Measuring Cloud Latency in Africa

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***Abstract*—Internet and Public Cloud adoption has been growing all over the world, and major Cloud Providers have a growing presence in Africa. However, little research has been conducted on performance of the Cloud in Africa, particularly from end users' point of view. This study measures network latencies experienced in Africa when accessing public Cloud infrastructure, and compares this with what is achievable in Europe. We use the RIPE Atlas platform to run latency and traceroute measurements to CDN endpoints and servers in datacenters in Africa and Europe. Reverse measurements are also conducted from the Virtual servers to non-RIPE endpoints in both Africa and Europe. Our results show that clients in Africa mostly use CDN nodes located outside the continent, resulting in higher latencies. We also observed some clients making use of circuitous routes to cloud destinations within Africa. In Europe, we found that a majority of CDN endpoints used were local, which resulted in lower latencies. We also find that using CDN nodes in Africa provides up to 87% lower latencies than accessing the Data Centres directly. In Europe, CDN access provided up to 142% lower latencies than accessing Data Centers. Results of this study should motivate cloud providers to continue increasing their CDN presence in Africa and to work with local ISPs to optimise routing and content delivery from their cloud infrastructure.**

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

Public cloud adoption has kept growing, and there has been a growing demand by many organisations to deploy or migrate their applications to the cloud. This trend has been adopted in major countries across Europe, America and Asia, as well as in Africa [1]. For a while, most of the public cloud infrastructure was North America, Europe, and South-East Asia, among others, with no presence in Africa. As such, African organisations using the cloud have had to use infrastructure in other regions. This means hosting data in remote regions, thereby losing sovereignty of their data. In addition, African users would incur additional latencies for their traffic traversing intercontinental links [2].

Apart from datacenters, Points of Presence (PoPs) usually serve as locations where the Cloud providers host their Content Delivery Network (CDN) servers to act as a cache for users. Using CDNs to bring content closer to users is a commonly used technique by Service Providers to reduce latency, thereby providing improved performance [3]. At the moment, the three major public cloud providers, Amazon Web Services (AWS), Microsoft Azure, and Google[1] have some degree of presence in Africa. Amazon Web Services (AWS) has its datacenters in Cape Town, South Africa, and PoPs in Cape Town and Johannesburg (South Africa) and Nairobi (Kenya)[2]. Azure also has its datacenters in Cape Town and Johannesburg (South Africa) and PoPs in Cape town and Johannesburg (South Africa), Nairobi (Kenya) and Lagos (Nigeria)[3]. Google Cloud has no datacenters in Africa, but has PoPs in Johannesburg(South Africa), Lagos (Nigeria) and Mombasa (Kenya). In addition, Cloudflare has the most PoPs, located in countries such as Algeria, South Africa, Senegal, Morocco, Madagascar, Tanzania, Zimbabwe, Nigeria, Rwanda, Kenya, Liberia, Mauritius, Tunisia and Angola[4].

A. Motivation and Objectives

Past studies have suggested that cloud infrastructure providers need to deploy more infrastructure in Africa [2]. This research explores cloud latency from Africa to major global cloud providers and CDN operators (AWS, Azure, Google and Cloudflare). As mentioned earlier, cloud providers have some presence already within Africa. They have established datacenters (also called Regions), as well as CDN nodes to serve African customers. This research measures latency to current cloud and CDN infrastructure of the major Providers in Africa, and provides some comparison with Europe. This research can help organisations and Internet Providers to devise the right cloud strategies to ensure that they are getting maximum performance for their cloud applications.

B. Research Questions

In this research, we measure and discuss latency characteristics from hosts in Africa to infrastructure provided by public cloud providers and these characteristics will be understood in terms of network latency and network paths. This paper aims to answer the following questions:

1) What are the Internet latencies between African clients and CDN PoPs of major Cloud Providers?
2) What are the Internet latencies between African clients and Datacenters of major Cloud Providers?
3) How do these characteristics differ for Cloud users in Europe?

