Visualizing and Simulating Africa's Internet Topology Project Proposal

Willie Macharia
mchwil006@myuct.ac.za
Department of Computer Science
University of Cape Town
Cape Town, South Africa

Blessed Chitamba
chtble001@myuct.ac.za
Department of Computer Science
University of Cape Town
Cape Town, South Africa

Gerald Ngumbulu
ngmger002@myuct.ac.za
Department of Computer Science
University of Cape Town
Cape Town, South Africa

CCS CONCEPTS

• **Networks → Overlay and other logical network structures**.

KEYWORDS

AS, ISP Peering, IXP, Network Measurements,Internet Topology

1 PROJECT DESCRIPTION

In the last decade, internet has become the biggest network of interconnected entities. Internet's continued growth has brought new challenges and problems that require research attention. One of such problems, is mapping and visualizing Internet's topology instantaneously. In the African context, solving this challenge will enable performance analysis of the internet infrastructure to be done. From the analysis, various challenges affecting the internet can be identified and possible improvements to the infrastructure can be recommended.

Researchers have found that Africa's intra-continental internet traffic has been characterized by high end-to-end latency[20]. This has been caused by circuitous routes that internet traffic tends to follow[10]. These paths are a result of many ISPs in Africa peering at international IXPs and not at local IXPs[23]. Researchers have suggested that peering African ISPs at Africa's IXPs will lower intra-continental end-to-end internet latency[23]. However, this raises the question of how various African ISPs can be peered while considering factors such as the number of IXPs in a country and the economies of scale that many ISPs consider before deciding on how to peer with other ISPs. This project proposes a solution to this question by visualizing and then simulating Africa's internet topology. It aims at providing researchers with a web platform to evaluate performance of various peering scenarios that can be carried out across Africa. The web platform will launch internet measurements through existing internet measurement platforms and collect data that will be used to visualize and simulate Africa's internet topology. This project has been broken into three parts: launching internet measurements, topology visualization and topology simulation.

Internet measurements can be referred to as measurements done to acquire more knowledge on the internet's ever-changing and complex topology[7]. Internet measurements play an important role in mapping the internet and examining network performance. However, internet measurements are relatively harder to accomplish at a large scale. This has resulted to the use of Internet measurement platforms to reduce the effort needed in developing and deploying large-scale measurements[1]. Internet measurement platforms can be referred to as distributed set of dedicated probes that repeatedly run tests on the internet[8]. The measuring platforms implement a range of internet measurement techniques to infer network performance[25]. We intend to use these Internet measurements platforms to collect internet topology data that will be used to map internet topology during the visualization process.

In the visualization process, the collected data will be used to construct the Africa's internet topology at AS level. We intend to use the web platform to visualize internet topology that is dynamic. This means that any changes to the internet topology data will trigger an update to the visualized topology map. Internet measurements and data processing infrastructure will continuously work in the background to check for changes to the topology data in order to achieve dynamic visualization of the internet topology. After obtaining the internet topology graph, we will then use the obtained Africa's internet topology to carry out simulation.

Through simulation, we aim to explore various peering scenarios for ISPs to achieve better internet performance. The simulation will consider various factors such as geographical location of an ISP, resources of the ISP and the coverage of the ISP. Simulating internet topology requires one to have a network topology simulator. Most of the current network simulators such as n3[9] and Qualnet[4] require prior software installation to be done on the machine where simulation will be done on. Furthermore, these simulators model synthetic topologies that are used during simulation. These synthetic topologies may not reflect the real scenario of internet topology. Therefore, we propose to create a simulation platform that will be web-based to ensure it can be used without prior installation. The topology used during simulation will be generated from the actual data to ensure that simulation will give reliable results.

2 PROBLEM STATEMENT

The ability to visualize the internet topology and simulate synthetic topologies have helped in better understanding different aspects of the internet and how different networks perform in Africa. This has led to researchers suggesting ways on how to improve the network performance. However, with the current ways of visualization and simulation of Africa's internet topology, questions arise on how various African ISPs be peered while considering factors such as the number of IXPs in a country and the economies of scale that affect ISPs in each country.

This project has both research and software engineering aspects. The main research problem we are trying to address is finding better ways through which we can provide a reliable and accurate representation of Africa's internet topology, which researchers can use to explore various peering scenarios that can be done by African ISPs. Other researchers have attempted to map African internet topology, however, their mapping process produced a static internet topology. Furthermore, the topology they created had no functionality to update as soon as topology data changes. This provides limited use of the visualized topology as it does not best represent the actual state of the internet that can be used in future research ventures.

