Internet Measuring Platforms used in Discovering Africa's Internet Topology

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Abstract

In the quest to discover internet topology in Africa, internet measurements have been seen to be necessary in conveying the information about the network infrastructure. This information is then used in mapping the internet topology. In this literature review, we discuss research done on internet measurements and their usefulness, the different approaches of internet measurements as well as existing measurement platforms. We also discuss research done on how these platforms can be used to discover internet topology in Africa.

CCS Concept Networks

Keywords Internet measurements, Internet topology, Internet measurement platforms

1 Introduction

Internet measurements can be referred to as measurements done to acquire more knowledge on the internet's ever-changing and complex system [1]. With the growth of internet usage, there is a need to acquire a better understanding of how the internet system behaves. This has led to the development of internet measurements that look at different aspects of the internet such as routing dynamics, reachability and latency.

The ability to understand and measure the internet allows us to show whether changes to the network performance improves or degrades it by observing how packets (data) progress through the network [2]. It also allows us to discover internet topology. Internet topology can be referred to as the representation of how autonomous systems, routers or hosts are connected to each other [3]. The discovery of internet topology helps in mapping of the internet so as to better understand how traffic flows between locations.

In this literature review we discuss how one can use internet measurements platforms to shed light on network performance in terms of metrics such as packet loss, latency and reachability. The main focus in this review will be on platforms that can be used to discover internet topology and measure network performance in Africa. Section 2 starts by detailing different internet measurement approaches and methodologies used to discover internet topology. Section 3 then addresses the most common metrics used when assessing network performances. This links it to section 4 which talks about existing measurement platforms. Section 5 discusses research done on Africa's Internet. We also point out some of the gaps in research done. Section 6 narrows the discussion on what has been observed in terms of discovering internet topology and the network performance in Africa. Finally, section 7 concludes on which platforms can be used to discover the topology in Africa.

2 Internet Measurements Methodologies

In the quest of discovering internet topology, there are two types of internet measurements:Passive and Active measurements. Passive or Active measurements are used to convey information regarding the network infrastructure [4]. The sections below further elaborates on these two types of internet measurements.

2.1 Passive measurements

Passive measurements are non-intrusive measurements that do not generate additional traffic. They observe and collect information that is already flowing over specific vantage points in the network [5]. This involves capturing of packets and their corresponding timestamps transmitted by a device such as a router over a network path [6]. This provides insight into activities happening on links or at nodes.

Passive measurements contain mechanisms such as RMON and IPFIX [7] which are mostly built-in mechanisms in modern devices [8]. RMON, Remote Monitoring, gathers different types of data such as lost packets and number of sent bytes while IPFIX gathers IP flow data [8]. The data obtained from these built-in mechanisms provide little information on the network state because the data is highly aggregated [8]. Syslog data, Simple Network Management Protocol (SNMP) data and NetFlow data from routers and switches in the network are some of the techniques passive measurements use to collect data produced by these built-in mechanisms. Simple Network Management Protocol data provides information such as packet errors at switch and router level, NetFlow data provides link utilization information between routers, and Syslog data provides details of activities and failures of networks and routers [6].

Some common passive measurement tools include tcpdump and border gateway protocol. Tcpdump is a network traffic capturing tool. It captures TCP/IP packets and dumps the packets in a raw format without much analysis [9]. The raw data can then be analyzed to understand networking concepts. Border Gateway Protocol (BGP) can be referred to as an exterior gateway protocol used to exchange routing information and reachability among Autonomous Systems [10]. BGP protocol uses routing tables such as the BGP Routing Table to give information on a network as shown from a given vantage point, and indicate how many announced paths are available [11].

Passive measurements generate a lot of data which leads to a storage problem [8].Different methods are employed to try mitigate the storage problem. Compression of data and traffic sampling are solution employed to reduce storage space [8]. Different compression and sampling methods employed are discussed in [12] and [13] respectively.

2.2 Active measurements

Active measurements consist of sending probe packets into the network from a source to a destination [14]. Properties chosen at departure such as packet size can be used to calculate the metrics by analyzing the probe stream characteristics such as arrival time at the destination [14]. Routing behaviors, propagation delays, losses and queuing delays are made available by injection of probe packets into the network [11].

