Networks and Internet Systems Assignment (CSC5032Z)

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1. Introduction

The objective of this assignment was to analyse the Internet topology interconnecting African universities using the distributed measurement platform called Ripe Atlas [1]. We were tasked with studying the geo-topology and performance of 20 African universities.

There were two main tasks for this assignment. Task-1 was intra-country measurements, where we needed to analyse the ping and traceroutes from target probes within each country. Task-2 was intercountry measurements, where we needed to analyse ping and traceroutes from probes in different countries.

For both Task-1 and Task-2 we needed to analyse three items. Item 1: end-to-end delays which I measured using RTT (Round-Trip Time), Item 2: AS (Autonomous System)-level hops such as the number of AS hops and which ASs were traversed - we could find this using the AS's Numbers (ASNs) and, lastly Item 3: country level hops (which countries were traversed between the source and destination). These items are composed of sections 3 and section 4 respectively for Task-1 and Task-2.

RTT is the duration in milliseconds (ms) it takes for a network request to go from a starting point to a destination and back again to the starting point [2].

To get the 20 universities I chose somewhat randomly from lists of top universities in Africa [3,4,5]. First, I ensured that the country I was choosing from had a minimum of 3 or more working/available Ripe-Atlas probes for the measurements. I mostly used the top 3 universities in each country but because this was different according to different sources, this was not strictly enforced. The 20 universities I chose to do measurements on are listed in Table 1 on the next page:

Each university was tested by connecting to it from Ripe-Atlas probes within the same country, as well as from Ripe-Atlas probes from the other countries; this was how I simulated intra-country connectivity as well as intercountry connectivity respectively. The results from these tests and a discussion of the results are provided in the sections that follow, as well as the methods used to conduct the tests and some of the shortcomings are also provided.

Name of University	Website URL	IP Address	Country
University of Cape Town	www.uct.ac.za	137.158.154.230	South Africa
Stellenbosch University	www.sun.ac.za	146.232.21.213	South Africa
University of The Witwatersrand	www.wits.ac.za	146.141.13.50	South Africa
University of Ghana	www.ug.edu.gh	197.255.125.213	Ghana
Kwame Nkrumah University of Science and Technology	www.knust.edu.gh	129.122.16.228	Ghana
University of Cape Coast	www.ucc.edu.gh	156.38.97.11	Ghana
Université de Dschang	www.univ-dschang.org	5.135.142.207	Cameroon
Université de Buéa	www.ubuea.cm	50.87.98.153	Cameroon
Université des Montagnes	www.udesmontagnes.aed-cm.org	109.234.162.16	Cameroon
Makerere University	www.mak.ac.ug	196.43.133.108	Uganda
Kampala International University	kiu.ac.ug/www.kiu.ac.ug (*note different)	172.67.189.181/**104.21.65.90**	Uganda
Mbarara University of Science and Technology	www.must.8m.net	64.136.20.36	Uganda
University of Dar es Salaam	www.udsm.ac.tz	196.44.161.196	Tanzania
Sokoine University of Agriculture	www.sua.ac.tz	41.73.194.141	Tanzania
Muhimbili University of Health and Allied Sciences	www.muhas.ac.tz	41.93.40.69	Tanzania
University of Nairobi	www.uonbi.ac.ke	41.204.161.206	Kenya
Kenyatta University	www.ku.ac.ke	41.89.10.16	Kenya
Strathmore University	www.strathmore.edu	198.57.179.99	Kenya
University of Zambia	www.unza.zm	41.63.1.1	Zambia
The Copperbelt University	www.cbu.ac.zm	192.124.249.110	Zambia

Table 1: List of universities measured: Red - Ping rejected; Green - Ping accepted

2. Methodology

The universities were selected from Africa as described in the Introduction section. Once the 20 universities were selected, the measurements were carried out. These were done using the RIPE Atlas measuring platform [1]. The RIPE-Atlas platform allowed me to find probes from certain countries by requesting country-specific probes and allowed connections to the university websites using the chosen probes as the source. Ping and traceroute measurements were conducted for each country from within the same country as well as from each country to the other selected countries of which there were 7 (countries) in total. I used RIPE Atlas Cousteau to create the measurements [6] and the results were then extracted using Python and they were then refined for the analysis. The 4 protocols for measurements were SMTP (Ping) and TCP, UDP, and ICMP for traceroutes.

