NATIONALE DES TELECOMMUNICATI ONS (Tunisie Telecom)	https://ipinfo.io/AS327934	196.185.159.144
	Mauritius Targets	https://bgp.he.net/country/MU	
	ISP	ipinfo	IP address
1	Mauritius Telecom LTD	https://ipinfo.io/AS23889	102.115.149.214
2	Rogers Capital Technology Services	https://ipinfo.io/AS36868	196.46.48.118
3	Emtel Limited	https://ipinfo.io/AS30999	102.163.44.77
4	Kaldera LTD	https://ipinfo.io/AS37722	169.255.161.247
5	Mahanagar Telephone	https://ipinfo.io/AS37622	41.222.98.1
	Ghana targets	https://bgp.he.net/country/GH	
	ISP	ipinfo	IP address
1	Dolphin telecoms		41.242.113.136
2	Ghana telecommunications company limited (Vodafone Ghana)	https://ipinfo.io/AS29614	197.251.208.187
3	Ghana Internet Exchange association	https://ipinfo.io/AS30997	196.49.14.2
4	Ecoband	https://ipinfo.io/AS327814	196.44.104.188
5	Dimension Data	https://ipinfo.io/AS37350	102.22.10.99

	Major African Targets		
	ISP	ipinfo	IP address
1	Seacom	https://ipinfo.io/AS37100	105.19.57.72
2	WIOCC	https://ipinfo.io/AS37662	196.250.237.218
3	Liquid Intelligent Technologies	https://ipinfo.io/AS30844	196.41.32.18
4	Angola Cables	https://ipinfo.io/AS37468	197.149.148.224

Appendix 4: Reverse Measurements to Europe

		https://bgp.he.net/country/RU	
	ISP	ipinfo	IP address
1	PJSC Rostelecom	https://ipinfo.io/AS12389	87.226.192.239
	Joint Stock Company		
2	TransTeleCom	https://ipinfo.io/AS20485	62.33.32.100
3	PJSC "Vimpelcom"	https://ipinfo.io/AS3216	195.16.62.67
4	CJSC RASCOM	https://ipinfo.io/AS20764	80.64.104.78
5	PJSC MegaFon	https://ipinfo.io/AS31133	94.25.232.249
		https://bgp.he.net/country/FR	
	ISP	ipinfo	IP address
1	Orange SA	AS5511	90.65.89.129
2	Zayo France SAS	https://ipinfo.io/AS8218	94.103.129.11
	Acorus network		
3	SAS	https://ipinfo.io/AS35280	185.196.72.10
4	Jaguar Network SAS	https://ipinfo.io/AS30781	95.143.65.185
	IELO-LIAZO		
5	SERVICES SAS	https://ipinfo.io/AS29075	91.226.98.164
		https://bgp.he.net/country/DE	
	ISP	ipinfo	IP address
	Deutsche Telekom		
1	AGcationIX GmbH	https://ipinfo.io/AS3320	80.150.6.143
	Core-Backbone		
2	GmbH	AS201011	92.43.105.130
3	euNetworks GmbH	https://ipinfo.io/AS13237	80.86.174.190
	Versatel		
4	Deutschland GmbH	https://ipinfo.io/AS8881	194.39.185.103

5	Vodafone GmbH	https://ipinfo.io/AS3209	134.98.84.169
		https://bgp.he.net/country/IT	
	ISP	ipinfo	IP address
1	TELECOM ITALIA SPARKLE S.p.A.	https://ipinfo.io/AS6762	213.144.173.101
2	Fastweb SPA	https://ipinfo.io/AS12874	93.42.238.40
3	Reti Telematiche Italiane S.p.A	https://ipinfo.io/AS28716	164.138.48.18
4	Fiber Telecom S.p.A.	https://ipinfo.io/AS41327	5.183.110.121
5	WIND TRE S.P.A.	https://ipinfo.io/AS1267	151.11.85.83
		https://bgp.he.net/country/IE	
	ISP	ipinfo	IP address
1	BT Communications Ireland	https://ipinfo.io/AS2110	185.90.76.30
2	Digiweb ltd	https://ipinfo.io/AS31122	80.93.28.12
3	Eircom ltd	https://ipinfo.io/AS5466	86.43.38.103
4	Blacknight Internet Solutions Limited	https://ipinfo.io/AS39122	78.153.212.172
5	Enet Telecommunications Network Limited	https://ipinfo.io/AS207044	213.133.67.41
		https://bgp.he.net/country/GB	
	ISP	ipinfo	IP address
1	RETN Limited	https://ipinfo.io/AS9002	87.245.224.1
2	Reliance Globalcom Limited	https://ipinfo.io/AS15412	80.77.14.1

3	IPTP LTD	https://ipinfo.io/AS41095	176.56.178.20
4	Colt Technology Services Group	https://ipinfo.io/AS8220	213.86.30.71
5	IX Reach LTD	https://ipinfo.io/AS43531	91.196.184.1
		Other top 50 European ASNs for other countries	
	ISP	ipinfo	IP address
1	Vodafone Group PLC	https://ipinfo.io/AS1273	193.195.78.74
2	Telia	https://ipinfo.io/AS1299	80.239.150.26
3	Telefonica Global Solutions SL	https://ipinfo.io/AS12956	213.140.62.138
4	Liberty Global	https://ipinfo.io/AS6830	46.140.138.35

Appendix 5: Confirmed AWS African CDN Endpoints utilized by Reverse DNS with Airport Code Location