To solve this problem, we will answer some key questions, such as how do we ensure that we collect reliable internet topology data from the available platforms, as well as how to transform such data into the appropriate data structures that show relationships between the internet elements being studied. Previous efforts have used two main methods to carry out measurements: traceroute and information from BGP routing tables[26]. However, how these methods and tools are used is what makes the difference in how accurate the results are. For instance, most previous researchers have only carried out traceroute measurements from one vantage point, which if done in Africa would fail to reveal critical links between routers and ASes in the rest of the continent. Also, heuristics to infer AS level connectivity information from BGP tables vary among researchers and this then affects the accuracy of the resulting topologies. Another important research question is, after having collected reliable raw measurement data, which techniques are most suitable for transforming data collected into a data structure of links and nodes, making sure to do proper alias resolution, resolving anonymous routers, and discovering backup links[15].

2.1 Software Engineering aspect

In terms of the software aspect of the project, the main challenge is to develop an internet mapping and visualizing implementation that constantly updates with the latest information on any changes to the internet topology. Previous tools created by previous researchers are static; they measure once and then just represent that information onto a topology map for the purposes of visualizing existing connections. However, our task is to make a dynamic version of that where internet measurements are constantly being collected and any changes to the topology noted and processed and reflected on the simulation interface. Furthermore, our platform would allow researchers to analyse any changes to internet traffic flow under different changes to any of the network infrastructure components. So for instance, they might want to observe how traffic would re-route when a node is removed/added or when a link goes down. This would help them to determine better solutions to improve Africa's internet performance.

2.2 Key intended users

Users of this software implementation would be internet researchers who seek to study the African internet topology. Often, researchers have to resort to tools that offer an instantaneous representation of the internet topology, and have to perform multiple measurement and visualization processes. However, with our implementation, researchers would spend less time as our implementation would constantly be updating the simulation with the latest changes to the topology.

2.3 Important design considerations

In designing our tool, there are some key design considerations we will take into account. Firstly, the user interface has to be intuitive and interactive enough for one to use with minimal assistance. Secondly, it should have a robust infrastructure that continuously collects internet topology data, pass that data for processing, and update the simulation interface appropriately. Thirdly, the visualization interface needs to allow for zooming in and out in order to toggle between a continent wide AS level map and a country specific router level map.

2.4 Research objectives

As stated earlier on, the aim of this project is to enable researchers to evaluate performance of various peering scenarios that can be carried out across Africa. The following research objectives would facilitate the achievement of this aim:

- How efficient are the current internet measuring techniques used in collecting data?
- How can we implement visualization of a constantly updating internet topology?
- How do various ISPs in Africa peer at local African IXPs?
- What will be the effect peering African ISPs at local IXPs on internet performance in Africa?

3 PROCEDURES AND METHODS

This project will involve creating a web based simulator, visAIT platform, which will be composed of three subsystems: data collection subsystem, visualization subsystem and simulation subsystem. These three subsystems can be seen on figure 1.

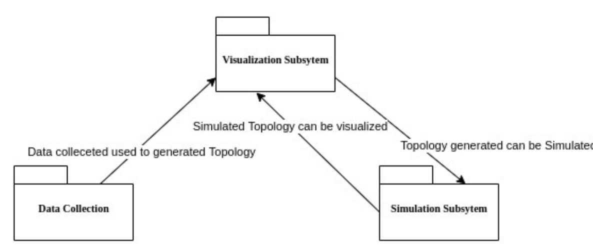


Figure 1: Subsystems of the visAIT platform

3.1 Data Collection Subsystem

Speedchecker[6], RIPE Atlas[2] and CAIDA Ark[1] are the three internet measurement platforms that will be used to collect internet topology data. Topology data collected will contain IP addresses of routers encountered for internet traffic flowing from source to destination. The data will also contain RTT(Round Trip Time) for the traffic. Each IP hop will also be attached with its geolocation.

Topology data will be collected by launching traceroute from all platforms' Africa-based probes to randomly selected destinations located in African countries. The destinations will mostly be IP addresses of ASNs in Africa. The measurements will be launched, with a six hour time-interval, four times a day. Each probe will be configured to launch 10 consecutive traceroutes (one second apart) to randomly selected IP addresses of ASNs in Africa. The platforms' API will return traceroute data. For each router hop in the traceroute data, we will find the Autonomous System (AS) using the RIPE Routing Information Service and also the location of each router using MaxMind GeoLite2-City [20]. We will restrict analysis to AS level as this will be easier to display than when it is at IP level. We will also obtain routing information, which will be useful in inferring internet topology from inter-domain BGP routing tables returned once a day from RIPE's API.