[1] https://cloud.google.com/cdn/docs/locations

[2] https://aws.amazon.com/cloudfront/features/

[3] https://azure.microsoft.com/en-us/global-infrastructure/geographies/#overview

[4] https://www.cloudflare.com/network

II. Background and Related Work

The Cloud has been advantageous to the global economy [4]. It democratises access to different technologies across several domains like Compute, Networking, Security, Database, Analytics, Big Data, Artificial Intelligence and Machine Learning [5]. 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. Organisations 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 email, storage services, and many other applications [6]. 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 [6]. As the public cloud grows in Africa, and adoption continues to rise, understanding the performance attributes for traffic originated within Africa to these cloud endpoints can help providers, organisations and governments to strategize.

A. Challenges to Public Cloud Adoption in Africa

The primary mode for organizations to consume public cloud services is through the Internet [7]. Africa has been experiencing massive growth in its broadband penetration rate. As of 2018, of all ITU regions, Africa recorded the most robust growth in Internet usage, as the percentage of people using the Internet increased from 2.1% in 2005 to 24.4% in 2018[5]. 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 in the continent had to face performance barriers due to high latencies 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 and being subject to the law of other jurisdictions [8]. African organizations using the cloud had to make use of the infrastructure in other regions for hosting their data in these regions, thereby losing 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 [8].

B. CDN Client Redirection

To achieve adequate latencies to CDN Edge caches, providers employ approaches that redirect clients to the closest cache. These approaches use either DNS based redirection or Anycast based redirection to the closest cache [9]. DNS measurements are vital for evaluating CDN performance. The DNS results 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 [10]. 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 directs clients to CDN with least latency, Azure makes use of the geographic locations of the clients, and Google uses Anycast. Just like Google, Cloudflare relies on Anycast to direct requests to the nearest Cloudflare PoP [6].

The different approaches for determining the CDN server that a user should use has several advantages and disadvantages. Geolocation results may be inaccurate and should not be solely relied upon for getting the location of an IP address. If the location of an IP address is incorrectly calculated, a client may have to use 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 as well, irrespective of where the client computer is located. This has been a well known problem with DNS, and a feature known as EDNS-Client-Subnet (ECS) [11], [12] is gaining popularity. ECS takes the actual client computer into consideration, such that Recursive Resolvers forward details of the query's origin network when talking to other nameservers. However, DNS resolvers need to support this extension. 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 ISP may cause such high latency as the traffic path the ISP takes may be based on sub-optimal routing and peering policies [13]. 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 [10].

Anycast technology works such that IP prefixes are announced and advertised from multiple locations hosting the edge servers. The edge server that a user would get directed to is based on the ISP, and its BGP relationships with other service providers as well as its BGP routing policies. 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 [9].

III. Measurements Methodology

This study is based on two sets of internet measurements carried on the public cloud infrastructure, focusing on Africa. The first set of measurements were traceroute and latency measurements from RIPE Atlas Probes to websites hosted on CDN infrastructure of four public cloud providers - AWS, Azure, Google and Cloudflare. This was done to study geolocation of CDN PoP utilised by clients in Africa and Europe, and the corresponding latencies. The second set of measurements were traceroute and latency measurements from RIPE Atlas Probes to public cloud Datacenters (or Regions). These measurements

[5]https://www.itu.int/en/ITU-D/Statistics/Documents/publications/misr2018/MISR-2018- V ol-1-E.pdf

[6]https://www.cloudflare.com/network

reveal performance characteristics to Africa's regional Data Centers.