Destination IP address	DNS results
52.222.128.153	server-52-222-128-153.fco50.r.cloudfront.net
52.222.128.147	server-52-222-128-147.fco50.r.cloudfront.net
18.66.92.96	server-18-66-92-96.fra56.r.cloudfront.net
18.66.92.61	server-18-66-92-61.fra56.r.cloudfront.net
18.66.92.161	server-18-66-92-161.fra56.r.cloudfront.net
18.66.92.159	server-18-66-92-159.fra56.r.cloudfront.net
18.66.121.179	server-18-66-121-179.fra60.r.cloudfront.net
18.65.80.108	server-18-65-80-108.fco50.r.cloudfront.net
143.204.237.90	server-143-204-237-90.cph50.r.cloudfront.net
143.204.237.25	server-143-204-237-25.cph50.r.cloudfront.net
143.204.226.154	server-143-204-226-154.cdg3.r.cloudfront.net
143.204.170.155	server-143-204-170-155.lhr50.r.cloudfront.net
13.249.12.177	server-13-249-12-177.cdg53.r.cloudfront.net
13.225.242.121	server-13-225-242-121.lis50.r.cloudfront.net
13.224.89.111	server-13-224-89-111.zrh50.r.cloudfront.net
13.224.58.11	server-13-224-58-11.cdg50.r.cloudfront.net
52.222.128.219	server-52-222-128-219.fco50.r.cloudfront.net
52.222.128.5	server-52-222-128-5.fco50.r.cloudfront.net
52.222.137.156	server-52-222-137-156.ams50.r.cloudfront.net
52.222.137.45	server-52-222-137-45.ams50.r.cloudfront.net
99.86.154.101	server-99-86-154-101.mxp64.r.cloudfront.net
99.86.105.206	server-99-86-105-206.lhr61.r.cloudfront.net
65.9.98.39	server-65-9-98-39.prg50.r.cloudfront.net
65.9.84.194	server-65-9-84-194.ams1.r.cloudfront.net
65.9.58.80	server-65-9-58-80.fra56.r.cloudfront.net
65.9.191.69	server-65-9-191-69.zag50.r.cloudfront.net
54.230.159.162	server-54-230-159-162.otp50.r.cloudfront.net
54.230.108.203	server-54-230-108-203.mrs52.r.cloudfront.net
54.230.108.115	server-54-230-108-115.mrs52.r.cloudfront.net
13.224.194.169	server-13-224-194-169.fra2.r.cloudfront.net
52.85.65.176	server-52-85-65-176.pmo50.r.cloudfront.net
52.85.65.124	server-52-85-65-124.pmo50.r.cloudfront.net
52.85.65.113	server-52-85-65-113.pmo50.r.cloudfront.net
52.84.66.204	server-52-84-66-204.mad51.r.cloudfront.net
52.84.66.198	server-52-84-66-198.mad51.r.cloudfront.net

52.84.40.148	server-52-84-40-148.mrs52.r.cloudfront.net
52.84.193.87	server-52-84-193-87.cdg52.r.cloudfront.net
52.84.193.31	server-52-84-193-31.cdg52.r.cloudfront.net
52.84.186.87	server-52-84-186-87.cdg50.r.cloudfront.net
52.222.137.9	server-52-222-137-9.ams50.r.cloudfront.net
52.85.65.136	server-52-85-65-136.pmo50.r.cloudfront.net
52.84.193.118	server-52-84-193-118.cdg52.r.cloudfront.net
18.66.137.108	server-18-66-137-108.fra60.r.cloudfront.net
13.225.242.186	server-13-225-242-186.lis50.r.cloudfront.net
13.224.89.131	server-13-224-89-131.zrh50.r.cloudfront.net
13.224.89.148	server-13-224-89-148.zrh50.r.cloudfront.net
99.86.154.24	server-99-86-154-24.mxp64.r.cloudfront.net
99.86.154.169	server-99-86-154-169.mxp64.r.cloudfront.net
52.84.66.187	server-52-84-66-187.mad51.r.cloudfront.net
52.84.193.103	server-52-84-193-103.cdg52.r.cloudfront.net
52.222.137.222	server-52-222-137-222.ams50.r.cloudfront.net
54.230.108.165	server-54-230-108-165.mrs52.r.cloudfront.net
52.85.183.150	server-52-85-183-150.jnb50.r.cloudfront.net
52.85.24.101	server-52-85-24-101.cpt52.r.cloudfront.net
52.85.183.229	server-52-85-183-229.jnb50.r.cloudfront.net
52.85.183.59	server-52-85-183-59.jnb50.r.cloudfront.net
52.85.183.174	server-52-85-183-174.jnb50.r.cloudfront.net
52.85.24.168	server-52-85-24-168.cpt52.r.cloudfront.net
13.225.234.18	server-13-225-234-18.bru50.r.cloudfront.net
13.224.206.146	server-13-224-206-146.phl50.r.cloudfront.net
13.224.227.13	server-13-224-227-13.lhr61.r.cloudfront.net
13.224.68.19	server-13-224-68-19.dub2.r.cloudfront.net
143.204.119.112	server-143-204-119-112.dxb50.r.cloudfront.net
13.249.178.226	server-13-249-178-226.bos50.r.cloudfront.net
13.226.156.54	server-13-226-156-54.dus51.r.cloudfront.net
13.226.156.66	server-13-226-156-66.dus51.r.cloudfront.net
13.249.198.131	server-13-249-198-131.slc50.r.cloudfront.net
143.204.101.135	server-143-204-101-135.fra50.r.cloudfront.net
13.226.156.188	server-13-226-156-188.dus51.r.cloudfront.net
99.86.249.143	server-99-86-249-143.lhr3.r.cloudfront.net
52.85.24.136	server-52-85-24-136.cpt52.r.cloudfront.net
143.204.157.64	server-143-204-157-64.dfw3.r.cloudfront.net
99.86.105.130	server-99-86-105-130.lhr61.r.cloudfront.net
99.86.105.158	server-99-86-105-158.lhr61.r.cloudfront.net