A script will be written to run in the background returning data to the system. The data obtained from these measurement platforms need to be in the same format. The data returned from RIPE Atlas and Speedchecker are in JSON format. However, the data obtained from scamper tool, a tool used by CAIDA Ark, will be in warts. This data needs to be converted to JSON format as well. Once the data is in the same format it will then be used to visualize internet topology. There will be test scripts designed to make sure that correct data is retrieved as expected. The test scripts will perform a set of instructions such as checking if data is fetched and comparing if the data fetched fields match with sample data fields.

3.2 Visualization Subsystem

When topology data has been collected and stored into an appropriate database, the visualization implementation has to geolocate all the IP address destinations probed as the first step in our visualization. This is done by performing a DNS lookup of the IP address destinations. The primary database we will consult is the IPv4 Routed /24 Topology Dataset from CAIDA [14]. This will help us get information such as geolocation, names, and IP adresses of some routers. However, the database might not contain all the IP addresses' locations and we will then have to resort to other sources such as the GeoLite Database from Maxmind and the WHOIS register [21]. These sources, however, are claimed to be less accurate than Ark's one.

We will then perform alias resolution to resolve IP addresses that belong to the same routers. This will be done by using tools like CAIDA's scammper and kapar, tools that will greatly the alias resolution process. These tools will do this by probing again every IP address in the data and analysing similarities in response times and response structure to infer which IP addresses belong to the same router. The output of this step will be a simple undirected graph of links within the router topology [14]. Depending on the accuracy of the DNS data, we might notice distortions due to incorrectly named routers. To deal with these, we might need to implement techniques highlighted by Zhang et al. [28] to resolve those misnamings. We might also need to resolve distortions caused by anonymous routers that appear with a (*) in path traces using techniques described by Gunes et al. [22].

In order to produce the AS level topology map, we will consult BGP tables such as Route Views[5] to map the IP addresses in our dataset to the AS numbers that advertise the longest IP prefixes matching the corresponding IP addresses gathered in our path traces from trace-route [14]. From this, links between ASes can be inferred. However, there will still be some distortion due to indirect links, private ASes, multi origin ASes etc. Those can then be discarded.

To make the map more complete and useful, we will add annotations between links and on nodes by implementing techniques developed by CAIDA based on multi-objective optimization [14]. From this we can be able to infer the different business relationships between the individual ASes and their peering status.

3.3 Simulation subsystem

The main aim of the simulation subsystem is to allow the user to simulate various peering scenarios in which ISPs could be peered in local African IXPs.

The visualization subsystem will generate internet graph to be used during simulation. The topology graph generated will consist of nodes as ASes and IXPs, while links on the graph will be of two types: link between two ASes and link between an AS and an IXP. The simulation will be activated by the user choosing to run the simulation mode.

In the simulation mode, the user will be able to either remove or add interconnection links on the topology graph. Our project focuses on interconnection between two ASes and an IXP, which illustrates peering. Hence, during simulation, various ASes that initially do not peer at a local IXP, will be peered and internet measurements will be taken and compared with when they do not peer. ASes which belong to the same country but do not peer in their national IXPs will be peered in their national IXP and internet measurements will be taken. ASes that belong to the same region but do not peer, will be peered in their regional IXP and internet measurements will be taken

The simulation platform will work concurrent with the visualization system. When a user makes changes of the topology graph either by removing or adding a connection link, the simulated topology graph will be updated according.

4 ETHICAL, PROFESSIONAL AND LEGAL ISSUES

Data used in this project will be collected from CAIDA, RIPE Atlas, and Speedchecker. CAIDA and RIPE Atlas are open source platforms meaning we are free to collect data while Speedchecker is a commercial platform where we will pay to run measurements. We will also use open public internet data in our project. We will ensure that every public dataset we use in this project, is used according to the prescribed license of the dataset.
To use CAIDA API and integrate it in our system, we are meant to send an email to CAIDA notifying them our intended use. When collecting data from these platforms, we do have an ethical obligation to ensure that the internet traffic that we generate does not overload one target. For measurements done on RIPE Atlas, we are meant to observe extra rules and guidelines which have been illustrated in *Ethics of RIPE Atlas Measurements* [3].

There will be no intellectual property rights attached to this project as we aim to make it open source for other users to utilize.