Some of the active measurement tools include Ping, Traceroute, OWAMP [15], Pathchar [16] and Pathload [17]. Most of these active measurement tools, excluding Ping and Traceroute, use sophisticated packet probing techniques to determine the network topology, packet one-way delay, loss and round trip delay. The most commonly used active measurement tools include Ping and Traceroute, which use ICMP packets to determine round-trip delays and network topologies. ICMP stands for internet control message protocol and is used to generate error messages when there is a failure in the delivery of the IP packets. It should be noted that probing should be done politely since it disturbs the network by injecting traffic into the network. An aggressive type of probing might lead to an inaccurate data collection.

2.2.1 Traceroute

Traceroute is a network diagnostic tool, created by Van Jacobson, that makes it possible to discover the path a data packet takes from the source or a monitor to the destination [18]. A monitor can be referred to as a source of the traceroute. Traceroute, just like ping, is supplied as a part of host's operating system [2].

Traceroute is an active measurement tool that actively sends probes into the network and is widely used to discover internet topology [5]. A logical map of the internet is obtained from this discovery.

Traceroute works by sending multiple ICMP (Internet Control Message Protocol) [19] packets with increasing time-to-live fields in the IP header [20]. A packet with a time-to-live of one gets discarded when it reaches a host, and the host sends an ICMP time exceeded packet to the sender [20]. This leads to the capturing of the IP addresses of the hosts that the packets have traversed on their route to destination. The time-to-live gets incremented after each response and the overall path taken by the packets is then obtained.

2.2.2 Ping

Ping is a tool used to measure round trip time (latency) and packet delays in the network [21]. Ping works by sending an ICMP packet to a specific address (host), the specified host (sever) sends back an ICMP echo reply packet and round trip time is calculated [2]. Ping can send a single packet or a series of packets at a known interval. Upon termination, it calculates summary statistics which include packet loss percentage and round trip times [2]. Ping can also be very helpful in figuring out the IP addresses that are reachable from a specific host, and hence aid in discovering of the internet topology.

3 Internet Metrics

Metrics in this section can be referred to as measurements done when accessing network performance. In this section we are going to discuss two of the most common metrics used and looked at when trying to measure network performance in Africa.

3.1 Latency

Latency can be referred to as the time delay one waits for something to happen [2]. Round trip time (RTT) is widely used in measuring network latency and it is the time a packet takes to go from a source to destination and for the response to come back [14].

Components that contribute to network latency include transport time, queuing and transmission time and sever response time [2]. These are accounted in measurement of the RTT. RTT is done by stamping a packet with the current time and sending it to the destination [14]. The destination then sends out a corresponding response packet back to the source upon completion of receiving the packet at the destination. RTT is then calculated by taking the difference of the receiving time at the source and the time stamp value [14].

3.2 Packet Loss

Packet loss can be referred to as the fraction of packets lost when traversing from source to destination and back over a specified time interval, expressed as the percentage of the total number of sent packets in that interval [2]. Network congestion is one of the cause of packet loss. Network congestion mostly occurs when packets arrive at the router at a greater rate than it is possible to send. This causes a queue in the router and if the router queue is full, the router discards some of the packets resulting in packet loss. TCP (Transmission Control Protocol) is used to detect lost packets and sense congestion. In response, TCP controls the rate at which packets are sent and resends the lost packets.

Packet loss rate varies from 0% (no congestion) to higher levels of up to 15% (sever congestion) which deems the network unusable for normal purpose [2].

4 Internet Measurement Platforms

Internet measurement platforms can be referred to as platforms of dedicated probes that repeatedly run network measurement tests on the internet [21].The platforms implement a range of measurement techniques to infer network performance in terms of metrics such as latency, packet loss, delays and throughput [22].iPlane [23], Speedchecker [24], Archipelago, RIPE Atlas and DIMES are some of the known internet measurement platforms. In this literature review we focus on the most common internet measurement platforms that lead to the discovery of the internet topology.