99.86.105.75	server-99-86-105-75.lhr61.r.cloudfront.net
65.9.84.133	server-65-9-84-133.ams1.r.cloudfront.net
52.84.98.10	server-52-84-98-10.nbo50.r.cloudfront.net
52.84.98.130	server-52-84-98-130.nbo50.r.cloudfront.net
52.84.98.6	server-52-84-98-6.nbo50.r.cloudfront.net
52.84.98.80	server-52-84-98-80.nbo50.r.cloudfront.net
143.204.42.176	server-143-204-42-176.osl50.r.cloudfront.net
99.84.47.21	server-99-84-47-21.ewr52.r.cloudfront.net
99.86.97.23	server-99-86-97-23.iah50.r.cloudfront.net
99.86.97.152	server-99-86-97-152.iah50.r.cloudfront.net
99.86.245.55	server-99-86-245-55.vie50.r.cloudfront.net
99.86.178.142	server-99-86-178-142.kul50.r.cloudfront.net
99.84.109.131	server-99-84-109-131.iad79.r.cloudfront.net
65.9.98.58	server-65-9-98-58.prg50.r.cloudfront.net
65.9.156.3	server-65-9-156-3.qro51.r.cloudfront.net
65.8.55.209	server-65-8-55-209.ord52.r.cloudfront.net
54.230.9.104	server-54-230-9-104.man50.r.cloudfront.net
54.230.167.91	server-54-230-167-91.icn51.r.cloudfront.net
52.222.230.100	server-52-222-230-100.waw50.r.cloudfront.net
52.84.107.78	server-52-84-107-78.bud50.r.cloudfront.net
52.84.186.17	server-52-84-186-17.cdg50.r.cloudfront.net
99.84.232.101	server-99-84-232-101.sfo5.r.cloudfront.net
143.204.226.38	server-143-204-226-38.cdg3.r.cloudfront.net
65.9.58.159	server-65-9-58-159.fra56.r.cloudfront.net
143.204.170.29	server-143-204-170-29.lhr50.r.cloudfront.net
13.32.196.171	server-13-32-196-171.iad66.r.cloudfront.net
13.32.169.88	server-13-32-169-88.lhr62.r.cloudfront.net
13.32.169.35	server-13-32-169-35.lhr62.r.cloudfront.net
13.227.178.33	server-13-227-178-33.bom51.r.cloudfront.net
13.225.234.130	server-13-225-234-130.bru50.r.cloudfront.net
13.224.89.35	server-13-224-89-35.zrh50.r.cloudfront.net
143.204.226.39	server-143-204-226-39.cdg3.r.cloudfront.net
65.9.84.68	server-65-9-84-68.ams1.r.cloudfront.net
143.204.226.84	server-143-204-226-84.cdg3.r.cloudfront.net
54.192.100.128	server-54-192-100-128.ewr53.r.cloudfront.net
52.84.186.57	server-52-84-186-57.cdg50.r.cloudfront.net
52.84.186.26	server-52-84-186-26.cdg50.r.cloudfront.net
54.182.1.35	server-54-182-1-35.bom52.r.cloudfront.net
52.84.112.18	server-52-84-112-18.sof50.r.cloudfront.net

65.9.47.35	server-65-9-47-35.arn54.r.cloudfront.net
52.222.230.68	server-52-222-230-68.waw50.r.cloudfront.net
52.84.112.170	server-52-84-112-170.sof50.r.cloudfront.net
52.222.196.145	server-52-222-196-145.cdg50.r.cloudfront.net
52.222.130.220	server-52-222-130-220.fco50.r.cloudfront.net
54.230.108.42	server-54-230-108-42.mrs52.r.cloudfront.net
54.230.159.112	server-54-230-159-112.otp50.r.cloudfront.net
54.230.159.139	server-54-230-159-139.otp50.r.cloudfront.net
54.230.252.210	server-54-230-252-210.atl56.r.cloudfront.net
54.230.51.20	server-54-230-51-20.yul62.r.cloudfront.net
65.8.55.94	server-65-8-55-94.ord52.r.cloudfront.net
65.8.55.97	server-65-8-55-97.ord52.r.cloudfront.net
65.9.47.82	server-65-9-47-82.arn54.r.cloudfront.net
65.9.84.118	server-65-9-84-118.ams1.r.cloudfront.net
52.84.66.41	server-52-84-66-41.mad51.r.cloudfront.net
54.230.159.49	server-54-230-159-49.otp50.r.cloudfront.net
13.32.56.226	server-13-32-56-226.hel50.r.cloudfront.net
13.224.206.111	server-13-224-206-111.phl50.r.cloudfront.net
13.224.227.34	server-13-224-227-34.lhr61.r.cloudfront.net
13.225.231.112	server-13-225-231-112.jfk51.r.cloudfront.net
13.225.234.106	server-13-225-234-106.bru50.r.cloudfront.net
13.227.205.136	server-13-227-205-136.scl50.r.cloudfront.net
13.227.70.113	server-13-227-70-113.eze51.r.cloudfront.net
13.249.125.164	server-13-249-125-164.atl51.r.cloudfront.net
13.249.126.93	server-13-249-126-93.atl51.r.cloudfront.net
13.249.178.194	server-13-249-178-194.bos50.r.cloudfront.net
13.32.56.135	server-13-32-56-135.hel50.r.cloudfront.net
13.32.56.181	server-13-32-56-181.hel50.r.cloudfront.net
13.32.56.80	server-13-32-56-80.hel50.r.cloudfront.net
13.32.84.191	server-13-32-84-191.mia3.r.cloudfront.net
13.32.84.75	server-13-32-84-75.mia3.r.cloudfront.net
13.33.93.202	server-13-33-93-202.mrs52.r.cloudfront.net
13.33.93.206	server-13-33-93-206.mrs52.r.cloudfront.net
13.33.93.39	server-13-33-93-39.mrs52.r.cloudfront.net
13.33.93.43	server-13-33-93-43.mrs52.r.cloudfront.net
13.35.78.44	server-13-35-78-44.bos50.r.cloudfront.net
143.204.170.142	server-143-204-170-142.lhr50.r.cloudfront.net
143.204.46.111	server-143-204-46-111.osl50.r.cloudfront.net
65.9.98.135	server-65-9-98-135.prg50.r.cloudfront.net