The measurements were conducted from a diverse number of African countries, of which five are the major economies in the different regions of Africa. These include Ghana (West Africa), Kenya (East Africa), South Africa (SADC), Tunisia (North Africa) and Mauritius. Other African countries included are; Morocco, Algeria, Botswana, Senegal, Tanzania, Mauritius, Namibia, Rwanda, Zambia, Togo, Burundi, Cameroon and Madagascar. In total, 69 RIPE Atlas probes were used across the African countries. Measurements from these probes were run against CDN caches and data centres available in Africa. As earlier mentioned, while there are multiple CDN locations in Africa, only AWS and Azure have regions in the continent, and this is in South Africa. Our non-CDN measurements in Africa were therefore run against the South African Region. In Europe, we run measurements from 57 RIPE Atlas probes distributed in six countries, viz-a-viz, Russia (Eastern Europe), France (Western Europe), United Kingdom (North-Western Europe), Ireland (North-Western Europe), Germany (Central Europe) and Italy (Southern Europe). We run measurements against CDN caches in these countries and to an existing Cloud region in Ireland.

A. *Measurements from RIPE Atlas Probes to CDN Servers*

We deployed a simple custom web application to activate the CDN services on four cloud platforms as well as in the cloud regions:

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

For each cloud provider, ping measurements and traceroute measurements to the respective domains were run every 8 hours for 30 days in September, 2021.

B. *Measurements from RIPE Atlas Probes to Public Cloud Regions*

We run ping and traceroute measurements from the RIPE Atlas probes to public cloud regions in Africa and Europe. The region used in Africa is the one based in South Africa, as this is the only one with AWS and Azure presence in the African continent. For Europe, we chose the region in Ireland as a reference for these measurements. In each of these regions, virtual servers were launched as targets for the measurements carried out from the RIPE probes. For both the South African Region and Ireland regions, half of the measurements were targeted to the AWS server and the other half to the server in the Azure region. For each cloud provider, we run ping and traceroute measurements every 8 hours to the respective virtual servers for 30 days in September 2021.

IV. RESULTS

The measurements to AWS returned 226 unique IP addresses belonging to CDN servers, Azure returned 81 unique destination IP addresses belonging to CDN servers, Cloudflare and Google returned two unique Anycast IP addresses each. These are Anycast IP addresses shared by all of the respective CDN servers. Hence, there's no exposed visibility by the providers to determine the actual number of CDN servers that responded to the measurement requests.

A. *Geolocation of CDN endpoints*

We use geolocation tools ipinfo.io and Maxmind to determine countries where the non-RIPE endpoints were located. To geolocate AWS and Azure CDN endpoint IP addresses, we use reverse DNS lookup [14]. This worked because AWS and Azure use latency and geographic based DNS routing respectively. For the Reverse DNS lookup, a bulk tool, https://www.infobyip.com/ipbulklookup.php, was used. The returned DNS results include airport codes that represent the city location of the CDN servers. We do not geolocate Google and Cloudflare CDN endpoints, as these use Anycast where all CDN servers share the same set of IP addresses, and geolocating them using the IP address is impossible.

Looking at the IP addresses accessed by the probes in Africa, 95% of the AWS IP addresses resolved by reverse DNS were geolocated to European cities (66%) - with the top locations being Roissy-en-France, Frankfort, and Longford. The US was location for 15% of the IPs, with Atlanta, Chicago, and Boston being the top destinations (Figure 1) . About 9% of the IPs were geolocated to Asia and South America. Only 5% of IP addresses were geolocated to Africa, exclusively in South Africa and Kenya (Cape Town, Johannesburg, and Nairobi). With Azure, out of the 18 IP addresses accessed by probes in Africa, only two were within Africa (Egypt and Nigeria), while the rest were in Europe. Figure 2 shows the distribution of AWS CDN PoPs used by clients in Africa.