This is in efforts to enable the internet community to utilize it for further studies on internet topology. The publishing of the final paper will follow the University of Cape Town's policy which is the Creative Common license.

Usability tests will be done to test whether the developed platform achieved its design objectives. Users will be recruited to test the platform created. To do usability tests, an ethics application is required to be submitted to the Science Ethics Committee for approval. We will submit our application in the course of the project.

Throughout the project, we are going to conduct ourselves professionally during our interactions with all stakeholders in the project namely: project supervisor, project collaborators and staff of Department of Computer Science.

5 RELATED WORK

This section examines what has been done in the literature already and how the literature has impacted the proposed research.

5.1 Internet Measurements

This component of the project borrows from work done by Formoso et al. [20]. Their work presented a measurement campaign methodology that explored the current state of African Internet. They used various vantage points, provided by Speedchecker [6], across the continent to map inter-country delays in Africa. In their paper [20], they showed how data is collected in such a way it can be used in mapping of the internet topology. Throughout their work, the authors acknowledged Speedchecker as a good measurement platform to be used to conduct internet measurements in Africa. Their acknowledgement was influenced by the fact that most of Speedchecker's probes covered 91% of African countries and it is not biased towards university networks. The authors also acknowledged that using Speedchecker had some limitations such as limited insight into the devices launching the measurements. This means that they could not provide causal insight into the performance of individual measurement samples.

The use of a distributed network measurement method in this project was heavily influenced by Sanby et al. [27]. In their paper, efficient topology discovery for African NRENs, the authors talked about how distributed network probing uses many vantage points to get a more accurate view of a network topology. The authors also talked about how varying location of vantage points further increase the accuracy and completeness of the discovered topology.

The use of distributed network measurement platforms are seen in a number of research done in discovering internet topology and analyzing network performances in Africa. Fanou et al.[16, 17] used data collected in 2014 from RIPE Atlas probes located in African countries to highlight lack of peering between African ISPs, which results to very high internet traffic delays [16, 17]. Fanou et al. [18] also used RIPE Atlas to dissect the web ecosystem in Africa to shed light on that most of the content accessed by users in Africa is still served from overseas. Chavula et al. [11] researched communications among African research networks. The authors used CAIDA Ark to launch traceroutes to 95 university locations in 29 African Countries. They observed and analyzed how round-trip time is affected and suggested ways to make it better. The measurements lasted for 14 days. Formoso et al [20]. as mentioned in the first paragraph, also used a distributed network measurement platform: Speedchecker[6].

5.2 Topology visualization

Gilmore et al. [21] performed a study where they sought to map the African internet and they used methods and procedures that are similar to our proposed approach. The future improvements we drew from their study were that firstly, performing probing measurements from multiple vantage points greatly increases the accuracy of the topology map discovered. One of the reasons is that certain paths that would not have been discovered due to defective routers that are unable to send back ICMP messages might be discovered by probes coming from another vantage point since the router can be bypassed.
Our second takeaway, which was also highlighted by Chavula et al. [12], was the need for us to use more accurate databases for IP geolocation, as their accuracy also greatly has an impact on the geolocation. Geolocation is even more important in our project since we aim to create an overlay of the internet topology onto the actual African map. Both researchers in these two studies mention how GeoLite and Maxmind databases are not as accurate for IP geolocation, hence in our study we decided to primarily resort to CAIDA's IPv4 Routed Topology Dataset which Claffy et al. [14] used in their study.
Claffy et al. [14] used Ark's *iffinder* and *APAR* tools for alias resolution for producing the router level map. They then reproduced their AS level map from BGB routing tables. After having both the AS and router level maps, their goal was to merge the two and produce a dual AS router level map, which they left for future work in a separate research because of how non-trivial it is.
Gupta et al. [24] conducted this study from a different perspective; their main aim was to study ISP inter-connectivity in Africa and observe and study the main trends. After performing their AS level map visualization process, they were able to analyse ISP peering across African internet providers.

5.3 Simulating Africa's Internet Topology

Chavula et al. [13] simulated Africa's Internet topology by creating a proxy African IXP where all the interconnection links connecting African ISPs with international IXPs were transferred to the proxy African IXP. It was found that the end-to-end latency reduced by 50% [13]. The simulation was not carried out with a real IXP but it did show that further exploration of peering scenarios in African ISPs was required. The simulation part of our project borrows a lot from this work. The simulation done on our platform will be improved as it will consider other factors such as geographical position of ISPs when carrying out the simulation.
Most of the existing network simulators uses synthetic topologies to carry out their simulation. Due to the ever-changing structure of internet topology [19], using synthetic topologies to carry out internet simulation may not provide reliable results. Many researchers have used these simulators such as ns-3[9] in the past to carry out their studies. This problem have influenced our

project to develop a simulation interface that simulates an internet topology generated from real data.

