AfriNREN Project Literature Review

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Previous research on National Research and Education Networks (NRENs) in Africa has shown high latency in traffic exchange between networks with 75% of this traffic taking circuitous routes through Europe. What has not been documented is the amount and type of traffic that is exchanged within and between African NRENs. For this to occur, an understanding of the underlying topology of NRENs at the Autonomous System (AS) and Point of Presence (PoP) level is necessary using a form of traceroute. Furthermore, an analysis of Internet logs from NRENs also needs to be conducted where traffic can either classified via port number, payload content, host behavior or statistics. Creation of a visualization tool would also help provide greater insight into this data whether a graph-based representation or some other novel approach is used.

Categories and Subject Descriptors: **C.2.1 [Computer-Communication Networks]**: Network Topology

General Terms: Design, Measurement

Additional Key Words and Phrases: National Research and Education Networks, Autonomous Systems, Traceroute, Point-of-Prescence, Network Topology Visualisation, Network Traffic Visualisation, Traffic Classification

1. INTRODUCTION

With over 100 implementations around the world, National Research and Education Networks (NRENs) are increasingly being utilised by researchers and educators to conduct cross-border collaborations in a number of fields from high energy physics to radio astronomy [Fryer, 2012]. This requires large amounts of data to be transmitted at high connection speeds [Fryer, 2012]. For this reason, network performance and latency are important aspects of NRENs [Chavula et al., 2014]. Studies examining the routing of Internet traffic within Africa show that traffic traverse circuitous routes via Europe thereby resulting in high latency [Gilmore et al, 2007; Gupta et al., 2014]. Similar results were obtained in an analysis of traffic between African NRENs: 75% of traffic with African sources and destinations were found to make use of network links outside of the continent [Chavula et al., 2014]. Possible reasons for this are a lack of peering or physical interconnectivity between African NRENs – an issue that the regional (eastern and southern Africa) research and education network, UbuntuNet Alliance, has been trying to address by setting up Internet Exchange Points (IXPs) [Chavula et al., 2014; UbuntuNet Alliance, 2014].

That being said, little research has been done on quantifying the amount of traffic exchanged between and within African NRENs nor has a determination been made on the nature of this traffic. The AfriINREN Project therefore seeks to fill this gap by building on by Chavula et al. [2014] work on latency and circuitous routes of NREN traffic within Africa. Understanding the traffic patterns of NRENs, and having a tool for visualising the physical and logical topology of NRENs would provide better insight into why such high latencies occur. For this reason, the project will involve the collection of data for topology discovery of African NRENs and the analysis of Internet logs. These will be provided by institutions participating in the study and be used to determine the type of traffic sent within NRENs (eg. http, p2p, etc.). Once this is done, an appropriate visualisation will be designed and generated for each respective data set.

The purpose of this paper is to survey current literature related to network topology discovery at the AS and PoP level, classification of network traffic and visualisations of network topology and traffic. First, the relationship between NRENs as autonomous systems and the Point of Presence of institutions within these NRENs will be discussed, before looking at different traceroute methods that can be used to map these topologies. After this, different methods of traffic classification will be examined, keeping the organisation of Internet traffic logs in mind. Next, general strategies for effective information visualisation applications will be considered, before evaluating existing network topology and network traffic data visualisations.

2. DISCOVERING NETWORK TOPOLOGY IN AND BETWEEN NRENS

Properties of network topology have an effect on network protocols and consequently, the performance of network applications and services [Motamedi et al., 2013]. Network topology is therefore an important concern for NRENs who provide a multitude of network services (such as point-to-point connectivity and identity federations). However, not much research has been done on topology mapping within the subject domain of NRENs especially in Africa [Fryer, 2012]. A mapping of such a topology would help create further insight how traffic is exchanged between NRENs (eg. from Kenya's NREN, KENET to South Africa's NREN, TENET) and within African NRENs (between TENET members). Information such as this would be valuable in discerning whether or not the placement of IXPs between certain NRENs is necessary.