3 probes were randomly selected from each country (Ripe-Atlas chose them), the only probes that were set were for Ghana and this was due to Ghana probes being unreliable even when extra probes were requested only 2 worked as requested. This issue was fixed by setting the 3 probes to specific ones that worked.

3.1. Intra-country measurements

Ping results

Only 13 of the 20 universities accepted Ping requests, the others presumably had firewalls blocking these attempts for security reasons as Pings can be used by hackers to gain insight into networks that they can use for malicious intent. However, since only **all** of the South African universities blocked the Ping requests, we still have Ping data for all the other countries.

In order to make the tests as fair as possible, the measurements were taken at multiple points throughout the day and were then averaged to create an overall generalisation on the network topology.

Due to countries having different time zones, this may have affected traffic and therefore RTTs might have been affected by this. This is an unfortunate constraint but times were averaged in the hopes of mitigating this factor slightly. The specific days that measurements were taken might also affect the traffic amount. Due to this a combination of week days and weekends were used.

The results showed that the average RTT time for all the available (universities that accepted Ping requests) universities was **111.2331174** ms. The fastest average RTT was 5.664053133 ms and that was produced by Muhimbili University of Health and Allied Sciences and the slowest average RTT was 340.4282551 ms and that was produced by Mbarara University of Science and Technology.

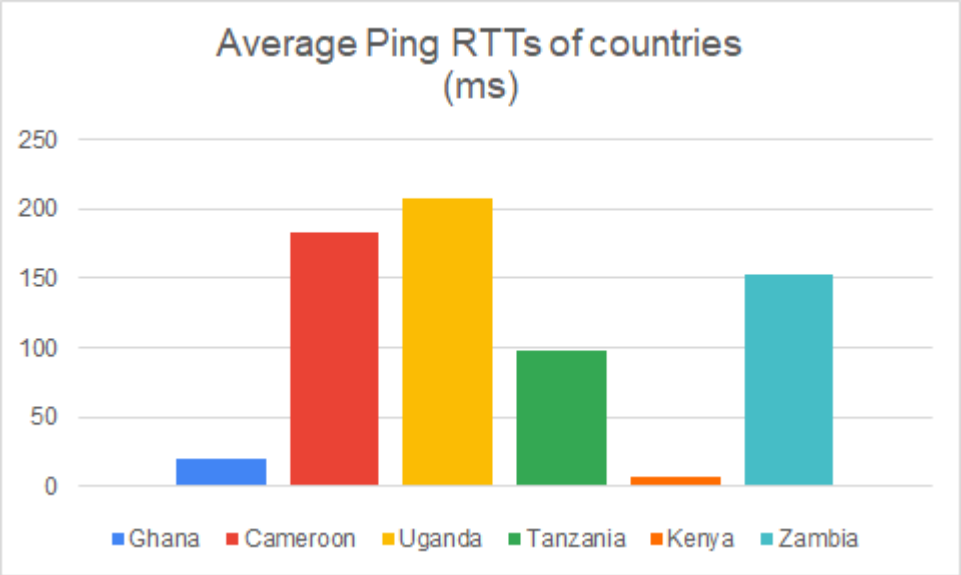


Figure 1: Average Ping RTTs Intra-country

Ghana clearly has amazing network infrastructure as all of their selected universities consistently performed well. They had the second lowest RTT besides Kenya, but Kenya only had one university participating in the Ping measurements.

Cameroon is lacking good network infrastructure as they consistently had poor RTT averages.

Uganda is difficult to classify because there is a big difference in the infrastructure between Kampala International University and Mbarara University of Science and Technology. This may be because Mbarara hosts their servers out of country.

Tanzania seems to have a well-rounded field of RTT averages ranging from very quick times (Muhimbili University of Health and Allied Sciences) to poor RTT averages (University of Dar es Salaam).

Dar es Salaam appears to not be able to handle network traffic or congestion well and that is shown by some of their very high RTT averages. Dar es Salaam had erratic RTTs with some relatively decent (in overall comparison) RTTs and some poor.

The University of Nairobi has the second fastest RTT averages after Muhimbili University of Health and Allied Sciences, however, a single data point (university) isn't enough to create a reliable average for Kenya as a whole.

Zambia also has a wide range of RTT averages with fast RTTs from University of Zambia and slow from The Copperbelt University.

The fastest RTT averages per universities were under 10 ms and the slowest were upwards of 250 ms.