4.1 Distributive Internet Measurements and Simulation (DIMES)

DIMES [25] is an internet measurement platform that attempts to build a router level map of the internet [20]. DIMES uses agents to perform internet measurements such as ping and traceroute at a rate not exceeding a peak of 1KB/sec [18]. DIMES agent can be installed on any computer connected to the internet. The installation of DIMES agent on a computer is voluntary and relies on volunteers who are willing to run light weight low signature measurement agents as a background process [25]. The data collected is then sent to a central collection station after a period of time. Redundancy reduction in data collected from DIMES is a cumbersome process because DIMES does not attempt to resolve router aliases haddadi2008network.

4.2 Speedchecker

Speedchecker is an active measurement platform that offers internet performance monitoring through DNS, traceroute and ICMP ping [26]. Data such as latency measurements based data and topology measurements based data can be collected from Speedchecker probes and stored in the Speedtest servers [27]. The collected data is then used to analyze the behavior of a network. As of 2018 [26], there were 850 probes in Africa covering 52 countries.

4.3 Archipelago Measurement Platform

Archipelago [28] is an active measurement platform that is deployed and maintained by CAIDA with two primary goals: support large-scale measurements and collect data to support various research interests. RADclock, Dolphin and scamper are some of the tools Archipelago uses [28]. We will briefly discuss more on scamper in this section. Scamper probes the internet so as to analyze performance and topology [29]. Apart from implementing trace route, ping, Multi-path Discovery Algorithm (MDA) [30, 31] techniques, scamper also uses Paris-traceroute to control packet header contents and obtain a more precise picture of the specific routes a packet follow [32].The data outputted by scamper contains data surrounding each measurement conducted and details of responses received [29].Currently, Archipelago has about 12 monitors in Africa [33].

4.4 RIPE Atlas

RIPE Atlas [34] is an active measurement platform that collects information regarding internet reachability, connectivity and performance. This information collected can also be used to discover internet topology in a specific area. RIPE Atlas has hardware probes globally that perform active measurements (see Figure1) to collect performance data about the global internet [35].RIPE Atlas is capable of performing RTT, ping, traceroute, DNS, SSL, NTP and HTTP measurements [36].

RIPE Atlas has been used in most of the research studies aimed at discovering internet topology and measuring network performance in Africa. This is mostly due to the number of active probes it has. As of 2018 [26], there were 229 active RIPE Atlas probes in Africa. Unfortunately, approximately half of them are hosted in South Africa. The more scattered the probes are the better the measurement of the internet. Ripe Atlas also requires one to host a probe to conduct measurements, which can be limiting for

MEASUREMENT	TARGET
ping, ping6	first hop, second hop (derived from traceroute measurements), *.root-servers.net, *.atlas.ripe.net
traceroute, traceroute6	*.root-servers.net, *.atlas.ripe.net, topology4.dyndns.atlas.ripe.net, topology6.dyndns.atlas.ripe.net, labs.ripe.net
dns, dns6	*.root-servers.net: TCP (SOA), UDP (SOA, version.bind, hostname.bind, id.server, version.server)
sslcert, sslcert6	www.ripe.net, atlas.ripe.net
http, http6	www.ripe.net/favicon.ico, ip-echo.ripe.net

Figure 1. A list of built-in measurements performed by RIPE Atlas' hardware probes

some researchers who just want to do academic research on available probes without having to host one.

4.5 Differences in the internet measuring platforms

In this section we are going to discuss few differences in the measurement platforms. There are other differences between platforms apart from the number of vantage points they have. Isah *et al*. [22] pointed out that while Speedchecker can measure throughput, RIPE Atlas does not possess that measurement feature. However, RIPE Atlas is seen to be more beneficial in studies focusing on network latency compared to Archipelago. Formoso *et al.* [26] also talked about how RIPE Atlas has a strong bias towards university network and how most of the probes are hosted in South Africa. Speedchecker on the other hand, is not biased towards university networks and covers 91% of African countries [26].

Archipelago is not as focus on satisfying immediate operational troubleshooting needs such as network reachability as how RIPE Atlas is [37]. Archipelago can perform many other kinds of measurements that currently RIPE Atlas can not do, such as studying the congestion at inter-domain peering links, because of how powerful Archipelago probes are compared to RIPE Atlas [37].