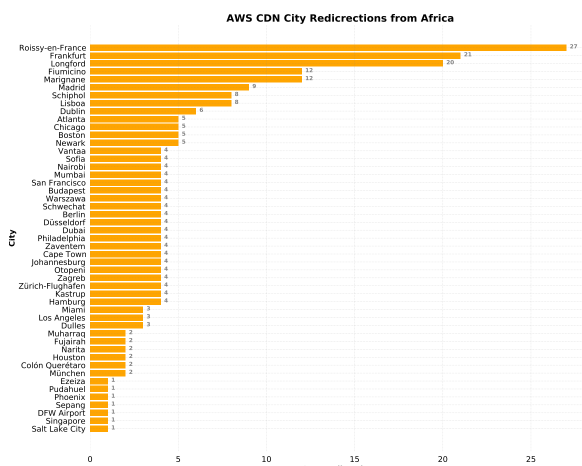

Fig. 1. Geolocation of CDN PoP IP addresses; 95% of CDN redirections from Africa vantage points were to cities America, Europe, Asia.

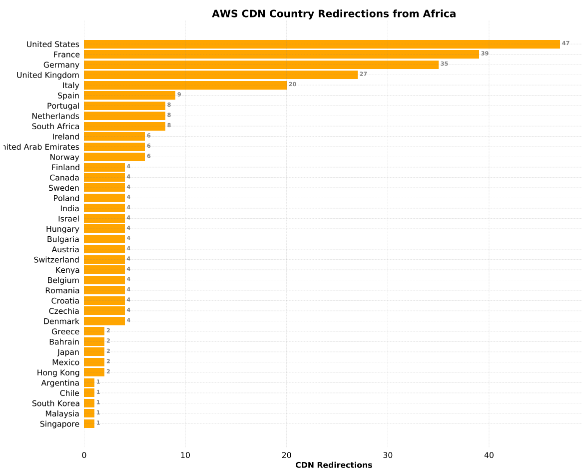

Fig. 2. Distribution of CDN redirections from African vantage points America, Europe, Asia.

B. Latency from African RIPE Probes to CDN servers and Cloud Regions

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, Cameroon and Madagascar) ranged from 29ms to 65ms to the different CDN endpoints. Figure 3 shows latencies from RIPE Atlas Probes in African Countries to websites hosted on the CDN endpoints in AWS, Azure, Google Cloud and Cloudflare. 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.

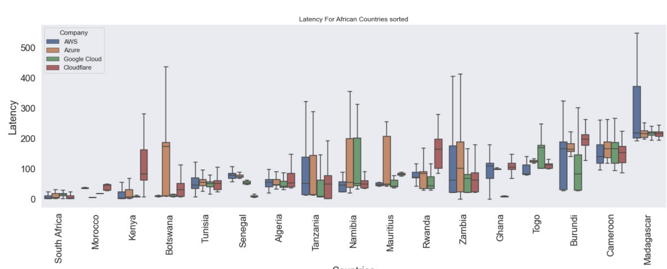

Fig. 3. Median Latency across selected African countries to CDN Endpoints.

The recorded median latencies from African countries to the Regions/Data Centers based in South Africa were higher than to CDN endpoints (Figure 4. The median latency to AWS Africa Region increased from 45ms (for CDN) to 84ms (for the region), whereas for Azure, it increased from 59ms (for CDN) to 74ms for the region (Figure 5.

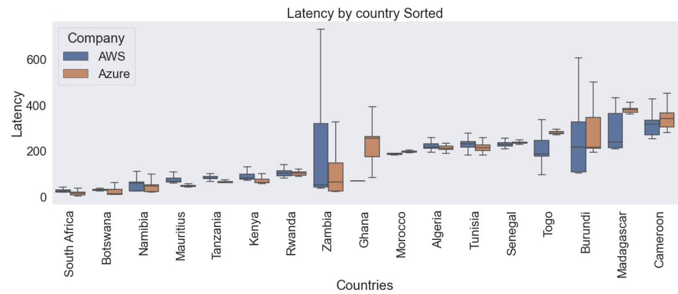

Fig. 4. Median Latency across selected African countries to Datacenters in South Africa.