52.222.161.2	server-52-222-161-2.cdg52.r.cloudfront.net
52.222.190.229	server-52-222-190-229.ham50.r.cloudfront.net
52.222.230.9	server-52-222-230-9.waw50.r.cloudfront.net
52.85.158.95	server-52-85-158-95.ath50.r.cloudfront.net
54.230.209.87	server-54-230-209-87.ord53.r.cloudfront.net
54.230.9.66	server-54-230-9-66.man50.r.cloudfront.net
65.9.191.119	server-65-9-191-119.zag50.r.cloudfront.net
99.84.232.9	server-99-84-232-9.sfo5.r.cloudfront.net
99.86.249.101	server-99-86-249-101.lhr3.r.cloudfront.net
99.86.249.203	server-99-86-249-203.lhr3.r.cloudfront.net
99.86.249.64	server-99-86-249-64.lhr3.r.cloudfront.net
65.9.98.70	server-65-9-98-70.prg50.r.cloudfront.net
13.224.118.2	server-13-224-118-2.mad50.r.cloudfront.net
13.224.227.26	server-13-224-227-26.lhr61.r.cloudfront.net
13.225.234.143	server-13-225-234-143.bru50.r.cloudfront.net
13.32.169.221	server-13-32-169-221.lhr62.r.cloudfront.net
143.204.101.221	server-143-204-101-221.fra50.r.cloudfront.net
18.66.168.129	server-18-66-168-129.dub56.r.cloudfront.net
18.66.168.143	server-18-66-168-143.dub56.r.cloudfront.net
13.32.169.30	server-13-32-169-30.lhr62.r.cloudfront.net
52.84.107.230	server-52-84-107-230.bud50.r.cloudfront.net
52.84.70.34	server-52-84-70-34.mad51.r.cloudfront.net
99.84.155.173	server-99-84-155-173.txl52.r.cloudfront.net
99.86.245.168	server-99-86-245-168.vie50.r.cloudfront.net
13.224.118.14	server-13-224-118-14.mad50.r.cloudfront.net
13.224.118.176	server-13-224-118-176.mad50.r.cloudfront.net
13.224.58.71	server-13-224-58-71.cdg50.r.cloudfront.net
13.224.68.49	server-13-224-68-49.dub2.r.cloudfront.net
13.224.87.114	server-13-224-87-114.man50.r.cloudfront.net
13.224.87.144	server-13-224-87-144.man50.r.cloudfront.net
13.225.242.189	server-13-225-242-189.lis50.r.cloudfront.net
13.249.12.59	server-13-249-12-59.cdg53.r.cloudfront.net
143.204.101.119	server-143-204-101-119.fra50.r.cloudfront.net
54.192.100.26	server-54-192-100-26.ewr53.r.cloudfront.net
54.230.252.158	server-54-230-252-158.atl56.r.cloudfront.net
54.230.51.161	server-54-230-51-161.yul62.r.cloudfront.net
54.230.51.52	server-54-230-51-52.yul62.r.cloudfront.net
54.230.57.26	server-54-230-57-26.msp50.r.cloudfront.net
54.230.57.5	server-54-230-57-5.msp50.r.cloudfront.net

65.9.58.88	server-65-9-58-88.fra56.r.cloudfront.net
52.84.40.230	server-52-84-40-230.mrs52.r.cloudfront.net
65.9.47.64	server-65-9-47-64.arn54.r.cloudfront.net
13.224.206.183	server-13-224-206-183.phl50.r.cloudfront.net
13.224.206.49	server-13-224-206-49.phl50.r.cloudfront.net
13.33.25.181	server-13-33-25-181.phx50.r.cloudfront.net
13.35.78.222	server-13-35-78-222.bos50.r.cloudfront.net
52.84.107.52	server-52-84-107-52.bud50.r.cloudfront.net
143.204.46.142	server-143-204-46-142.osl50.r.cloudfront.net
143.204.42.164	server-143-204-42-164.osl50.r.cloudfront.net
13.225.245.197	server-13-225-245-197.lis50.r.cloudfront.net
52.85.24.38	server-52-85-24-38.cpt52.r.cloudfront.net
99.86.154.99	server-99-86-154-99.mxp64.r.cloudfront.net
99.84.155.109	server-99-84-155-109.txl52.r.cloudfront.net
65.9.126.203	server-65-9-126-203.qro50.r.cloudfront.net
54.230.244.179	server-54-230-244-179.ewr53.r.cloudfront.net
54.192.41.39	server-54-192-41-39.nrt51.r.cloudfront.net
54.230.9.169	server-54-230-9-169.man50.r.cloudfront.net
13.32.84.58	server-13-32-84-58.mia3.r.cloudfront.net
13.225.141.102	server-13-225-141-102.lax3.r.cloudfront.net
143.204.101.95	server-143-204-101-95.fra50.r.cloudfront.net
13.249.178.114	server-13-249-178-114.bos50.r.cloudfront.net
13.225.245.88	server-13-225-245-88.lis50.r.cloudfront.net
13.225.245.8	server-13-225-245-8.lis50.r.cloudfront.net
13.225.245.50	server-13-225-245-50.lis50.r.cloudfront.net
13.225.242.63	server-13-225-242-63.lis50.r.cloudfront.net
13.224.118.203	server-13-224-118-203.mad50.r.cloudfront.net
18.65.80.194	server-18-65-80-194.fco50.r.cloudfront.net
65.9.110.187	server-65-9-110-187.tlv50.r.cloudfront.net
52.84.107.212	server-52-84-107-212.bud50.r.cloudfront.net
99.84.155.89	server-99-84-155-89.txl52.r.cloudfront.net
13.227.178.153	server-13-227-178-153.bom51.r.cloudfront.net
99.86.245.220	server-99-86-245-220.vie50.r.cloudfront.net
13.227.178.83	server-13-227-178-83.bom51.r.cloudfront.net
99.84.155.19	server-99-84-155-19.txl52.r.cloudfront.net
18.66.168.216	server-18-66-168-216.dub56.r.cloudfront.net
13.227.9.81	server-13-227-9-81.bah53.r.cloudfront.net
18.66.168.62	server-18-66-168-62.dub56.r.cloudfront.net
18.65.80.53	server-18-65-80-53.fco50.r.cloudfront.net