The total average for all countries RTT was 111.2331174 ms.

The results from the intra-country ping measurements showed that Ghana and Kenya had excellent Ping RTT averages, however, it must be noted that only a single university in Kenya had measurements available. Tanzania had average Ping RTT averages. Zambia, Cameroon and Uganda had high Ping RTT averages.

The reasons for the vast differences in RTT averages could be due to multiple factors such as: distance from probes to universities network destinations, number of hops between the probe source and destination (number of hops does not necessarily relate to speed though) , random probe selection (Ripe-Atlas chose which probes to use), network congestion, hosting for the university websites could be out-of-country or even worse hosted in another continent, probes are routed to Autonomous Systems (ASs) outside of the country and are then routed back [7]. Many of these issues could be fixed with better university network design and infrastructure improvement on a country-level.

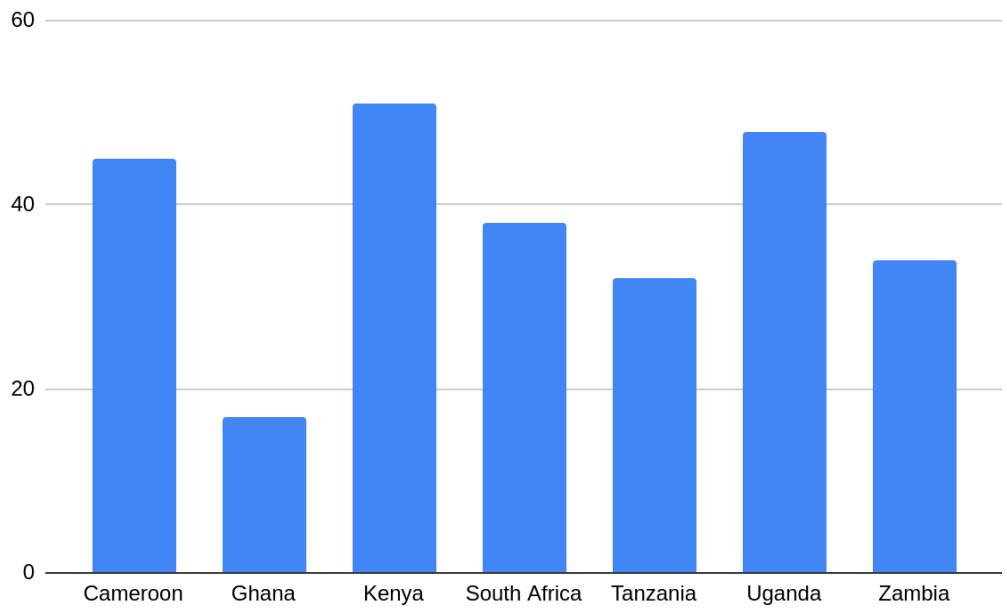
Traceroute results

Cameroon, Kenya, and Uganda all had over 40 hops on average, while South Africa, Tanzania, and Zambia had between 20 and 40 hops on average. Ghana had under 20 hops on average. The traceroutes can provide insight into the Ping RTTs.

Ghana had an average of only 17 hops for intra-country traceroutes. South Africa, Tanzania and Uganda had between 20-40 , while Cameroon, Kenya and Uganda had over 40 average hops.

The reasons for the differing number of hops could include things such as: underlying infrastructure for the country and university network topology and design. Factors such as where universities chose to host their website must also be considered (locally vs in another country vs in another continent)

Figure 2: Average number of hops for each country from intra-country traceroute measurements using a combination of the 3 traceroute types



