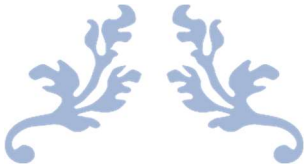

INTERNET SYSTEMS

Network Measurements

SEPTEMBER 15, 2023

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CSC5032Z: Assignment 2

Contents

1. Goals

The goal of this paper and the experiments was to measure and analyse internet performance and geo-topology interconnecting African universities. This was to help gain a better understanding of the dynamics of networked systems in Africa. Understanding this will help in future with knowing how to allocated resources for better network optimization and could also lead to more resource sharing as well as joint projects and collaboration among African universities.

2. Methods

To achieve the objective of the paper 20 African universities were chosen based on two requirements

1. The universities has to have their web-servers hosted within their respective country. This was verified through the use of Maxmind country and ASN databases.
2. The university's country had to have at least Ripe Atlas probes to act as sources when targeting universities within and outside of the country.

The first point was more challenging than expected as it not many African universities seemed to meet that standard as many had their web-server hosted overseas. This could be due to overseas servers being more reliable due to greater investment in network infrastructure such as fibre optic networks. This could also be due to political reasons. This could be to avoid censorship of university papers and ensure academic freedom.

For the second point, I verified this on the ripe atlas site online. The countries were chosen to cover the African continent to avoid sampling bias and ensure the results would be representative of the network. One country in central (Senegal), one in northern (Morocco), one in western (Senegal), one in eastern (Tanzania) and 3 in southern Africa (South Africa, Namibia & Malawi).

Ripe Atlas is the distributed internet measurement system use to conduct ping and traceroute measurements. The measurements were created using the Cousteau tool that binds python code to the Ripe Atlas API. I created 20 recurring traceroute and ping measurements (for each university) through python code I had written (measurements.py) and using a Rile Atlas API key. Measurement IDs for each university were then stored in a text file (measurements.txt). Both measurements where scheduled to start on the 10th on Sunday at 05:30 UTC and reoccur every 8 hours with the last one being on the 12th on Tuesday at 21:30. Every measurement to a target involved 21 probes as sources. Ping involved sending 5 packets, where as traceroute involved sending 7 packets. I had intentionally increased the standard number of packets so I get a more accurate average round-trip-time (RTT) for my measurement readings. These measurements were possible thanks to the atlas credits received from our Lecturer.

Ping was used to measure the latency (time for packets to be sent from a probe to the university web-server) and the reachability of the web-server (response frequency for sent packets). Ping, however falls short in that it cant really show you why there could be an large or low end-to-end delay or where sent packets could be getting lost. This was where the traceroute measurement would come in, as I could now follow the paths packets take when sent to a destination. Each router or device IP address from the traceroute was checked on the Maxmind database to determine the country it is in and the autonomous system number in the network. These measurements allowed us to assess packet size, latency and packet loss as well as autonomous systems and country level hops

The readings of the measurements were extracted and stored under the universities' respective country directory. This could used as metadata to get more context on the results I will be discussing in the next section. Version Control was used so the logs can be referred to. This also aids in reproducibility. The data was then filtered (data.py) and then visualised (visualise.py).