18.66.137.160	server-18-66-137-160.fra60.r.cloudfront.net
18.65.80.101	server-18-65-80-101.fco50.r.cloudfront.net
18.65.61.164	server-18-65-61-164.fco50.r.cloudfront.net
13.249.12.14	server-13-249-12-14.cdg53.r.cloudfront.net
143.204.170.59	server-143-204-170-59.lhr50.r.cloudfront.net
13.224.194.180	server-13-224-194-180.fra2.r.cloudfront.net
13.224.250.169	server-13-224-250-169.sin52.r.cloudfront.net
13.225.100.40	server-13-225-100-40.hkg60.r.cloudfront.net
52.222.196.40	server-52-222-196-40.cdg50.r.cloudfront.net
52.84.40.176	server-52-84-40-176.mrs52.r.cloudfront.net
18.65.199.135	server-18-65-199-135.nrt57.r.cloudfront.net
99.84.232.14	server-99-84-232-14.sfo5.r.cloudfront.net
143.204.119.68	server-143-204-119-68.dxb50.r.cloudfront.net
143.204.119.214	server-143-204-119-214.dxb50.r.cloudfront.net
13.35.183.58	server-13-35-183-58.fjr50.r.cloudfront.net
143.204.119.146	server-143-204-119-146.dxb50.r.cloudfront.net
13.227.21.60	server-13-227-21-60.sfo20.r.cloudfront.net
13.227.9.28	server-13-227-9-28.bah53.r.cloudfront.net
13.35.183.31	server-13-35-183-31.fjr50.r.cloudfront.net
13.249.90.10	server-13-249-90-10.ord52.r.cloudfront.net
52.222.190.124	server-52-222-190-124.ham50.r.cloudfront.net
52.222.190.60	server-52-222-190-60.ham50.r.cloudfront.net
143.204.237.20	server-143-204-237-20.cph50.r.cloudfront.net
52.84.112.149	server-52-84-112-149.sof50.r.cloudfront.net
65.9.47.215	server-65-9-47-215.arn54.r.cloudfront.net
65.9.58.158	server-65-9-58-158.fra56.r.cloudfront.net
65.9.191.28	server-65-9-191-28.zag50.r.cloudfront.net
65.9.110.190	server-65-9-110-190.tlv50.r.cloudfront.net
65.9.110.174	server-65-9-110-174.tlv50.r.cloudfront.net
13.227.153.171	server-13-227-153-171.muc51.r.cloudfront.net
13.224.58.26	server-13-224-58-26.cdg50.r.cloudfront.net
13.224.194.208	server-13-224-194-208.fra2.r.cloudfront.net
99.86.245.117	server-99-86-245-117.vie50.r.cloudfront.net
143.204.46.199	server-143-204-46-199.osl50.r.cloudfront.net
52.222.230.186	server-52-222-230-186.waw50.r.cloudfront.net
52.84.112.130	server-52-84-112-130.sof50.r.cloudfront.net
54.192.100.98	server-54-192-100-98.ewr53.r.cloudfront.net
143.204.42.36	server-143-204-42-36.osl50.r.cloudfront.net
13.224.194.225	server-13-224-194-225.fra2.r.cloudfront.net

52.222.161.97	server-52-222-161-97.cdg52.r.cloudfront.net
13.225.141.103	server-13-225-141-103.lax3.r.cloudfront.net
13.225.231.53	server-13-225-231-53.jfk51.r.cloudfront.net
13.226.124.185	server-13-226-124-185.hkg62.r.cloudfront.net
13.226.251.176	server-13-226-251-176.lax50.r.cloudfront.net
65.9.191.165	server-65-9-191-165.zag50.r.cloudfront.net
143.204.237.30	server-143-204-237-30.cph50.r.cloudfront.net
13.226.156.46	server-13-226-156-46.dus51.r.cloudfront.net
13.224.58.156	server-13-224-58-156.cdg50.r.cloudfront.net
13.224.227.199	server-13-224-227-199.lhr61.r.cloudfront.net
52.85.158.213	server-52-85-158-213.ath50.r.cloudfront.net
13.224.87.106	server-13-224-87-106.man50.r.cloudfront.net
54.230.51.197	server-54-230-51-197.yul62.r.cloudfront.net
52.222.161.56	server-52-222-161-56.cdg52.r.cloudfront.net
54.230.9.202	server-54-230-9-202.man50.r.cloudfront.net
65.9.110.227	server-65-9-110-227.tlv50.r.cloudfront.net
13.225.231.164	server-13-225-231-164.jfk51.r.cloudfront.net
52.222.130.102	server-52-222-130-102.fco50.r.cloudfront.net
13.227.153.228	server-13-227-153-228.muc51.r.cloudfront.net
18.66.121.175	server-18-66-121-175.fra60.r.cloudfront.net
52.222.196.159	server-52-222-196-159.cdg50.r.cloudfront.net
18.66.121.16	server-18-66-121-16.fra60.r.cloudfront.net
52.222.130.23	server-52-222-130-23.fco50.r.cloudfront.net
52.222.190.123	server-52-222-190-123.ham50.r.cloudfront.net
13.249.12.106	server-13-249-12-106.cdg53.r.cloudfront.net
99.84.221.220	server-99-84-221-220.iad79.r.cloudfront.net
54.230.252.101	server-54-230-252-101.atl56.r.cloudfront.net
52.222.161.147	server-52-222-161-147.cdg52.r.cloudfront.net
52.84.40.3	server-52-84-40-3.mrs52.r.cloudfront.net

Appendix 6: Confirmed AWS European CDN Endpoints utilized by Reverse DNS with Airport Code Location

Destination IP Address	DNS results
52.84.186.87	server-52-84-186-87.cdg50.r.cloudfront.net
52.84.186.57	server-52-84-186-57.cdg50.r.cloudfront.net
52.84.186.26	server-52-84-186-26.cdg50.r.cloudfront.net
52.84.186.17	server-52-84-186-17.cdg50.r.cloudfront.net
52.222.196.174	server-52-222-196-174.cdg50.r.cloudfront.net
52.222.196.145	server-52-222-196-145.cdg50.r.cloudfront.net
52.84.193.103	server-52-84-193-103.cdg52.r.cloudfront.net
143.204.226.84	server-143-204-226-84.cdg3.r.cloudfront.net
143.204.226.39	server-143-204-226-39.cdg3.r.cloudfront.net
143.204.226.38	server-143-204-226-38.cdg3.r.cloudfront.net
143.204.226.154	server-143-204-226-154.cdg3.r.cloudfront.net
13.249.12.59	server-13-249-12-59.cdg53.r.cloudfront.net
13.249.12.106	server-13-249-12-106.cdg53.r.cloudfront.net
13.224.58.71	server-13-224-58-71.cdg50.r.cloudfront.net
13.224.58.26	server-13-224-58-26.cdg50.r.cloudfront.net
52.84.193.118	server-52-84-193-118.cdg52.r.cloudfront.net
65.9.84.194	server-65-9-84-194.ams1.r.cloudfront.net
13.33.93.43	server-13-33-93-43.mrs52.r.cloudfront.net
52.84.193.31	server-52-84-193-31.cdg52.r.cloudfront.net
13.33.93.39	server-13-33-93-39.mrs52.r.cloudfront.net
13.249.12.177	server-13-249-12-177.cdg53.r.cloudfront.net
13.224.58.11	server-13-224-58-11.cdg50.r.cloudfront.net
52.222.161.147	server-52-222-161-147.cdg52.r.cloudfront.net
13.224.58.156	server-13-224-58-156.cdg50.r.cloudfront.net
13.224.227.34	server-13-224-227-34.lhr61.r.cloudfront.net
18.66.92.159	server-18-66-92-159.fra56.r.cloudfront.net
13.32.169.30	server-13-32-169-30.lhr62.r.cloudfront.net
18.66.92.161	server-18-66-92-161.fra56.r.cloudfront.net
13.224.194.208	server-13-224-194-208.fra2.r.cloudfront.net
54.230.108.42	server-54-230-108-42.mrs52.r.cloudfront.net
54.230.108.203	server-54-230-108-203.mrs52.r.cloudfront.net
52.84.193.87	server-52-84-193-87.cdg52.r.cloudfront.net
13.224.194.180	server-13-224-194-180.fra2.r.cloudfront.net
18.66.92.61	server-18-66-92-61.fra56.r.cloudfront.net
13.224.227.13	server-13-224-227-13.lhr61.r.cloudfront.net