In the field of internet network topology discovery, both Donnet et al. [2007] and Motamedi et al. [2013] present comprehensive literature surveys in which they discuss the different levels and resolutions at which Internet topologies can be mapped from finest to coarsest – namely: the interface level, router level, point of presence (PoP) level and the autonomous system (AS) level. We focus on the AS and PoP level as NRENs are Autonomous Systems that contain various Points of Presence for different institutions [Motamedi et al., 2013; Chavula et al., 2014].

Besides this, Donnet et al. [2007] and Motamedi et al. [2013] also investigate various tools and methods for collecting information for topology discovery. Motamedi et al. [2013] offer brief explanations on the data plane versus the control plane and the difference between passive and active measurements used to collect information for topology discovery.

The control plane refers to the part of the network that is responsible for routing whereas the data plane is the part of the network that carries traffic packets [Sdntutorials, n.d]. Thus measurements performed in the control plane collect data and information about Internet routing ("reachability") and measurements in the data plane reveal the actual paths that packets travel along ("connectivity") [Motamedi et al., 2013]. These measurements can either be passive or active where passive measurements analyse traffic that is already flowing over a wired connection whilst active measurements send probe messages in the form of packets into the network of interest to collect network replies [Motamedi et al., 2013].

Although both active and passive measurements can be used for network topology discovery, for purposes of the AfriNREN research project, active measurements (particularly that of traceroute), has been deemed appropriate for use for topology discovery at an AS and PoP level (Section 2.2) [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014]. At the PoP level, Motamedi et al. [2013] describes three ways of topology discovery: traceroute data aggregation, *ping* measurements and online ISP maps (discussed in Section 2.3).

2.1 NRENs and the AS and PoP Level

National Research and Education Networks are described as being a mesh of interconnected networks that are used by researchers within a country [Fryer, 2012]. As such, NRENs are classified on the Autonomous System level – an Autonomous System (AS) is a single network or group of networks controlled by a single organisation. At this level, an AS is represented by a node and identified by a16-bit AS number (ASN) [Donnet et al. 2007; Motamedi et al., 2013]. While ASes may be physically connected by multiple links to various PoPs within another AS, AS links are abstractions of the underlying physical topology where an edge represents a business relationship of traffic exchange [Donnet et al. 2007, Motamedi et al., 2013].

Points of Presence are a grouping of routers that belong to the same AS in a specific location [Motamedi et al, 2013]. A link between two PoPs indicates that there is a physical link between the routers of the two PoPs [Donnet et al., 2007; Motamedi et al., 2013]. Interconnected PoPs that belong to the same AS form a backbone [Donnet et al., 2007; Motamedi et al., 2013]. Thus, it is also necessary that the PoP level be examined as a map of PoPs could shed light on the physical topology between and within NRENs. Furthermore, each institution may (also) have multiple campuses and Points of Presence (whether located in a city or suburb).

2.2 Topology Discovery at the AS Level

Although there are various techniques for topology discovery at the AS level, including the use of Border Gateway Protocol (BGP) Information and Internet Routing Registries (IRR) data sources, these sources have been found to be limited, incomplete or outdated [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014]. Having said that, both BGP routing tables and IRR can be used to correlate IP to AS mappings collected from interface level traceroute measurements [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014].

Mapping IP addresses to AS numbers is not a trivial task and there are several challenges to this, including the multiple origin AS problem ("MOAS") in which an IP routing prefix appears to come from more than one AS and the incompleteness of prefix registries [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014]. Mao et al. [2003] presents heuristics for creating more accurate IP to AS mappings by comparing BGP and traceroute AS paths and performing reverse DNS lookups though, as Donnet et al. [2007] notes, this is a labour intensive process. Additionally, there is the fact that BGP is a measurement conducted on the control plane while traceroute is a data plane measurement and it is discrepancies between these two planes that could result in inconsistent AS-level topologies [Motamedi et al., 2014]. In order to address this issue, geolocation databases such as Maxmind's GeoIPLite or GeoLite City have been used to retrieve the geographic location (latitude/longitude) of router IP addresses [Gilmore et al. 2007; Chavula et al., 2014].