6 ANTICIPATED OUTCOMES

6.1 System based outcomes

We anticipate to produce a tool that is capable of measuring, visualizing, and graphically simulating the African internet topology. Our measurement implementation will be configured to run frequent traceroute measurements so that our tool is always up to date with any changes in the network topology. The measurement data will be collected and stored in a format that is easy to parse and process.

The next component of the system will be the visualization implementation, which will be able to frequently check for new measurements, resolve IP addresses that belong to the same routers (alias resolution), anonymous routers, and any incorrectly named routers. The visualization implementation will also be able to create a router level topology in the form of a graph data structure. It will also be able to use both the router level topology information and BGP tables information to create and keep an updated AS level topology map that shows peering relationships.

Lastly, the system will feature a web based graphical user interface on which a map of the African continent is shown with the AS level topology map overlain on top of it. The web platform should be dynamic and interactive, with an 'Update' feature which checks if the underlying topology data in the model part of the architecture has changed and hence update itself accordingly. The 'Simulate' feature will be activate the simulation mode where the user will be able to remove or add some interconnection links on the topology graph.

6.2 Expected impact of our project

The success of our project is going to make internet topology research easier for researchers as they can now focus more on exploring ideas and less on collecting measurements and building actual simulations. With the platform, they can simply test out their ideas and simulate them and receive dynamic feedback instantly. Additionally, anyone wishing to add more functionality to the system will be able to build on our implementation. Also, the project is going to help internet policy makers to better understand the topology and come up with ways to improve the internet experience in the continent. Network operators will be able to simulate the various effects of establishing different combinations of peering links between ASes in Africa, as well as simulating the effects of certain links going down and thus decide how they can mitigate such risks.

6.3 Key success factors

If our project succeeds, we will be able to reproduce a representation of Africa's internet topology and simulate it on a dynamic simulation interface whose parameters can be varied. To verify this, we will first test the success of data collection subsystem by running test scripts as stated in 3.1. We will then compare our topology with those previously reproduced by previous researchers; at the bare minimum our topology should resemble others' and must not be too different.
Secondly, the web interface has to be intuitive and easy to use by a first time user. We will perform usability tests with sample users whom we will invite on a voluntary basis. Our web interface design will be a success if 75% of the first time users indicates that they managed to navigate through the web platform easily.
Lastly, our intended users need to be able to perform simulations on the interface by varying the parameters (e.g. removing/adding links and nodes between ASes and IXPs). The interface should respond to these changes by indicating how the flow of internet traffic will change. To test the success of the simulation subsystem, the user should at least manage to remove or add an interconnection link between an ISP and IXP and the interface should indicate visually how the internet traffic flow was affected by the user action. If this test passes, the system will prove that it is working according to how it is expected to work.

7 PROJECT PLAN

7.1 Risks

Various risks that can affect this research project have been identified and are well tabulated in Appendix A shown below. The probability of the risks have categorised into three categories: low, medium and high. The impact of the risks have been categorised also into three categories: critical, negligible and marginal. The Appendix also shows how each risk has been accessed in terms of its management, mitigation and monitoring.

7.2 Resources

To collect data from RIPE Atlas, credits are needed to carry out the measurements. Credits to perform these measurements will be provided by the project supervisor.

To develop the system, the team members will be using their personal laptops to write the code. Any extra softwares needed, we believe will be open source.

Any server access needed will be provided by the Network for Development research group where this project will be located. For usability tests, we will utilise the Computer Honours' lab to set usability tests for our platform.

For assessment of the project and professional guidance, we will heavily rely on our supervisor, Josiah Chavula, for his expertise on internet measurements and internet visualization. External input from the collaborators that is AFRINIC and MLab, will also be useful for ensuring we develop a platform that is relevant to the internet community.

7.3 Milestones

The milestones of the project are shown in the table tabulated on figure 2.

7.4 Deliverables

Once the project is complete, our main deliverables would be:

- A working and fully tested implementation of our internet topology simulation system. This will include the source code, documentation to the code, and test results.

Honour Project Milestones.