99.86.249.203	server-99-86-249-203.lhr3.r.cloudfront.net
65.9.84.68	server-65-9-84-68.ams1.r.cloudfront.net
65.9.84.133	server-65-9-84-133.ams1.r.cloudfront.net
18.66.92.96	server-18-66-92-96.fra56.r.cloudfront.net
52.222.196.159	server-52-222-196-159.cdg50.r.cloudfront.net
52.222.137.9	server-52-222-137-9.ams50.r.cloudfront.net
52.222.137.45	server-52-222-137-45.ams50.r.cloudfront.net
52.222.137.222	server-52-222-137-222.ams50.r.cloudfront.net
52.222.137.156	server-52-222-137-156.ams50.r.cloudfront.net
52.222.161.2	server-52-222-161-2.cdg52.r.cloudfront.net
52.222.161.97	server-52-222-161-97.cdg52.r.cloudfront.net
13.249.12.14	server-13-249-12-14.cdg53.r.cloudfront.net
13.225.234.18	server-13-225-234-18.bru50.r.cloudfront.net
13.225.234.143	server-13-225-234-143.bru50.r.cloudfront.net
13.225.234.106	server-13-225-234-106.bru50.r.cloudfront.net
13.224.194.169	server-13-224-194-169.fra2.r.cloudfront.net
65.9.58.159	server-65-9-58-159.fra56.r.cloudfront.net
54.230.108.115	server-54-230-108-115.mrs52.r.cloudfront.net
52.222.196.40	server-52-222-196-40.cdg50.r.cloudfront.net
52.222.161.56	server-52-222-161-56.cdg52.r.cloudfront.net
13.32.169.88	server-13-32-169-88.lhr62.r.cloudfront.net
13.32.169.35	server-13-32-169-35.lhr62.r.cloudfront.net
13.32.169.221	server-13-32-169-221.lhr62.r.cloudfront.net
13.224.227.26	server-13-224-227-26.lhr61.r.cloudfront.net
13.224.194.225	server-13-224-194-225.fra2.r.cloudfront.net
13.224.227.199	server-13-224-227-199.lhr61.r.cloudfront.net
18.66.121.195	server-18-66-121-195.fra60.r.cloudfront.net
13.225.234.130	server-13-225-234-130.bru50.r.cloudfront.net
143.204.170.142	server-143-204-170-142.lhr50.r.cloudfront.net
13.33.93.206	server-13-33-93-206.mrs52.r.cloudfront.net
13.33.93.202	server-13-33-93-202.mrs52.r.cloudfront.net
52.84.66.187	server-52-84-66-187.mad51.r.cloudfront.net
52.84.66.41	server-52-84-66-41.mad51.r.cloudfront.net
99.86.105.130	server-99-86-105-130.lhr61.r.cloudfront.net
99.86.105.158	server-99-86-105-158.lhr61.r.cloudfront.net
13.227.153.77	server-13-227-153-77.muc51.r.cloudfront.net
13.226.156.54	server-13-226-156-54.dus51.r.cloudfront.net
99.86.249.64	server-99-86-249-64.lhr3.r.cloudfront.net
99.86.249.143	server-99-86-249-143.lhr3.r.cloudfront.net

99.86.249.101	server-99-86-249-101.lhr3.r.cloudfront.net
99.86.105.75	server-99-86-105-75.lhr61.r.cloudfront.net
99.86.105.206	server-99-86-105-206.lhr61.r.cloudfront.net
143.204.101.221	server-143-204-101-221.fra50.r.cloudfront.net
143.204.101.119	server-143-204-101-119.fra50.r.cloudfront.net
18.66.121.16	server-18-66-121-16.fra60.r.cloudfront.net
18.66.137.108	server-18-66-137-108.fra60.r.cloudfront.net
99.86.245.168	server-99-86-245-168.vie50.r.cloudfront.net
65.9.98.135	server-65-9-98-135.prg50.r.cloudfront.net
65.9.84.118	server-65-9-84-118.ams1.r.cloudfront.net
65.9.58.88	server-65-9-58-88.fra56.r.cloudfront.net
18.66.121.175	server-18-66-121-175.fra60.r.cloudfront.net
65.9.58.80	server-65-9-58-80.fra56.r.cloudfront.net
65.9.58.158	server-65-9-58-158.fra56.r.cloudfront.net
13.226.156.66	server-13-226-156-66.dus51.r.cloudfront.net
13.249.198.76	server-13-249-198-76.slc50.r.cloudfront.net
13.226.156.46	server-13-226-156-46.dus51.r.cloudfront.net
143.204.101.95	server-143-204-101-95.fra50.r.cloudfront.net
13.35.36.67	server-13-35-36-67.tpe51.r.cloudfront.net
13.33.165.50	server-13-33-165-50.yto50.r.cloudfront.net
13.33.165.39	server-13-33-165-39.yto50.r.cloudfront.net
13.33.165.108	server-13-33-165-108.yto50.r.cloudfront.net
13.249.90.9	server-13-249-90-9.ord52.r.cloudfront.net
13.249.198.131	server-13-249-198-131.slc50.r.cloudfront.net
13.249.126.33	server-13-249-126-33.atl51.r.cloudfront.net
13.33.165.221	server-13-33-165-221.yto50.r.cloudfront.net
52.222.190.229	server-52-222-190-229.ham50.r.cloudfront.net
13.226.156.188	server-13-226-156-188.dus51.r.cloudfront.net
99.84.232.91	server-99-84-232-91.sfo5.r.cloudfront.net
65.8.55.95	server-65-8-55-95.ord52.r.cloudfront.net
54.230.57.5	server-54-230-57-5.msp50.r.cloudfront.net
54.230.57.200	server-54-230-57-200.msp50.r.cloudfront.net
54.230.57.104	server-54-230-57-104.msp50.r.cloudfront.net
54.230.51.52	server-54-230-51-52.yul62.r.cloudfront.net
54.230.51.20	server-54-230-51-20.yul62.r.cloudfront.net
54.230.51.197	server-54-230-51-197.yul62.r.cloudfront.net
54.230.51.161	server-54-230-51-161.yul62.r.cloudfront.net
54.192.100.65	server-54-192-100-65.ewr53.r.cloudfront.net
54.192.100.128	server-54-192-100-128.ewr53.r.cloudfront.net