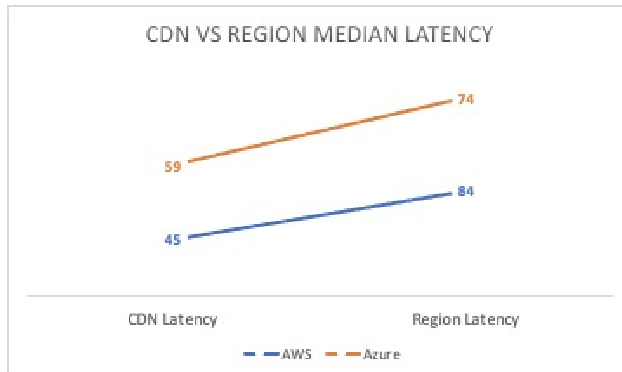

Fig. 5. AWS and Azure.comparison of CDN and Region median latency(ms) for selected African countries.

C. Latencies from European RIPE Probes to CDN Servers and Cloud Regions

For European countries in our measurements (Russia, France, United Kingdom, Ireland, Germany and Italy), the median latency to CDN endpoints was lower compared to those observed from African countries. The European median latencies ranged from 13ms to 17ms. In Europe, the countries with the lowest median latencies to the CDNs were France, Germany and UK, with values ranging from 11.99ms to 14.71ms, while Russia had median latency of 33.5ms, the highest latencies among the European countries measured. Figure 6 presents latencies between RIPE Atlas Probes in different European Countries to the CDN endpoints in AWS, Azure, Google Cloud and Cloudflare. These are sorted based on the mean of the aggregated results per country.

Similar to Africa, the European latencies to the CDN endpoints were much lower than the latencies to the Region/Datacenter (in this case in Ireland). The median latencies to CDN endpoints was 14ms, whereas to the Region, the median latency was 34ms. For Azure, median latencies to CDN servers was 17ms, and 31ms to the region. Figure 7 presents latencies between RIPE Atlas Probes in European Countries to the Regions for AWS and Azure. These are sorted based on the mean of the aggregated results per country.

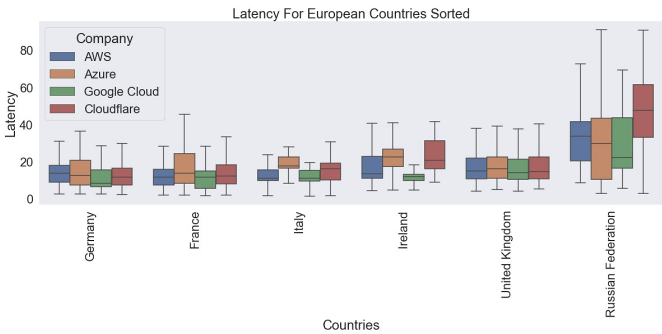

Fig. 6. Median Latency across selected European countries to CDN PoPs.

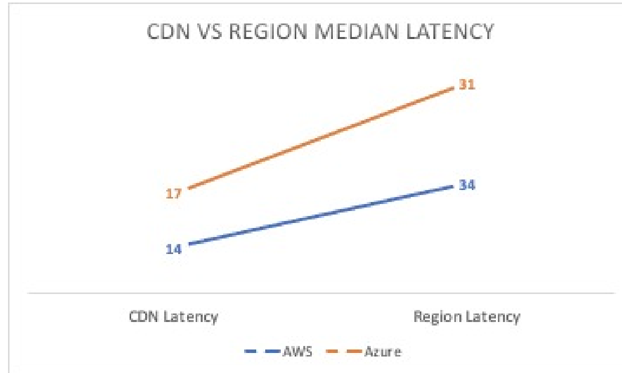

Fig. 8. AWS and Azure comparison of CDN and Region median latency(ms) for selected European countries.

It is not surprising that CDNs provide lower latencies that Datacenters, given that in their design, CDNs are meant to reduce the physical distance between a user and the origin – a web or an application server, which are generally located in Datacenters. Overall, the probes in Europe to the CDN endpoints showed lower latencies than from African countries.