3. Results & Analysis

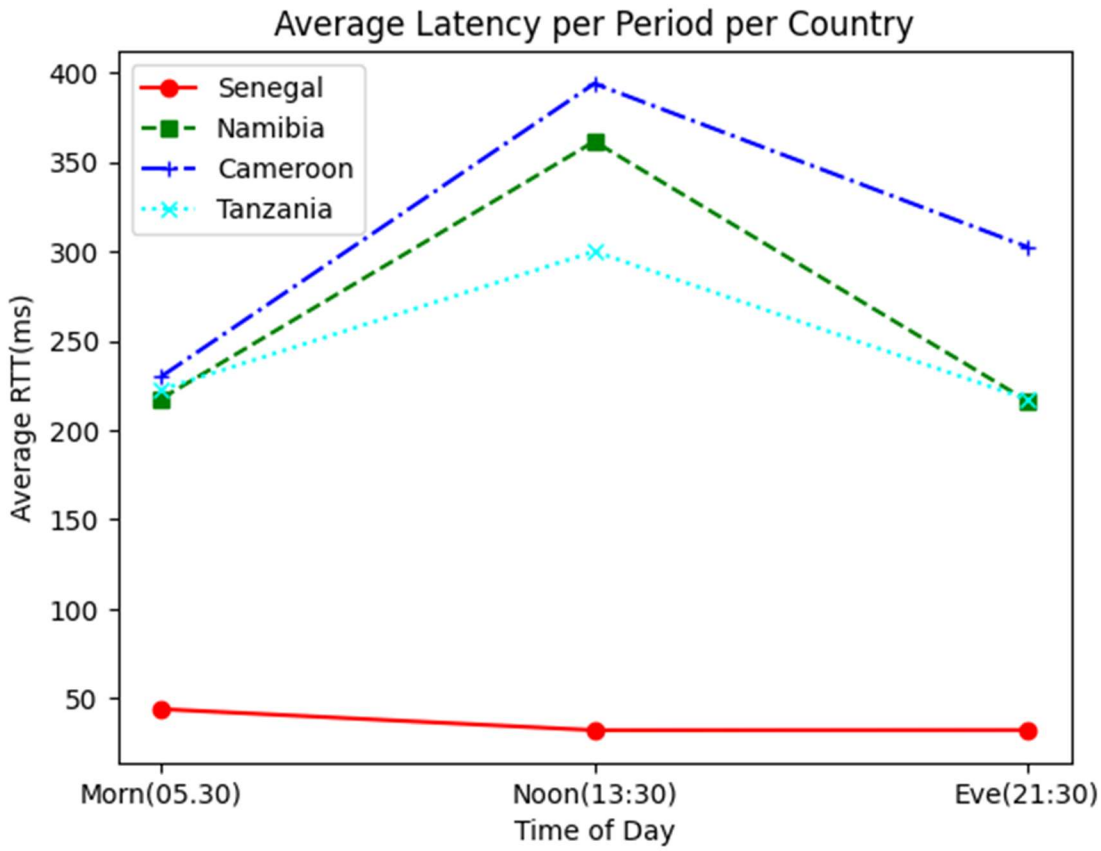


Figure 1: The Overall Average Latency to Reach each of Countries List From Senegal

Above we can see the overall end-to-end delay for each time of the day the experiments ran. The average RTT to reach a country from another was calculated by take the average RTT of each morning ping measurement from each of the probes in Senegal to every target university in that destination country. The same was done for the afternoon and evening results. This was done to see if the time of the day had an affect on the latency when trying to reach the universities in another country. So for

example, the overall RTT in the afternoon for each of the Senegal probes (52931 & 22522 – *one probe had no data to return, was disconnected*) to reach each for the Namibian universities (ium.edu.na, unam.edu.na, www.nust.na) took on average about 350ms. We see that there was also a peak in the afternoon latency when trying to reach Cameroon and Tanzanian universities from Senegal probes during the afternoon. This could be due to a number of reasons such as the targets experiencing high volumes of traffic at those time (students also accessing the site causing congestion) or there could be other reason for which we could have to cool at other data visualisation or the meta data. South Africa isn't shown as no probes from Senegal could reach any of the universities in South Africa. This may be due to the university firewall being configured to ICMP traceroute requests.

The table below serves to give us a little bit more context to the first one. This shows shortest and maximum autonomous system level paths taken to reach universities within and outside Senegal. The generated table also includes the South African, Malawi & Moroccan universities but I have manually filtered them out to better see the table data in relation to figure 1.

destCountry	website	PacketLoss	minASPath	maxASPath	minCountryPath	maxCountryPath
Senegal	uadb.edu.sn	75.56	[8346]	[8346]	['Senegal']	['Senegal']
Senegal	ugb.sn	0.0	[8346]	[8346]	['Senegal']	['Senegal']
Senegal	www.ucad.sn	0.0	[8346, 174, 37613, 6758, 37649]	[8346, 174, 37613, 6758, 37649]	['Senegal', 'United States', 'Ghana', 'Monaco', 'Senegal']	['Senegal', 'United States', 'Ghana', 'Monaco', 'Senegal']
Namibia	ium.edu.na	9.33	[8346, 174, 36996]	[8346, 174, 36996]	['Senegal', 'United States', 'France', 'Canada', 'Namibia']	['Senegal', 'United States', 'France', 'Canada', 'Namibia']
Namibia	unam.edu.na	100.0	[8346, 174, 36996]	[8346, 174, 36996]	['Senegal', 'United States', 'France', 'Canada', 'Namibia']	['Senegal', 'United States', 'France', 'Canada', 'Namibia']
Namibia	www.nust.na	0.0	[8346, 6453, 2914, 33763, 37513]	[8346, 6453, 2914, 33763, 37513]	['Senegal', 'Canada', 'United States', 'United Kingdom', 'Namibia']	['Senegal', 'Canada', 'United States', 'United Kingdom', 'Namibia']
Cameroon	uy1.uninet.cm	0.0	[8346, 6453, 12956, 15964]	[8346, 6453, 12956, 15964]	['Senegal', 'Canada', 'United Kingdom', 'Canada', 'Spain', 'Cameroon']	['Senegal', 'Canada', 'United Kingdom', 'Canada', 'Spain', 'Cameroon']
Cameroon	www.univ-maroua.cm	100.0	[8346, 174, 16637, 30992]	[8346, 174, 16637, 30992]	['Senegal', 'United States', 'South Africa', 'Cameroon']	['Senegal', 'United States', 'South Africa', 'Cameroon']