One needs to host a probe to conduct measurements on RIPE Atlas [37]. Archipelago, DIMES and Speedchecker on the other hand, does not require one to have a probe to conduct measurements for research purposes.

5 Africa Internet Measurements(topology and performance

Several studies have been done in regards to discovering of internet topology and analyzing network performances in Africa. Most of the studies have highlighted shortcomings in Africa's internet infrastructure. These shortcomings can be generalized into the lack of local and regional peering among African ISPs and how the intra-continental end-to-end internet latencies are comparably higher in Africa than in most other continents.

In [38], Gilmore *et al*. mapped router level and AS level maps of the African Internet showing the intra-African Internet paths. They developed a software to automate the transmission of traceroute probes and collected data. The data was then visualized using geographical visualization and three-dimensional hyperbolic visualization tools. They analyzed data obtained from measurements done from a single vantage point in South Africa towards all AFRINIC [39] allocated IP addresses. This data was then used to map internet connectivity from South Africa to all IP blocks that are allocated by AFRINIC. The key limitation in their work was that it only contained one-way paths from South Africa [26].

Gupta *et al*. [40] also performed traceroutes from access networks to sites hosting popular content to investigate Internet connectivity in Africa. Although they increased the number of vantage points, they targeted a small set of African countries [26]. The authors acknowledged that the broadband access networks in the countries that they performed traceroutes from are more developed [41] than in most of the remaining 51 countries [42]. They acknowledged that The result may affect the study as broadband access networks in the countries that they performed traceroutes from do not reflect connectivity in other countries. Chavula *et al*. [18] researched communications among African research networks. They used Caida Ark to launch traceroutes to 95 university locations in 29 African Countries [26]. They observed how the round trip time is affected and suggested ways to make it better. The measurements lasted for 14 days.

Fanou *et al*. [42, 43] examined how African networks are interconnected to one another as seen from end-use vantage points. It offered a wider view of the AS level topology interconnecting African ISPs [22]. They 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 delays [42, 43]. Fanou *et al*. [44] 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. Yang *et al*. [45] presented the design of a geospatial visualization of the network topology of African research networks in Africa using Traceroute data. This allowed the visualization of the data such as the locations of the Internet Exchange Points and where networks connect. The key limitations of this work were that the visualization was not an accurate representation of the traceroute data collected [45].

Formoso *et al*. [26] examined the current state of the African Internet by performing large-scale country delays covering 52 countries and 319 networks across Africa. They used speedchecker as their internet measurement platform to monitor internet performance through ICMP ping, DNS and traceroute and quantified inter-country latency.

6 Discussion

After a discussion of different types of internet measuring platforms and background work done in discovering internet topology in Africa, the following observations were made

- Combining data from different platforms, from the perspective of vantage point distribution, provides a wider view of the internet [36].
- Interms of accuracy of measurements, passive methods offer more accuracy than active measurements [8]. Since passive and active measurements produce different kind of information and results, a better understanding of the network can be gained by combining the results from both types of measurements [8].
- Formoso *et al*. [26] pointed out that there is a deficit of research infrastructure in Africa. Interms of the number of vantage points and ability to discover internet topology, there are two platforms: RIPE Atlas and Speedchecker.
- Active measurements does not require full access to a network resource because active measurements can be made over a network path that the measurer does not control [8]. Passive measurements on the other hand, work best when capture points can be freely selected [8].

7 Conclusion

There has been a growth of interest in measuring different aspects of internet connectivity and performance in Africa. The increase in the number of research studies that focus on network performance in Africa reflect that interest. However, we still fall short in deploying more probes to aid in better understanding of our network performance. This has led to having only two feasible platforms used to discover internet topology in Africa: RIPE Atlas and Speedchecker.

More people should host probes to increase the number of vantage points in a region. Platforms should also find ways to increase their numbers of probes especially in Africa. They should also continuously check that these probes remain connected to the internet. This will help us better understand our network and what we can do to improve it.

Lastly, the use of one measurement platform alone is not enough to analyze the network performance in Africa. However, the use of multiple platforms can propel us to a better mapping and understanding of the internet topology in Africa.

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