Date	Description
Tuesday 2nd June	Project Proposal due, including Project Plan
Monday 18th June	Review of staff feedback on proposals
Monday 29th June	Revised Proposal finalized and uploaded to Vula
Monday 3rd August	Second Semester starts
Monday 3rd August - Tuesday 11th August	Initial Software Feasibility Demonstration
Monday 17th August	Weighting for project marking decided
Friday 11th September	Final complete draft of paper
Monday 21st September	Project Paper final submission
Monday 5th - Friday 9th October	Final Project demonstration
Monday 12th October	Poster due
Monday 19th October	Web Page
TBA	Open Afternoon/Evening

Figure 2: Table showing project milestones.

- A completed project paper that details all the steps and research done in accomplishing our project. It will show the project details, motivations, research questions as well as our results.
- A web page that has further details about our project.

7.5 Work allocation among team members

The entire project has been divided into three main parts of which each part has been assigned to one team member. The parts has been assigned as shown below:

- Doing research, designing and implementing the internet measurements collection part of the system. This part was allocated to Gerald Ngumbulu.
- Researching, designing and implementing the data visualisation part of the system. This comprises every process involved to transform the raw measurement data into a usable graph data structure which can be fed into the simulation. This part was assigned to Blessed Chitamba.
- Designing and implementing the simulation web interface. This part involves taking the visualized topology from visualization process and simulating it on an interactive web interface. The simulation will also involve developing a routing algorithm which will be used during simulation. This part has been assigned to Willie Macharia.

7.6 Timeline

The timeline of the project is illustrated with a Gantt chart shown on Appendix B. The chart shows timeline from project proposal demonstration until the final reflection paper.

REFERENCES

[1] Caida. https://www.caida.org/research/topology/astopo%20comparisons/. (Accessed on 05/08/2020).

[2] Create measurements · ripe atlas api manual v2. https://atlas.ripe.net/docs/api/v2/manual/measurements/types/. (Accessed on 05/12/2020).

[3] Ethics of ripe atlas measurements — ripe labs. https://labs.ripe.net/Members/kistel/ethics-of-ripe-atlas-measurements. (Accessed on 05/29/2020).

[4] Qualnet - network simulation software | scalable networks. https://www.scalable-networks.com/products/qualnet-network-simulation-software-tool/. (Accessed on 05/08/2020).

[5] Route views archive project page. http://archive.routeviews.org/. (Accessed on 05/03/2020).

[6] Speedchecker - real world qoe analytics for telecoms and regulators. https://www.speedchecker.com/. (Accessed on 05/29/2020).

[7] Aceto, G., Botta, A., De Donato, W., Marchetta, P., Pescapé, A., and Ventre, G. Open source platforms for internet monitoring and measurement. In *2012 Eighth International Conference on Signal Image Technology and Internet Based Systems* (2012), IEEE, pp. 563–570.

[8] Bajpai, V., and Schönwälder, J. A survey on internet performance measurement platforms and related standardization efforts. *IEEE Communications Surveys & Tutorials 17*, 3 (2015), 1313–1341.

[9] Carneiro, G. Ns-3: Network simulator 3. In *UTM Lab Meeting April* (2010), vol. 20, pp. 4–5.

[10] Chavula, J., Feamster, N., Bagula, A., and Suleman, H. Quantifying the effects of circuitous routes on the latency of intra-africa internet traffic: a study of research and education networks. In *International Conference on e-Infrastructure and e-Services for Developing Countries* (2014), Springer, pp. 64–73.

[11] Chavula, J., Feamster, N., Bagula, A., and Suleman, H. Quantifying the effects of circuitous routes on the latency of intra-africa internet traffic: a study of research and education networks. In *International Conference on e-Infrastructure and e-Services for Developing Countries* (2014), Springer, pp. 64–73.

[12] Chavula, J., Feamster, N., Bagula, A., and Suleman, H. Quantifying the effects of circuitous routes on the latency of intra-africa internet traffic: A study of research and education networks. 64–73.

[13] Chavula, J., and Sibanda, C. C. An evaluation of peering and traffic engineering in the pan-african research and education network: A case for software defined internet exchange points.

[14] Claffy, K., Hyun, Y., Keys, K., Fomenkov, M., and Krioukov, D. Internet mapping: From art to science. In *2009 Cybersecurity Applications Technology Conference for Homeland Security* (2009), pp. 205–211.

[15] Donnet, B., and Friedman, T. Internet topology discovery: a survey. *IEEE Communications Surveys & Tutorials 9*, 4 (2007), 56–69.

[16] Fanou, R., Francois, P., and Aben, E. On the diversity of interdomain routing in africa. In *International Conference on Passive and Active Network Measurement* (2015), Springer, pp. 41–54.