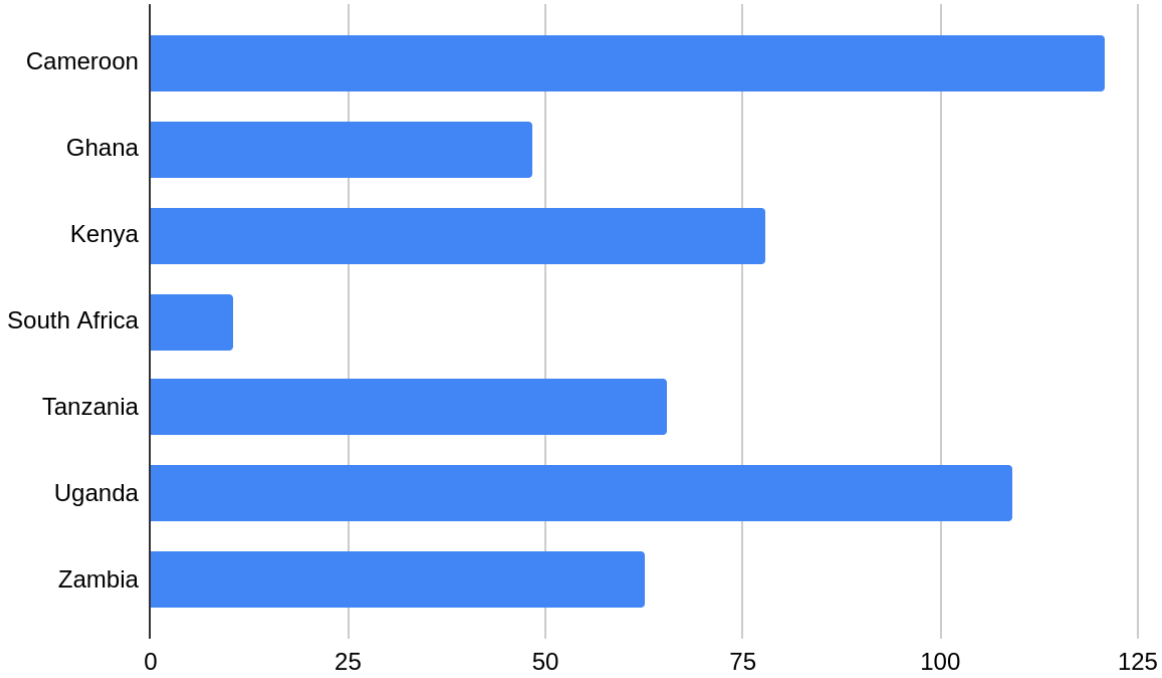


Figure 3: Average RTT time for traceroutes for intra-country measurements using a combination of the 3 traceroute types

South African universities displayed very fast RTTs. Ghana had the second fastest. Unfortunately for Kenya and Zambia, both averages suffered due to terrible RTTs from a single university each. These poor RTT examples could mean that those particularly poor performing universities could be reliant on external web servers to provide access to their websites and therefore the traceroutes have to travel long distances to connect to these servers. Cameroon and Uganda might be reliant on external Internet Service Providers (ISPs) to provide access to their internet which might indicate why their hops are so slow. Preventing inter-country hops could occur by choosing the correct ISP vendors or configuring the routing protocols to point to within the regional ISP if a regional ISP exists [7].

There appears to be a soft correlation between RTT and number of hops, however it is not always applicable as can be seen by South Africa which had a relatively high number of intra-country hops but still came out fastest for RTT. Cameroon and Uganda both had a high number of hops and the highest RTTs.

Cameroon and Uganda both struggle with depending on other countries to provide them with their web services to their universities.This heavily delays the packets and results in the slow RTTs [7].

Table 1: Traceroute of country-level hops for each university (Bold depicts final country hop) (3 countries in a row means that the hops remained in single country) (*First country hop was Zambia which was interesting to see for a Tanzanian university)

Country-level Hop number	**Université de Dschang**	**University of Ghana**	**University of Cape Town**	**University of Nairobi**	**University of Dar es Salaam**	**Makerere University**	**University of Zambia**
1	*Cameroon*	*Ghana*	*South Africa*	*Kenya*	*Zambia**	*Uganda*	*Zambia*
2	*Canada*	*Ghana*	*South Africa*	*Kenya*	*Mauritius*	*Uganda*	*Mauritius*
3	***France***	***Ghana***	***South Africa***	***Kenya***	***Zambia***	***Uganda***	***Zambia***
	Université de Buéa	**Kwame Nkrumah University of Science and Technology**	**Stellenbosch University**	**Kenyatta University**	**Sokoine University of Agriculture**	**Kampala International University**	**The Copperbelt University**
1	*Cameroon*	*Ghana*	*South Africa*	*Kenya*	*Tanzania*	*Uganda*	*Zambia*
2	*Canada*	*Ghana*	*South Africa*	*Kenya*	*Tanzania*	*Kenya*	*Mauritius*
3	***United States***	***Ghana***	***South Africa***	***Kenya***	***Tanzania***	*South Africa*	*South Africa*
4						*Uganda*	*Hong Kong*
5						*Mauritius*	*United States*
6						*Tanzania*	*Singapore*
7						*Uganda*	*United States*
8						*Mauritius*	*Zambia*
9						*Tanzania*	*Namibia*
10						***Uganda***	*Sweden*

