Data collection techniques for internet topology discovery and visualization methods

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ABSTRACT

Internet topology discovery techniques are important when attempting to acquire an accurate and complete view of the internet topology. The purpose of this paper is to describe the most common techniques, such as BGP and traceroute measurement, that were use to collect data at each topology level. These techniques from previous work will be classified as router level topology and AS level topology. The limitations on these data collection techniques and the solutions to these limitations based on prior work will be discussed. This paper also presents the methods that were used in the previous work to generate maps of the African internet at router level and autonomous system (AS) level. This paper will finally describe the 2D and 3D geographical visualization that were used to visualize the router level maps and the 3D hyperpolic visualization that was used to visualize the AS level maps.

KEYWORDS

Internet Topology Discovery, Traceroute, BGP, AS, Router level topology, AS level topology

1. Introduction

Internet is the world's largest network that is formed by a vast number of interconnected networks called autonomous systems (AS). Acquiring an accurate and complete view of the internet topology and visualizing it on the world's map may be beneficial because it allows the network research community to view and comprehend the structure of the network easily. However, due to the heterogenous nature of today's internet, it is extremely difficult and challenging to map the internet's global topology [14].

Possible reasons for the internet's heterogenous nature are most of the autonomous systems (ASs) are owned and operated separately by various companies. ASs can serve different purposes such as providing internet services to the internet users. Due to the diversity in network type, ASs are comprised of network devices that are created by different manufacturers. This means that ASs can have varying physical topologies [14].

Not being able to map the network topology accurately means that it will be difficult for the network researchers to identify the routes that network traffic traverses between different networks. This means that the network researchers may struggle to resolve the issues involving high latency in traffic exchange between networks [1]. Latency means the time it takes for a packet of data to reach its destination from its origination. Latency is usually measured as round trip time (RTT). Therefore, capturing an accurate view of the network topology enables the network researchers to make meaningful choices in peering decisions and to identify routing issues [2].

In order to infer and visualize relationships between networks in Africa, internet topology discovery and routing techniques are essential. In addition, Sophisticated methods and tools are also needed in order to generate AS level maps and router level maps of the African internet and visualizing its datasets on a map [4].

There are two most used internet topology discovery techniques which can be categorized into two groups: Active techniques and passive techniques. Active techniques use traceroute which is a network diagnostic tool that is used to send packets into the network with the aim to extract topology information. On the other hand, passive techniques involve collecting BGP (Border Gateway Protocol) routing updates from BGP routing tables to infer the network topology [8,14].

Visualizing the African internet topology on a map allows network researchers to study various topological properties of the internet. With a better understanding of the internet topology, network researchers can improve the network structure and the network protocols. Furthermore, having an accurate map of the internet topology allows network engineers and operators to optimize the allocation of network resources such as data centers [14].

The purpose of this paper is to review and compare the data collection techniques used to discover internet topology along with its limitations and the possible solutions to these limitations. The results of internet topology modeling that use the data collected from these techniques will also be discussed. In addition, the methods that were used to generate maps and how these maps were visualized will also be reviewed and discussed.

2. Data collection techniques and tools

Motamedi et al. [2015] describe the main data collection techniques and tools used for internet topology discovery at different levels. For the purpose of this paper, it will focus specifically on router level and AS level [14].

2.1 Router level topology

The router level topology displays the routers and the interconnectivity among the router's interfaces. There are two main techniques for discovering the router level topology: Alias Resolution and Recursive Discovery [14].

2.1.1 Alias Resolution

Alias resolution is the process of identifying a group of IP interfaces that belong to the same router where each interface has its own IP address. If any two IPs are assigned to the interfaces of the same router they can be referred as aliases [14]. Each router typically has more than two interfaces, but each interface can consist of multiple IP addresses. Traceroute can only reveal a single address of the router. This is why IP alias resolution is used to identify the IP address that belong to the same router and produce a more useful router level topology [9]. One of the limitations to this technique is that relating different interfaces of a router can be a challenge. This is because various interfaces of a router are discovered in different traceroute measurements.

2.1.2 Recursive Router Discovery

It is used to discover the router level topology by relying on the routers' capability to store information about their neighbouring routers on each interface. This technique is used recursively, as the name suggests, to discover their neighbouring routers and the connectivity between them. One drawback is that it is only limited to the interior of ASs.

Although this recursive router discovery can only be used within an AS, it creates an alternative method where AS connections can be inferred from the router level topology [6]. More specifically, traceroute measurements can be used to distinguish multiple AS connections between two ASs. Therefore, this allows the AS level connectivity information to be discovered from the internet's router level topology [6].

2.2 AS level topology

The AS level topology is usually modeled by using a simple graph where a node represents an AS which is identified by an autonomous system number (ASN). The links in the AS graph represent the logical connectivity between two ASs. There are many techniques that were used for discovering the AS level topology and most of the techniques use BGP information and traceroute measurements as their data sources [14].