[17] Fanou, R., Francois, P., Aben, E., Mwangi, M., Goburdhan, N., and Valera, F. Four years tracking unrevealed topological changes in the african interdomain. *Computer Communications 106* (2017), 117–135.

[18] Fanou, R., Tyson, G., Fernandes, E. L., Francois, P., Valera, F., and Sathiaseelan, A. Exploring and analysing the african web ecosystem. *ACM Transactions on the Web (TWEB) 12*, 4 (2018), 1–26.

[19] Floyd, S., and Paxson, V. Difficulties in simulating the internet. *IEEE/ACm Transactions on Networking 9*, 4 (2001), 392–403.

[20] Formoso, A., Chavula, J., Phokeer, A., Sathiaseelan, A., and Tyson, G. Deep diving into africa's inter-country latencies. In *IEEE INFOCOM 2018-IEEE Conference on Computer Communications* (2018), IEEE, pp. 2231–2239.

[21] Gilmore, J., Huysamen, N., Cronje, P., de Klerk, M., and Krzesinski, A. Mapping the African Internet. (English) [On recreating and mapping the african network].

[22] Gunes, M. H., and Sarac, K. Resolving anonymous routers in internet topology measurement studies. In *IEEE INFOCOM 2008 - The 27th Conference on Computer Communications* (2008), pp. 1076–1084.

[23] Gupta, A., Calder, M., Feamster, N., Chetty, M., Calandro, E., and Katz-Bassett, E. Peering at the internet's frontier: A first look at isp interconnectivity in africa. In *International Conference on Passive and Active Network Measurement* (2014), Springer, pp. 204–213.

[24] Gupta, A., Calder, M., Feamster, N., Chetty, M., Calandro, E., and Katz-Bassett, E. Peering at the internet's frontier: A first look at isp interconnectivity in africa.

[25] Isah, M., Phokeer, A., Chavula, J., Elmokashfi, A., and Asrese, A. S. State of internet measurement in africa-a survey. In *International Conference on e-Infrastructure and e-Services for Developing Countries* (2019), Springer, pp. 121–139.

[26] Mahadevan, P., Krioukov, D., Fomenkov, M., Dimitropoulos, X., Claffy, K., and Vahdat, A. The internet as-level topology: three data sources and one definitive metric. *ACM SIGCOMM Computer Communication Review 36*, 1 (2006), 17–26.

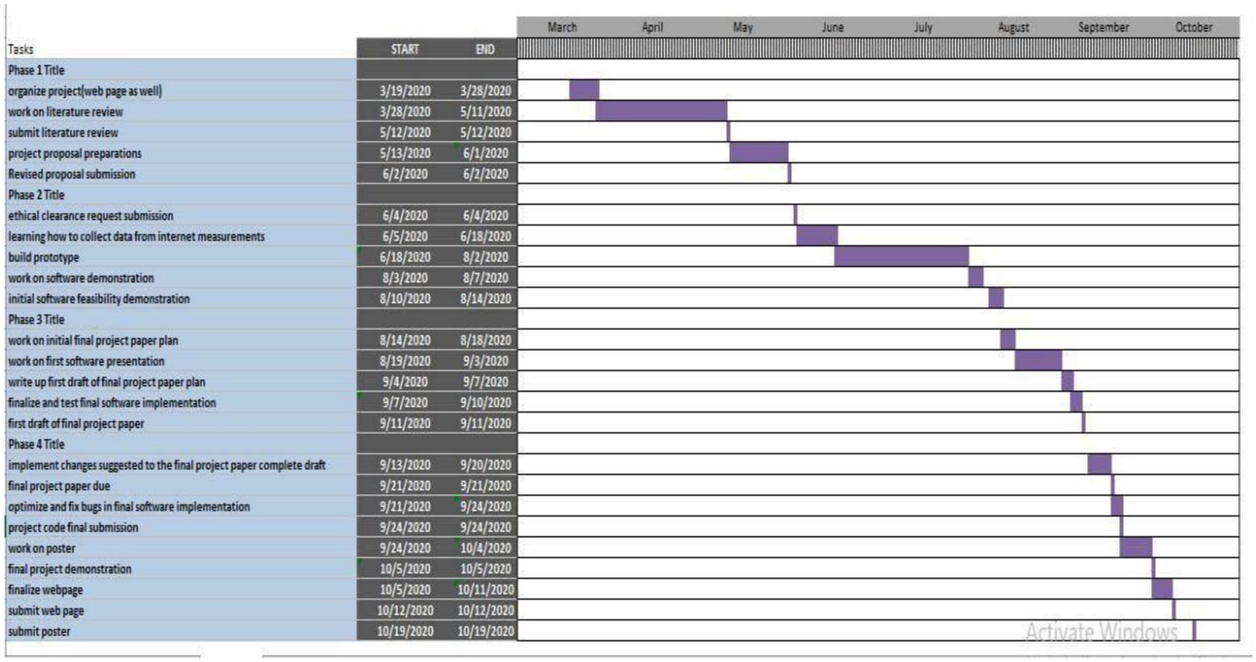
[27] Sanby, R., Suleman, H., and Chavula, J. Efficient topology discovery for african nrens. In *2016 IST-Africa Week Conference* (2016), IEEE, pp. 1–8.