Despite this, however, traceroute remains a commonly used network probing tool for the AS level discovery of forwarding paths along which data packets are sent [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014]. Round-trip times (RTT) are relayed at each hop [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014]. Reasons for it's continued use include the fact that fairly effective determinations of packet flows can be made without real-time access to proprietary routing data for different domains and that traceroute probes can easily be deployed from multiple vantage points, allowing for more complete mappings [Mao et al., 2003; Shavitt and Weinsberg, 2009; Motamedi et al, 2014]. These advantages outweigh the limitations that diminish the accuracy of the various traceroute methods (ICMP, UDP, TCP), such as firewalls, load-balanced routers and multi-protocol label switching (MPLS) [Donnet et al., 2007; Motamedi et al., 2014]. Furthermore, alternative traceroute methods (such as the Paris traceroute that resolves flow-based load balancing issues) have been implemented to circumvent these limitations [Donnet et al., 2007; Motamedi et al, 2014]. It is this traceroute method that Chavula et al. [2014] made use of in their study on RTTs and latencies in NRENs in Africa.

Subsequently, it is important to note that it has been shown that different traceroute methods yield different topologies: ICMP-based traceroute methods reach more destinations and collecting a greater number of AS links while UDP-based methods reach less destinations but infer a greater number of IP links [Luckie et al., 2008].

2.3 Topology Discovery at the PoP Level

According to Motamedi et al. [2013], three approaches to PoP level discovery can be done. First is the aggregation of data collected by traceroute measurements to identify PoPs where interface or router-level information is used as input and nodes belonging to a single PoP are grouped together. Second is the use of delay estimates from *ping* measurements where the presence of PoPs is inferred based on a model that relates end-to-end delays and to the sum of delays between consecutively traversed PoPs. The last approach is the use of information (such as

IP Geolocation databases) published by Internet Service Providers (ISPs) online, which are supposedly more accurate than mappings generated by measurement-based techniques (due to the fact they are published by the provider themselves) but are likely to be outdated [Motamedi et al., 2013].

3. TRAFFIC CLASSIFICATION

Traffic classification refers to the categorisation of traffic according to the applications that generate them [Karagiannis et al., 2005; Rossi and Valenti., 2010]. Such information is useful in that it helps facilitate network design, planning and operation and, in the distinct context of NRENs, aids in the determination of whether the establishment of an NREN between two communicating institutions within the same country is viable [Karagiannis et al., 2005; Kim et al, 2007; Rossi and Valenti., 2010]. This is of particular concern for institutions in Africa, where the cost of network communication is high [Jensen, 2006; UbuntuNet, 2014].

In Martin's [2005] paper, a description of different types of NREN users is made. Class A users are described as "lightweight users" who make use of client-server services such as Internet browsing, email and file transfers – essentially, a user no different than those who use the commercial Internet. Class B users, on the other hand, make use of a broader range of more advanced networking services through VPNs and Peer-to-Peer applications, performing tasks such as streaming and IP telephony. Class C users are more specialised in that they are involved in research and make use of data-intensive, scientific applications that require high speed connections [Martin, 2005; Fryer, 2012].

Thus the classification of traffic within NRENs is necessary in order to discern different NREN users and their need and help establish Quality of Service (QoS) needs of NRENs. However, like network topology discovery, this field is not without its challenges. Although the classification of Internet traffic has been the focus of many studies, currently there is no consensus among researchers on the most effective method for traffic classification statistics [Karagiannis et al, 2005; Kim et al., 2007; Kim et al., 2008].

Furthermore, a robust comparison of these traffic classifcation methods is stated to be difficult to conduct [Kim et al., 2007; Kim et al., 2008].

Kim et al. [2007] attributes this to three facts. First, there is a lack of a common source data to perfom studies with: few publically available payload trace sets exist and as a result methods are evaluated using locally collected payload traces. Second, exisiting classification approaches use different techniques that track different features with different parameters and have different categorisation application definitions. Third, authors of studies do not make their data and tools available with their published results, making an evaluation and replication of the study impossible [Kim et al., 2007; Kim et al., 2008].

Nevertheless, four common methods of traffic classifications based on port numbers, payload packet examinations, host behaviour and statistics [Karagiannis et al, 2005; Kim et al., 2007; Kim et al., 2008].