54.230.57.26	server-54-230-57-26.msp50.r.cloudfront.net
143.204.170.29	server-143-204-170-29.lhr50.r.cloudfront.net
18.66.137.59	server-18-66-137-59.fra60.r.cloudfront.net
13.224.89.35	server-13-224-89-35.zrh50.r.cloudfront.net
99.84.155.109	server-99-84-155-109.txl52.r.cloudfront.net
99.84.155.19	server-99-84-155-19.txl52.r.cloudfront.net
99.84.155.173	server-99-84-155-173.txl52.r.cloudfront.net
99.86.245.220	server-99-86-245-220.vie50.r.cloudfront.net
99.86.154.99	server-99-86-154-99.mxp64.r.cloudfront.net
99.84.155.89	server-99-84-155-89.txl52.r.cloudfront.net
65.9.47.215	server-65-9-47-215.arn54.r.cloudfront.net
18.66.121.179	server-18-66-121-179.fra60.r.cloudfront.net
65.9.47.35	server-65-9-47-35.arn54.r.cloudfront.net
13.225.125.99	server-13-225-125-99.icn54.r.cloudfront.net
65.9.47.64	server-65-9-47-64.arn54.r.cloudfront.net
99.86.154.24	server-99-86-154-24.mxp64.r.cloudfront.net
99.86.154.169	server-99-86-154-169.mxp64.r.cloudfront.net
13.224.89.148	server-13-224-89-148.zrh50.r.cloudfront.net
18.66.137.160	server-18-66-137-160.fra60.r.cloudfront.net
13.227.153.228	server-13-227-153-228.muc51.r.cloudfront.net
13.224.89.131	server-13-224-89-131.zrh50.r.cloudfront.net
13.224.89.111	server-13-224-89-111.zrh50.r.cloudfront.net
52.222.190.124	server-52-222-190-124.ham50.r.cloudfront.net
13.227.153.65	server-13-227-153-65.muc51.r.cloudfront.net
143.204.101.135	server-143-204-101-135.fra50.r.cloudfront.net
52.222.190.60	server-52-222-190-60.ham50.r.cloudfront.net
143.204.170.59	server-143-204-170-59.lhr50.r.cloudfront.net
99.86.154.101	server-99-86-154-101.mxp64.r.cloudfront.net
54.230.159.139	server-54-230-159-139.otp50.r.cloudfront.net
54.230.159.162	server-54-230-159-162.otp50.r.cloudfront.net
143.204.170.155	server-143-204-170-155.lhr50.r.cloudfront.net
13.32.56.181	server-13-32-56-181.hel50.r.cloudfront.net
13.225.245.197	server-13-225-245-197.lis50.r.cloudfront.net
13.224.68.226	server-13-224-68-226.dub2.r.cloudfront.net
18.66.168.62	server-18-66-168-62.dub56.r.cloudfront.net
18.66.168.216	server-18-66-168-216.dub56.r.cloudfront.net
18.66.168.143	server-18-66-168-143.dub56.r.cloudfront.net
18.66.168.129	server-18-66-168-129.dub56.r.cloudfront.net
13.224.68.49	server-13-224-68-49.dub2.r.cloudfront.net

13.224.68.19	server-13-224-68-19.dub2.r.cloudfront.net
13.224.68.36	server-13-224-68-36.dub2.r.cloudfront.net
13.224.241.142	server-13-224-241-142.lhr62.r.cloudfront.net
99.84.47.68	server-99-84-47-68.ewr52.r.cloudfront.net
99.84.47.143	server-99-84-47-143.ewr52.r.cloudfront.net
99.84.221.198	server-99-84-221-198.iad79.r.cloudfront.net
54.230.9.66	server-54-230-9-66.man50.r.cloudfront.net
54.230.9.169	server-54-230-9-169.man50.r.cloudfront.net
143.204.10.200	server-143-204-10-200.mxp64.r.cloudfront.net
143.204.10.23	server-143-204-10-23.mxp64.r.cloudfront.net
143.204.10.80	server-143-204-10-80.mxp64.r.cloudfront.net
52.222.128.153	server-52-222-128-153.fco50.r.cloudfront.net
52.222.128.219	server-52-222-128-219.fco50.r.cloudfront.net
52.222.130.102	server-52-222-130-102.fco50.r.cloudfront.net
52.222.130.220	server-52-222-130-220.fco50.r.cloudfront.net
143.204.10.116	server-143-204-10-116.mxp64.r.cloudfront.net
54.230.108.165	server-54-230-108-165.mrs52.r.cloudfront.net
52.84.112.18	server-52-84-112-18.sof50.r.cloudfront.net
65.9.98.70	server-65-9-98-70.prg50.r.cloudfront.net
99.86.245.117	server-99-86-245-117.vie50.r.cloudfront.net
52.222.128.5	server-52-222-128-5.fco50.r.cloudfront.net
52.222.130.59	server-52-222-130-59.fco50.r.cloudfront.net
52.222.130.23	server-52-222-130-23.fco50.r.cloudfront.net
52.84.40.230	server-52-84-40-230.mrs52.r.cloudfront.net
52.84.40.3	server-52-84-40-3.mrs52.r.cloudfront.net
13.32.56.226	server-13-32-56-226.hel50.r.cloudfront.net
13.32.56.135	server-13-32-56-135.hel50.r.cloudfront.net
65.9.47.82	server-65-9-47-82.arn54.r.cloudfront.net
13.32.56.80	server-13-32-56-80.hel50.r.cloudfront.net
52.222.230.100	server-52-222-230-100.waw50.r.cloudfront.net
52.222.230.186	server-52-222-230-186.waw50.r.cloudfront.net
52.222.230.68	server-52-222-230-68.waw50.r.cloudfront.net
52.222.230.9	server-52-222-230-9.waw50.r.cloudfront.net
52.84.107.212	server-52-84-107-212.bud50.r.cloudfront.net
99.86.245.55	server-99-86-245-55.vie50.r.cloudfront.net
13.225.100.194	server-13-225-100-194.hkg60.r.cloudfront.net
143.204.46.197	server-143-204-46-197.osl50.r.cloudfront.net
18.66.137.68	server-18-66-137-68.fra60.r.cloudfront.net
52.84.107.52	server-52-84-107-52.bud50.r.cloudfront.net