Cameroon	www.univ-ndere.cm	6.67	[8346, 6453, 15964]	[8346, 6453, 15964]	['Senegal', 'Canada', 'Cameroon']	['Senegal', 'Canada', 'Cameroon']
Tanzania	aru.ac.tz	100.0	[8346, 174, 33765, 327795]	[8346, 174, 33765, 327795]	['Senegal', 'United States', 'Tanzania']	['Senegal', 'United States', 'Tanzania']
Tanzania	sua.ac.tz	0.0	[8346, 174, 36930]	[8346, 174, 36930]	['Senegal', 'United States', 'United Kingdom', 'Tanzania']	['Senegal', 'United States', 'United Kingdom', 'Tanzania']
Tanzania	udsm.ac.tz	1.67	[8346, 174, 36944, 37182, 22354]	[8346, 174, 36944, 37182, 22354]	['Senegal', 'United States', 'Mexico', 'Malawi', 'Tanzania']	['Senegal', 'United States', 'Mexico', 'Malawi', 'Tanzania']

Table 1:Table Illustrates the hops path from Senegal to University targets shown

Looking at the table above we see that the maximum traceroute/path taken by Senegalese probes to uy1.uninet.cm in Cameroon is starting from Senegal to Canada to United Kingdom back to Canada then to Spain to finally Cameroon. I know from code that the average ASN level hops is 3. We know that autonomous systems basically determine the route traffic should take between collection of networks. When autonomous systems have to communicate with other autonomous systems to get traffic to reach its destination, this can cause a delay in the time taken to send packets. This can also cause packets to be lost and need resending especially if there is a misalignment the separate autonomous system configuration and policies. This could also cause inefficient routing paths as shorter paths may be prioritised for other traffic. In the maximum countries path – mentioned earlier – when targeting the university of Yaoundé we see that the packets go from Canada as some point and back to Canada again showing there is a loop in the route. This is not very efficiently configured and may be behind the spikes in RTT. Another reason for the high RTT could simply be the physical distance traverse by the packets being from Senegal, in the west, to the south (Namibia), central (Cameroon) and east Africa (Tanzania). We also see from figure 1 that the Senegal to Senegal as minimal jitter (consistent) and very low RTTs.

The pie chart below charts makes use of traceroute measurements to get average hops across all universities per country. Below shows compares each destination country hops averaged over the universities in that country.

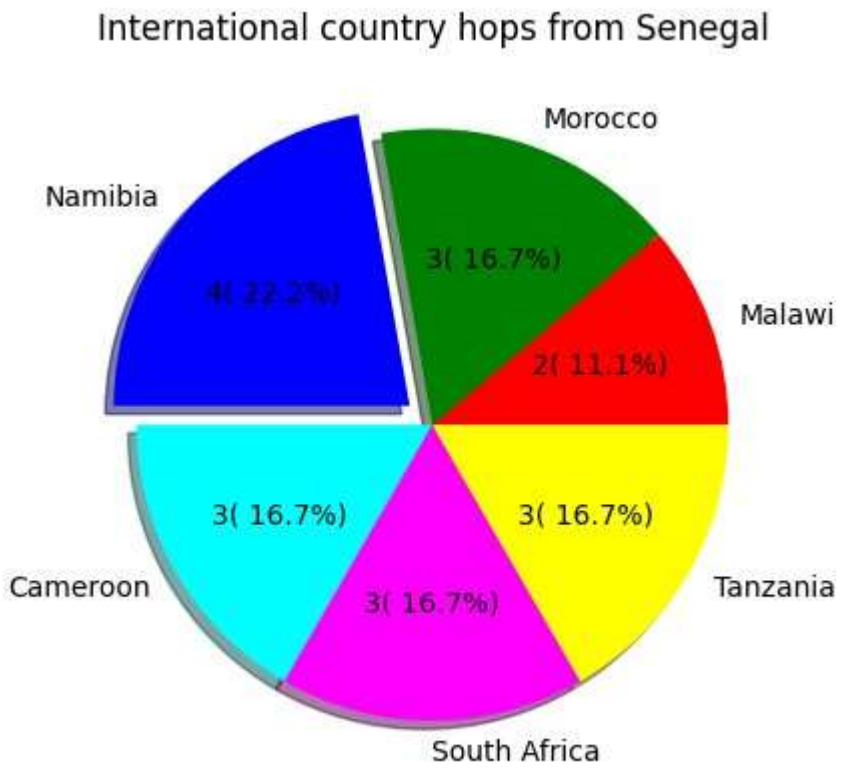


Figure 2: Traceroutes to Universities in each of the displayed countries resulted in the average number of country level hops across the university inside those countries, illustrated in the pie chart above