[28] Zhang, M., Ruan, Y., Pai, V., and Rexford, J. How dns misnaming distorts internet topology mapping. 369–374.

Appendix A: Risk Evaluation

Risk Condition	Consequence	Probability	Impact	Mitigation	Monitoring	Management
Team members failing to complete their work allocation on time.	The project falls behind the timeline.	Low	Marginal	Using tasks scheduling softwares to assign tasks to the members	Use Gantt chart to ensure project timeline is followed	Reassigning the uncompleted tasks.
Lack of clarity of the project requirements and scope	Team spends too much time developing what is not required for the project	Medium	Critical	Ensuring meeting minutes are taken during meetings with the supervisor.	Frequent Communicating with other team members to ensure everyone understands their parts.	Scheduling a meeting with the supervisor to seek clarity for the project.
COVID-19 prevents us from doing the user evaluations.,	The user testing will not be face to face.	High	Marginal	Doing virtual user testing. .	Keeping the team members updated with the regulations governing social places. .	Creating ZOOM/Google meet to do user testing virtually.
Internet measuring platforms get deactivated	The project get done with old data	Low	Critical	Researching a wide range of internet measuring platforms to ensure we have a good number of them.	Constantly keep testing the platforms by visiting their sites online.	Reaching out to the internet community through our supervisor on other platforms we can use.
Theft of team members' laptops or crashing of laptops containing the code.	The team fails to deliver the project on time as rewriting the code may take time	Medium	Critical	Using version online control softwares such as github and bitbucket.	Ensuring every team member constantly commit their code to the online repo	Reverting back to the older version of the code.
Team member falls sick and eventually drops out of the project	The project lags behind the timeline.	Low	Critical	Ensuring constant communication between team members where they can air issues affecting them.	Assessing how every team member is handling their section.	Reassigning the part the member was working on to another team member.
Choosing wrong frameworks for visualization and simulation implementation	The project lags behind as more time is wasted redoing the work with the right framework	Low	Marginal	Researching the best frameworks and libraries for visualization and simulation purposes.	Constant testing of the relevance of the frameworks used with the objectives of the project.	Choosing another framework that is relevant for the project.

Appendix B- Gantt Chart



Tasks	START	END
Phase 1 Title		
organize project(web page as well)	3/19/2020	3/28/2020
work on literature review	3/28/2020	5/11/2020
submit literature review	5/12/2020	5/12/2020
project proposal preparations	5/13/2020	6/1/2020
Revised proposal submission	6/2/2020	6/2/2020
Phase 2 Title		
ethical clearance request submission	6/4/2020	6/4/2020
learning how to collect data from internet measurements	6/5/2020	6/18/2020
build prototype	6/18/2020	8/2/2020
work on software demonstration	8/3/2020	8/7/2020
initial software feasibility demonstration	8/10/2020	8/14/2020
Phase 3 Title		
work on initial final project paper plan	8/14/2020	8/18/2020
work on first software presentation	8/19/2020	9/3/2020
write up first draft of final project paper plan	9/4/2020	9/7/2020
finalize and test final software implementation	9/7/2020	9/10/2020
first draft of final project paper	9/11/2020	9/11/2020
Phase 4 Title		
implement changes suggested to the final project paper complete draft	9/13/2020	9/20/2020
final project paper due	9/21/2020	9/21/2020
optimize and fix bugs in final software implementation	9/21/2020	9/24/2020
project code final submission	9/24/2020	9/24/2020
work on poster	9/24/2020	10/4/2020
final project demonstration	10/5/2020	10/5/2020
finalize webpage	10/5/2020	10/11/2020
submit web page	10/12/2020	10/12/2020
submit poster	10/19/2020	10/19/2020