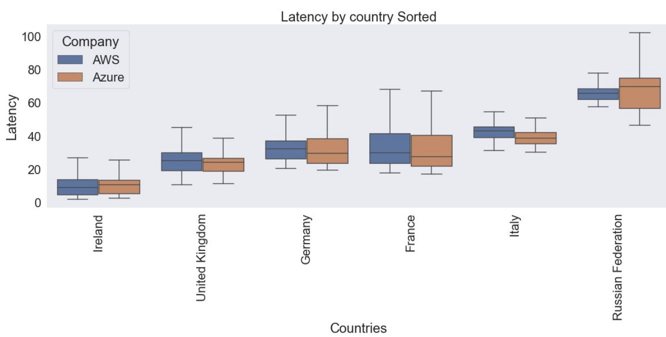

Fig. 7. Median Latency across selected European countries to Datacenters .

The European CDN performance advantage over Regions is higher than what we see in Africa. Europe AWS CDN had 142% lower median latency than the European region (Figure 8), whereas in Africa, AWS CDN had 87% lower latencies than the Africa Region (Figure 5). Azure had 82% better CDN performance in Europe than to the Region, while in Africa, Azure CDN advantage over the Region was only 25%. The difference in the observed CDN advantage could be due to the fact that the majority of CDN endpoints used in Africa were based outside the continent, hence experienced relatively higher latencies.

V. Discussion

This study was conducted to understand the latency characteristics when accessing cloud services in Africa from different African countries. 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 regions/datacenters in Africa for accessing various cloud services. The results show 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.

Looking at the instances of consistently highest latency values in the CDN measurements, we observe two behaviours: i) Traffic gets routed to CDN locations in a different continent: ii) Circuitous routing behaviour is present in some situations where traffic gets routed through Europe before returning to the CDN location in Africa. An example of this is with traffic from a 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 emphasise the need to not only have more CDN points of presence available in countries, but also to prevent sub-optimal routing through distant locations, and to keep traffic local within the continent. There's room for both Internet and cloud providers in Africa to deepen their relationships with other network providers and IXPs in Africa to avoid circuitous routing for destinations within Africa. Cloudflare's situation emphasises why a combination of both of these 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 did not necessarily have the least number of router hop counts. South Africa 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 to themselves. The traffic from Mauritius on the other hand went to destinations in South Africa and global cities like Berlin, Hong Kong, Zurich, and Dubai. Hence, hop count is not a very good measure of performance.

Using AWS as a reference, 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 did not 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.

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 was between 5.3ms and 10.3ms respectively. European countries like France, Germany, and the United Kingdom using their CDN endpoints had latencies between 11.99ms and 14.7ms.

A comparison of the the CDN and Datacenter latancies of both AWS and Azure in Africa suggests that CDNs in Africa are a great way to improve Internet performance. The latencies observed from African probes to the CDN endpoints were much lower than that of the same probes to the African region in South Africa. Based on this results, it's evident that African users can achieve a good level of performance improvement by adopting CDNs for suitable applications. 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.

VI. Conclusion

This study has looked at latencies cloud and content delivery infrastructure in Africa. We ran Internet measurements from selected African countries to CDN points of presence and Public Cloud Datacenters also known as Regions. We compared this with measurements from selected European countries. Our results have shown that African countries had much higher cloud and CDN latencies compared to Europe. We observe that a vast majority of the CDN PoPs used by clients in Africa are based outside the continent. We also noted cases of traffic 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% better performance having more CDN points of presence in Africa, which are less expensive than having full regional presence. In Europe, this CDN performance advantage is even higher at 142%, for which the majority of the CDN endpoints used are local to the continent, reducing the chances of incurring high cross continental Latencies.

The assumption that the DNS results are always indicative of the actual client location and performance has been shown to be false [13]. In addition, for optimal CDN redirection, 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 [15].

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