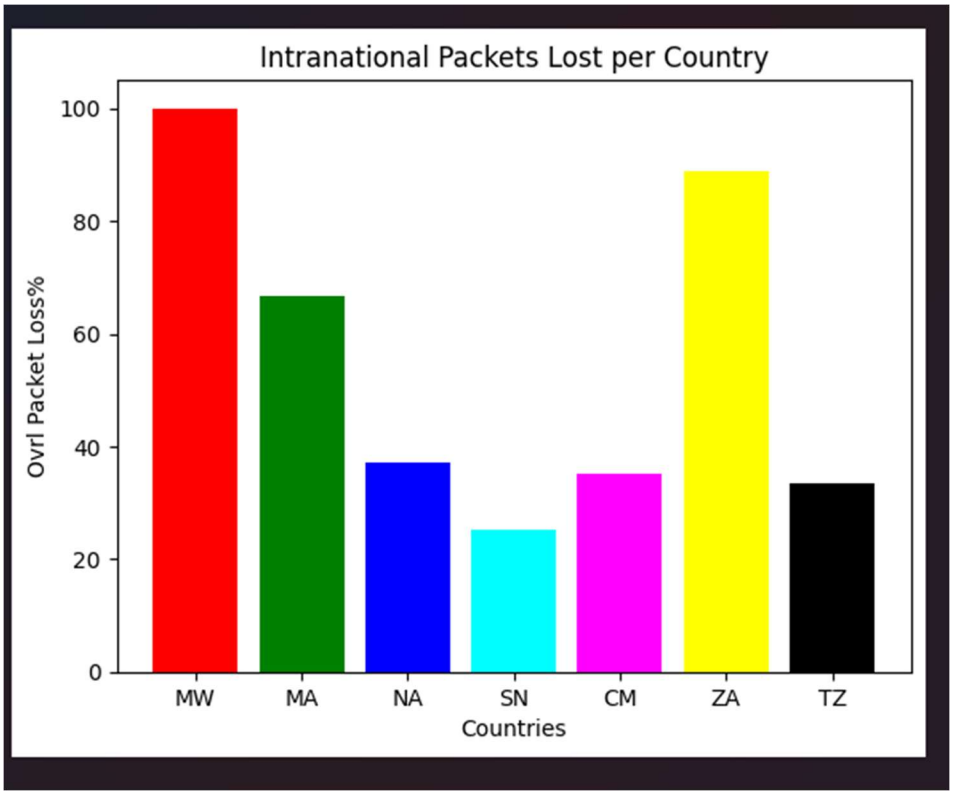
We see that on average, traceroutes to Namibian universities from Senegalese probes results in 4 country level hops.

Besides the pie chart, Figure 1 and Table 1 make intra and inter network analysis possible as these graphs were generated for each country as a source. There are also methods to get other information. For example the terminal command pictured below calls a method that outputs the average packet loss, ReturnTripTime, ASN level hops and country level hops (in that order) when doing ping and traceroute measurements to the universities within them.

```
eskaycee@LAPTOP-MDU2HG4U:/mnt/c/Users/sihle/OneDrive/Documents/Measurement Results$ python3 src/data.py
{'Namibia': [37.04, 11.57, 1, 0], 'Tanzania': [33.33, 5.16, 1, 0], 'Morocco': [66.67, 25.88, 1, 0], 'Senegal': [25.19, 31.15, 1, 1], 'South Afri
ca': [88.89, 6.73, 1, 0], 'Cameroon': [35.24, 71.22, 2, 1], 'Malawi': [100.0, -1, 1, 1]}
eskaycee@LAPTOP-MDU2HG4U:/mnt/c/Users/sihle/OneDrive/Documents/Measurement Results$
```

Figure 3: The terminal command is for example purposes but the function does exist within the python module in the picture

The data above is also used to create the following bar chart



Unfortunately, I was unable to generate the Geo-Topological map from the data. I had attempted to use tools such as IPMap to no luck.