11							*United States*
12							*Zambia*
13							*Malawi*
14							***United States***
	Université des Montagnes	**University of Cape Coast**	**University of The Witwatersrand**	**Strathmore University**	**Muhimbili University of Health and Allied Sciences**	**Mbarara University of Science and Technology**	
1	*Cameroon*	*Ghana*	*South Africa*	*Kenya*	*Tanzania*	*Uganda*	
2	*Canada*	*Ghana*	*South Africa*	*Hong Kong*	*Tanzania*	*Kenya*	
3	*United States*	***Ghana***	*South Africa*	*United States*	***Tanzania***	*United Kingdom*	
4	*France*		*South Africa*	*Kenya*		*United States*	
5	***Cameroon***		***South Africa***	*United Kingdom*		*Uganda*	
6				*United States*		*Malawi*	
7				*Kenya*		*United States*	
8				*South Africa*		*Uganda*	
9				***United States***		*Mauritius*	
10						*United Kingdom*	
11						***United States***	
Infrastructure Comments based off of country-hops	*Cameroon has poor infrastructure*	*Ghana has great infrastructure*	*South Africa has great infrastructure*	*Kenya has 2 great and 1 poor infrastructure(s)*	*Tanzania has 2 great infrastructure and 1 weird infrastructure(s)*	*Uganda has 2 poor and 1 great infrastructure(s)*	*Zambia has 1 poor infrastructure and 1 decent infrastructure*

4.1 Intercountry measurements

Traceroute results

From Table 1, we can see that there are a few routes that are used often. The most common routes are through South Africa, where an ASN called Tenet-1 has the highest number of hits of all of the ASNs (~35%). Tenet-1 is South African based so this makes sense. However, it must be remembered that 3 universities from South Africa were used so this could have skewed that finding. The most common overseas country was the United States which accounted for ~6.9% of all ASN hits. This closely correlates with Cogent ASN provider which is based in the United States seeing 5.2% of all ASs seen through the traceroute measurements. The other big ASN was SEACOM which operates in the regions of Kenya, Mozambique, South Africa, Tanzania, and Uganda (4 of which were directly used in the measurements) so the high 10.9% hit rate makes sense here. The last notable (>5% ASN) was Liquid Telecommunications which operates in Uganda, Kenya, Rwanda, Zambia, Zimbabwe, Botswana, DRC, Lesotho, and South Africa (again 4 of which were directly used in the measurements). Intercountry pings were omitted since only having 13 ping results would not be an accurate or fair representation of RTTs.