143.204.46.111	server-143-204-46-111.osl50.r.cloudfront.net
143.204.46.199	server-143-204-46-199.osl50.r.cloudfront.net
65.8.55.94	server-65-8-55-94.ord52.r.cloudfront.net
54.230.9.202	server-54-230-9-202.man50.r.cloudfront.net
65.8.55.97	server-65-8-55-97.ord52.r.cloudfront.net
65.9.126.129	server-65-9-126-129.qro50.r.cloudfront.net
54.230.9.104	server-54-230-9-104.man50.r.cloudfront.net
143.204.237.20	server-143-204-237-20.cph50.r.cloudfront.net
54.230.139.70	server-54-230-139-70.atl56.r.cloudfront.net
54.230.139.187	server-54-230-139-187.atl56.r.cloudfront.net
65.9.98.58	server-65-9-98-58.prg50.r.cloudfront.net
99.84.221.220	server-99-84-221-220.iad79.r.cloudfront.net
99.84.221.4	server-99-84-221-4.iad79.r.cloudfront.net
143.204.157.64	server-143-204-157-64.dfw3.r.cloudfront.net
13.224.87.144	server-13-224-87-144.man50.r.cloudfront.net
13.35.78.105	server-13-35-78-105.bos50.r.cloudfront.net
13.224.87.142	server-13-224-87-142.man50.r.cloudfront.net
13.32.84.75	server-13-32-84-75.mia3.r.cloudfront.net
13.32.196.69	server-13-32-196-69.iad66.r.cloudfront.net
13.249.90.75	server-13-249-90-75.ord52.r.cloudfront.net
13.249.90.104	server-13-249-90-104.ord52.r.cloudfront.net
13.249.198.12	server-13-249-198-12.slc50.r.cloudfront.net
13.249.126.171	server-13-249-126-171.atl51.r.cloudfront.net
13.226.220.127	server-13-226-220-127.lax50.r.cloudfront.net
13.226.201.229	server-13-226-201-229.dfw55.r.cloudfront.net
13.226.201.140	server-13-226-201-140.dfw55.r.cloudfront.net
13.226.201.130	server-13-226-201-130.dfw55.r.cloudfront.net
13.224.87.114	server-13-224-87-114.man50.r.cloudfront.net
13.224.87.106	server-13-224-87-106.man50.r.cloudfront.net
52.222.190.123	server-52-222-190-123.ham50.r.cloudfront.net

Appendix 7: Confirmed Azure African CDN Endpoints utilized by Reverse DNS with Airport Code Location

Destination IP address	DNS results
104.212.67.224	ber30r3.msedge.net
104.212.67.154	man30r3.msedge.net
104.212.67.223	bru30r3.msedge.net
104.212.67.162	lis01r3.msedge.net
104.212.67.188	rom30r3a.msedge.net
104.212.67.168	cai30r3a.msedge.net
104.212.67.245	mrs20r3.msedge.net
104.212.67.187	gva30r3a.msedge.net
104.212.67.157	muc30r3.msedge.net
104.212.67.234	buh01.msedge.net
104.212.67.148	ath01r3.msedge.net
104.212.67.144	fra31r3a.msedge.net
104.212.67.252	cph30r3.msedge.net
104.212.67.92	stor3.msedge.net
104.212.67.145	waw01r3.msedge.net
104.212.67.232	zrhr3.msedge.net
104.212.67.244	dx30r3.msedge.net
104.212.67.142	los30r3.msedge.net
104.212.67.88	hel01r3.msedge.net
104.212.67.251	prg01r3.msedge.net
154.0.171.154	poof.aserv.co.za

Appendix 8: Confirmed AWS European CDN Endpoints utilized by Reverse DNS with Airport Code Location

Destination IP address	DNS results
104.212.67.142	los30r3.msedge.net
104.212.67.144	fra31r3a.msedge.net
104.212.67.224	ber30r3.msedge.net
104.212.67.245	mrs20r3.msedge.net
104.212.67.252	cph30r3.msedge.net
104.212.67.188	rom30r3a.msedge.net
104.212.67.154	man30r3.msedge.net
104.212.67.232	zrhr3.msedge.net
104.212.67.88	hel01r3.msedge.net
104.212.67.162	lis01r3.msedge.net
104.212.67.145	waw01r3.msedge.net
104.212.67.251	prg01r3.msedge.net
104.212.67.223	bru30r3.msedge.net
104.212.67.187	gva30r3a.msedge.net
104.212.67.168	cai30r3a.msedge.net
104.212.67.92	stor3.msedge.net
104.212.67.148	ath01r3.msedge.net
104.212.67.157	muc30r3.msedge.net
104.212.67.234	buh01.msedge.net
104.212.67.244	dxb30r3.msedge.net