3.1 Port-based Classification

In port-based classification, traffic is characterised by the port number that an application uses. Though a simple method to conduct, it is unreliable due to the fact that applications reuse, randomly select or allows users to choose ports [Karagiannis et al, 2005; Kim et al., 2007; Kim et al., 2008; Rossi and Valenti., 2010; Donato and Dainotti, 2014]. Additionally, applications may use ephemeral ports (eg. P2P) or masquerade behind known-ports (streaming, gaming) [Kim et al., 2007; Kim et al., 2008]. This is not a problem for legacy applications and protocols that make use of their known, default ports which are seldom used by other applications (eg. SSH, SNMP, DNS) [Kim et al., 2007; Kim et al., 2008]. A study by Kim et al. [2008] showed that for such traffic, port-based classification tool Coral-Reef has high accuracy.

3.2 Payload Packet Examination

Payload packet examination methods are also problematic in that, while accurate in their inspection of non-encrypted packets, they present legal and privacy issues, are resource intensive and don't scale well in high bandwidth situations [Karagiannis et al, 2005; Kim et al., 2008].

3.3 Behaviour-based traffic classification

Behaviour-based traffic classification approaches construct profiles of a host based on destinations and ports it communicates with and applications it uses after which it classifies the traffic flows [Karagiannis et al, 2005; Kim et al., 2008]. Kim et al. [2008] conducted studies based on the BLINC tool proposed by Karagiannis et al. [2005] that implements this behaviour analysis. Results showed that the accuracy of classification depends on the connection under observation's topological placement [Karagiannis et al., 2005].

3.4 Statistical-based traffic classification and Machine Learning

Rather than one, specific classification method, this refers to the general approach of using different machine learning algorithms (either supervised or unsupervised) to classify traffic [Karagiannis et al, 2005; Kim et al., 2008; Donato and Dainotti, 2014]. Criteria used in these algorithms are formulated from statistical observations and distributions of flow properties in packet traces, including packet size distribution per flow and the inter-arrival times between packets [Karagiannis et al, 2005].

4. NETWORK TOPOLOGY AND NETWORK TRAFFIC CLASSIFCATION VISUALISATIONS

Once information on network topology has been collected and traffic from internet logs classified, it is necessary to visualise this information. Motivations for the value of the analyses of these data sources have already been discussed in Sections 2 and 3 but there is added value in presenting this data in an interactive, visual format: greater insight could be offered into the data itself through identification of gaps, anomalies, clusters or patterns [Becker et al. 1995; Schneiderman, 1996; Carr, 1999].

According to Schneiderman [1996], a practical starting point for user interface design is use of the Visual Information-Seeking Mantra which describes visual design guidelines for information visualisation applications. This consists of the principles of overview ("gain an overview of the entire collection"), zoom ("zoom in on items of interest"), filter ("filter out uninteresting items") and details-on-demand ("select an item or group and get details when needed"). Rather than a framework though, Craft & Cairns [2005] has noted that there is a need for the formalisation of the mantra and that a robust methodology should be devised. Despite this, Schneiderman's [1996] paper has been heavily cited since publication demonstrating its utility.

4.1 Network Topology Visualisations

The most common way of presenting network topology is a graph representation which consists of nodes and edges [Becker et al. 1995; Goodall et al, 2005; Withall et al., 2007] This is unsurprising as the data itself is defined as being of a network data type in which items are linked to an arbitrary number of other items and cannot be organised into a tree or hierarchical structure [carr, Schneiderman].

This presents a challenge in visualising such data as there can be both many nodes and many links all of which are connected to each other causing display clutter and occlusion edges [Becker et al. 1995; Goodall et al, 2005]. One way of addressing this issue is by aggregating links or nodes together but Becker et al. [1995] believes that this could obscure important information. This leaves the implementation of interactivity (eg. filtering and dynamic repositioning of nodes) to solve this problem [Becker at al., 1995].