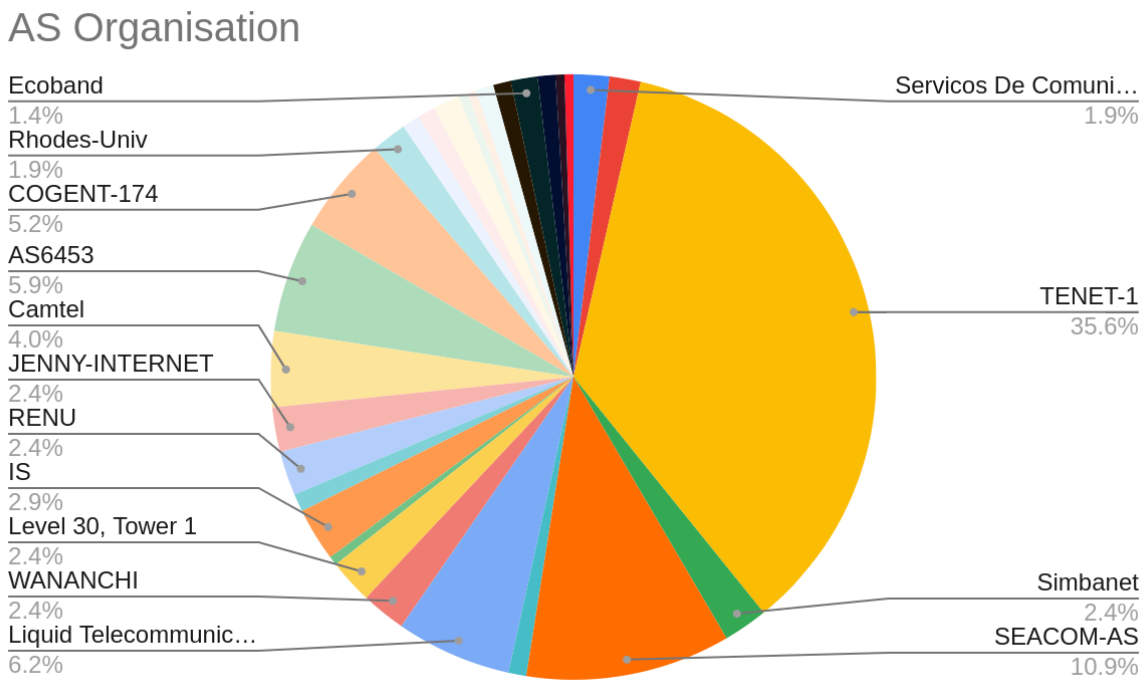


Figure 4: Percentage breakdown of AS Organisations from traceroutes

There was an average of 61 hops per country for all the 60 probes. This is a large number of hops for an average and the fact that many of them were not only out of country, but out of the continent is not a good sign for Africa's web architecture. Africa needs more CDNs and caches [9].

Figure 5: Histogram of the distribution of RTTs for all the probes running and the time it takes for traceroutes to return to the source probe

The histogram shows the distribution of RTTs for all the probes running and the time it takes for traceroutes to return to the source probe. Disturbingly some RTTs were upwards of 1500 ms. This means that those RTTs had to possibly travel far and through congested networks where they possibly had to queue before hopping to the next network. Improving poor infrastructure and improving network setup could avoid these issues.

The average RTT overall was 87.86829046 ms for all countries and all hops.

The main AS Organisations are displayed in Figure 4 and it depicts TENET-1 as being the largest organisation in terms of usage and SEACOM-AS as a close second followed by Liquid Telecommunications in third place based on usage.

Figure 5 below shows that many countries route via South Africa to connect to websites. Other overseas countries include the United States, Portugal, Spain, Canada, Hong Kong. These countries are far away from Africa and routing via them would be expensive to RTTs since the geographical distance to them is long. This is especially true for the United States yet they make up almost 7% of all the traceroute visits which may suggest that universities use United States based companies to host their web services. South Africa appears to be a central hub for interconnectivity between countries since the South African web infrastructure is better than most African countries.

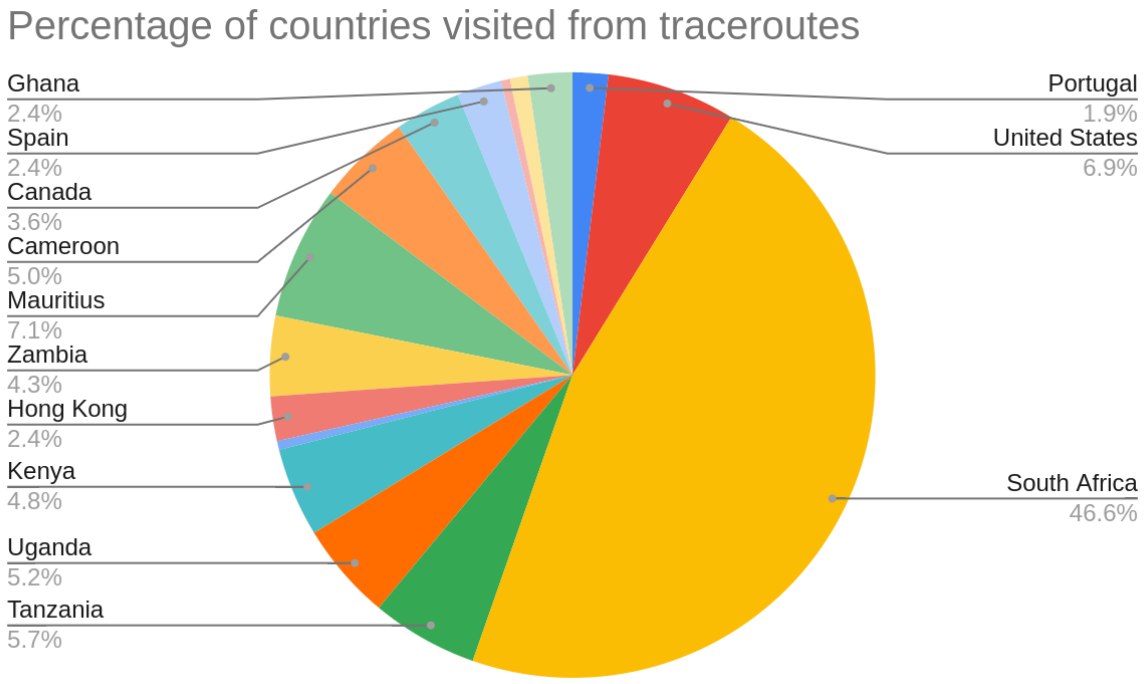


Figure 5: Country percentage visits from traceroute hops for all the probes running