In Withall et al. [2007], literature on numerous network visualisation applications are presented and although the paper classifies these into geographic visualisations (nodes are represented in respect to physical locations), abstract topological visualisations (nodes are independent of physical locations) and plot-based visualisations (focus on a single network point with respect to time), the effectiveness of these visualisations is not critically evaluated on the basis of any design principles.

Examples that have been found that relate more specifically to the AfriNREN case of mapping topology at an AS or PoP level are that of Fowler et al. [2014] and Gilmore et al.'s [2007] studies. An understanding of the taxonomy presented in Section 2 dictates whether the visualisation presents a physical representation (PoP level) or logical representation (AS level).

In Fowler et al. [2014], a novel logical visualisation of AS-level Internet topology is expressed in which ASes are grouped as contiguous regions based on their attributes (geo-location, type, rank and IP prefix space). The result is a map-like interface in which amorphous regions (representing real-life countries) contain points which show ASes. Approaches used in the visualisation present a possibility for use in the AfriNREN project in that regions are colour-coded according to continent; size of country regions demonstrates the importance of the its ASes and lastly, distance between country regions depicts the level of connectivity between those two countries.

In Gilmore et al.'s [2007] study, router and AS level maps of the African Internet were generated using data collected from traceroute probes sent to selected IP addresses. At the router level, a java-based tool Terrapix was specially created for the study presenting 2D and 3D visualisations mapping nodes and links to geographic locations. For the AS level, CAIDA's Walrus tool was used to generate logical node-link, graph visualisations in a 3D hyperbolic space. Using these visualisations, a "picture" of the African Internet was pieced together though the accuracy of this is questionable as traceroute probes were only conducted from a single vantage point [Shavitt and Weinsberg., 2009].

4.2 Network Traffic Classification Visualisations

In comparison to network topology visualisations, traffic classification visualisations have been difficult to find. Possible reasons for this are difficulties with the field of traffic classification itself in which the methods and tools vary thereby influencing the way in which the information can be depicted. Having said that, it is quite likely that a spreadsheet or table view would be available meaning that traditional graph methods such as bar graphs or histograms could be used as ways of portraying data much the same way Kim et al. [2008] displays the traffic classification results of their study.

5. CONCLUSIONS

In this paper, literature in fields of study related to the AfriNREN project were examined. These included the areas of network topology discovery, traffic classification and visualisation of network topology and visualisation of network traffic.

Extensive literature (Donnet et al.[2007], Motamedi et al. [2014]), was found on the taxonomy of network topology as well as the various methods that can be used for topology discovery which could either be active or passive measurements or conducted on the data or control plane. It was identified that the use of (some form of) traceroute would be appropriate for topology discovery at both an Autonomous System and PoP level despite its challenges and limitations which have been well-documented [Mao et al., 2003; Donnet et al., 2007; Motamedi et al, 2014]. Additionally, while there have been studies conducted on mapping Internet topology within Africa (eg. Gilmore et al., [2007]), studies in relation to NRENs on the continent have not been found.

After examining network topology, motivations for traffic classification were examined in relation to NRENs in Africa. It was established that network communication within the continent is expensive and that classifying NREN users by their needs is useful for QoS agreements for NRENs. Therefore, classifying network traffic by type when sent between and within NRENs is necessary for identifying users' needs. But while numerous studies on traffic classification have been conducted, a consensus on the effectiveness of the different classifications methods (port-based, payload packet examination, behaviour-based, use of machine learning algorithms) has not been reached among researchers due to a lack of common source data and variation of tools and methods [Karagiannis et al, 2005; Kim et al., 2007; Kim et al., 2008].

An analysis of literature on information visualisations found that the principles of Schneiderman's [1996] Visual Information Seeking Mantra remain an important guideline for interface design. In terms of network visualisations specifically though, use of graph representations of nodes and links is still popular as well though Fowler et al. [2014] presents a unique representation of AS level topology that differs from this norm. In contrast to Withall et al. [2007]'s paper which described multiple examples of applications visualising network data, no examples of network traffic classification visualisations could be found.

In conclusion, studies applying to NRENs in the aforementioned fields and in particular the context of Africa, are few, if any. This therefore presents an opportunity for contribution by the AfriNREN project in the work it will be conducting.

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