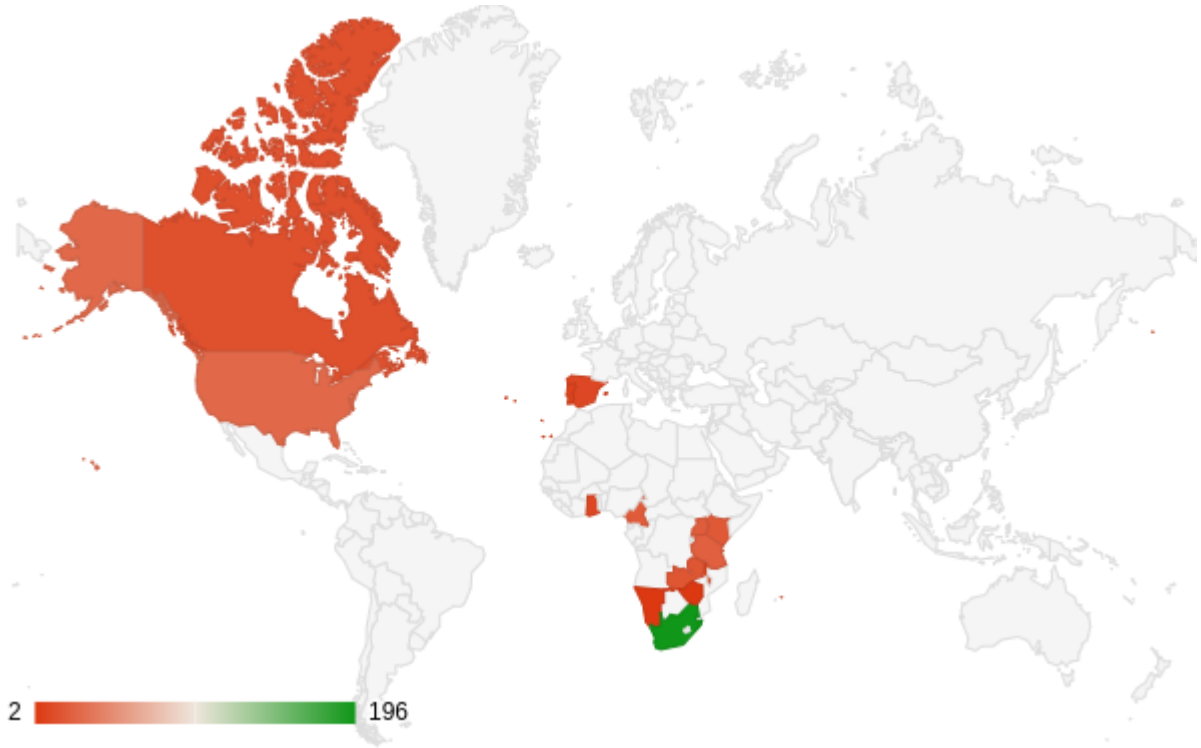


Figure 6: Average number of traceroute hops per country for all the probes running

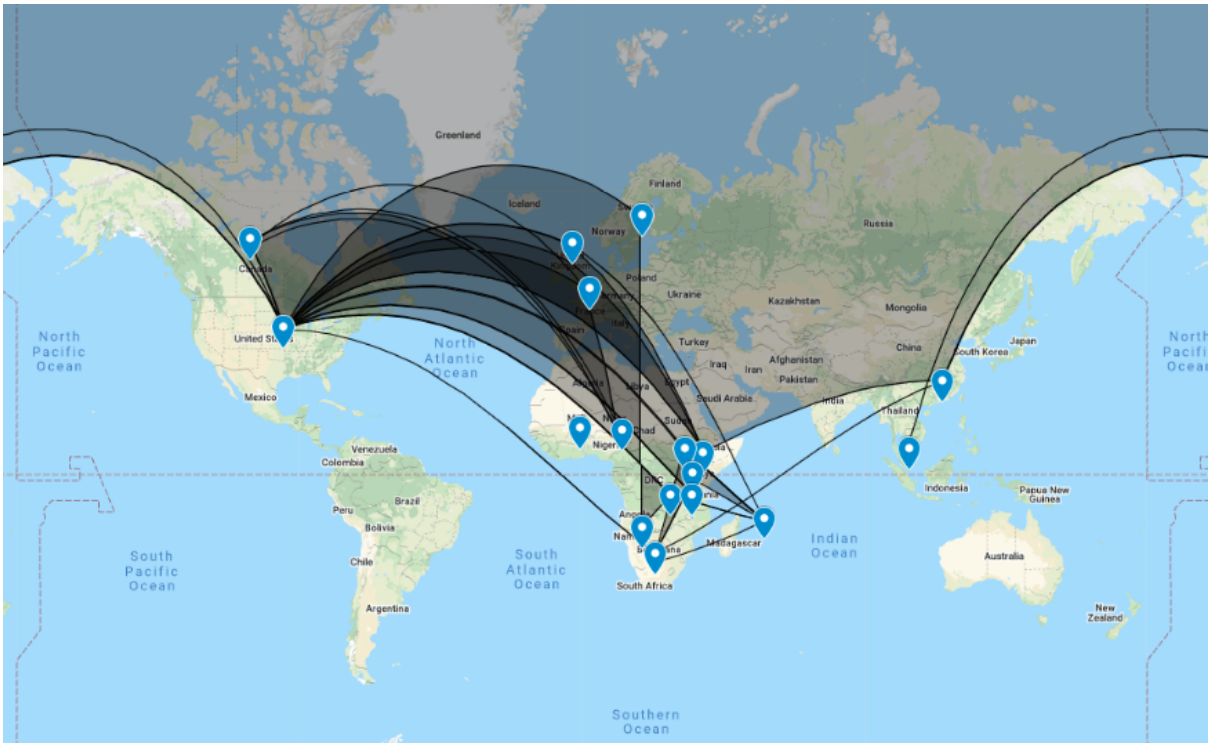


Figure 7: The above map is a map of the traceroute lines from intracountry-traceroutes. This shows that many universities rely on external countries to host their web services.

5. Conclusion

It must be noted that I do not believe that measuring 3 universities is a fair representation of a country's internet infrastructure as a whole since drastic differences were evident from RTT times even between universities within the same country. This shows that RTT was more closely related to the university's internet infrastructure than the county's infrastructure.

The Internet in Africa is evolving rapidly, yet it remains significantly behind other regions in terms of performance and ubiquity of access [8]. Africa seems to be struggling as a whole with a lack of good network infrastructure in many of their countries. However, this is not universally true [8] and some countries have very good infrastructure, similar in standards to relatively developed levels [8]. A key issue is the lack of inter-country connections and peering.

Many countries must rely on ISPs overseas to provide them with internet and access to other destinations. This results in high RTT in most of the countries and creates issues with traceroutes where countries have to perform a large number of hops to reach a destination.

6. References

1. https://atlas.ripe.net/
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3. https://www.timeshighereducation.com/student/best-universities/best-universities-africa
4. https://www.topuniversities.com/university-rankings-articles/world-university-rankings/top-universities-africa
5. https://www.4icu.org/top-universities-africa/
6. https://ripe-atlas-cousteau.readthedocs.io/en/latest/
7. Assignment example (some of the reasons listed in the example are correct and useful for my findings as well - certain facts given cannot be changed and would have appeared in my paper regardless of seeing them in the example assignment), the structure of this assignment is similar to the structure of the example assignment because that assignment is being used as a basis for this assignment - however, the results will be different since different data and universities and countries were measured.
8. Formoso, Agustin & Chavula, Josiah & Phokeer, Amreesh & Sathiaseelan, Arjuna & Tyson, Gareth. (2018). Deep Diving into Africa's Inter-Country Latencies. 2231-2239. 10.1109/INFOCOM.2018.8486024.
9. Singh, Rachee & Dunna, Arun & Gill, Phillipa. (2018). Characterizing the Deployment and Performance of Multi-CDNs. IMC '18: Proceedings of the Internet Measurement Conference 2018. 168-174. 10.1145/3278532.3278548.