2.2.1 Traceroute Measurement

One of the common ways for discovering the internet's AS level topology is to use traceroute measurements. IPs obtained from the traceroute measurements are mapped to its corresponding AS [14]. This technique allows a more detailed view of the AS level topology to be revealed. In addition, traceroute measurement can use multiple vantage points. With more than one vantage point, a more complete view of the AS level topology can be obtained [16].

However, traceroute measurement has some limitations to it. One of the limitations is the research done by Zhang et al. [2011] who believes that the approach of using traceroute to discover AS links in AS level topology is highly error-prone. Mapping IP addresses in traceroute paths to ASN is a challenging problem and remains as a challenge for many researchers. To mitigate this issue, a systematic framework was developed to quantify the impact of the potential errors of traceroute measurements on AS level topology [18].

2.2.2 BGP Information

BGP is the standardized interdomain routing protocol that is designed to exchange reachability information among ASs on the internet. The information from BGP was used to map the AS level topology and then infer the AS level topology [14].

There are several benefits when using information from BGP to infer the AS level topology. One of the benefits is the data collected from BGP do not tend to stale or incorrect because BGP shows accurate reachability information. Another benefit is that BGP information can be used to study the behaviour of internet routing [14].

Although using BGP information has many benefits, it also comes with its own limitations. For example, BGP is unable to process a large amount of routing information. There is a solution to this issue which is a multipath routing technique called BGP-Multipath (BGP-M) [7]. BGP-M can be used for load balancing by utilizing the Equal Cost Multipath (ECMP) function at a border router to share traffic to a destination on different border links [7].

3. Map generation and visualization methods

In the paper by Gilmore et al. [2007], the African internet is mapped at different levels (Router level and AS level). At each level, different mapping methods have been used to generate a map of the African internet. The generated maps will then be visualized using different visualization methods.

3.1 Router level

At the router level, a database is required to store all the data that will be generated and processed by a mapping software. The SQLite database was chosen. In order to discover the routes in the internet topology, the traceroute utility is used to send special packets to destination IP addresses to record the routes that the packets have traversed to reach its destination [4].

However, according to Zhuqing et al. [2003], some networks do not respond to the traceroute packets because certain networks may prevent the response packets from leaving their networks. Despite this, most intermediate routers have their IP addresses attached to the ICMP (Internet Control Message Protocol) reply in case the response packets are blocked from exiting networks.

A tracer program is used to collect all the data from the database. After the tracer program has collected the data, another program called TerraPix is used to draw connection graphs. The output of TerraPix is in the form of a list of connections. Each connection consists of a router's source and destination addresses and the average latency between the two connections. The connections will then be mapped on a map of African continent [4].

This method can be improved by having more than one vantage point. Shavitt et al. [2011] studied that having more than one vantage point can have a substantial effect on the quality of the internet topology. In order to infer the internet topology, having a broad distribution of vantage points is important as it can reduce the results of biased topologies [17]. In addition, multiple vantage points also enable certain techniques to identify the IXPs (Internet Exchange Point) and IXPs play an important role in today's internet ecosystem [12].

3.2 AS level

At the AS level, Border gateway protocol (BGP) speakers are used to collect all the BGP information. In order to map the connectivity of African ASs, BGP speakers must peer with other ASs locally to store the incremental updates in the RIB (Routing Information Base). The RIB contains a table of all the routing information. Finally, the routing information is used to generate an adjacency matrix which describes the connectivity of the ASs. This matrix may be used to create a visual presentation of the Internet topology [4].

The BGP data processer produces a list of prefix/path pairs from a view of the network. These prefix/path pairs are transformed into a list of AS to AS links whenever an adjacency matrix is generated. The generated adjacency matrix is then used in a graphing program to create a visual representation of the AS level graph [4].

This method can be improved by introducing additional peers because it provides a more complete view of the network. As a result, identifying IXPs become even more necessary [12]. IXPs allow the ASs to set up a peering agreement at a common location and this also allows the network traffic to be exchanged quicker without worrying about high latency [11].

3.3 Visualizing router level maps

2D and 3D geographical visualizations were used to map the nodes and links to geographic locations. The program Terrapix is developed specifically to visualize 2D and 3D level router maps [4].

3.3.1 Two dimensional geographic mapping

2D geographic map was created by mapping the world map to a x,y plane. The nodes are then each given a position in the plane where the chosen position represents the physical location of the node on the world map. The links represent the line segments between two coordinates on the world map. In 2D geographic maps, the router level maps can be visualized by covering the world map with the drawn graph [4].

3.3.2 Three dimensional geographic mapping

3D geographic maps were created by mapping the world maps to a sphere. Instead of plotting the links as line segments, the links are plotted as arcs between the points (Geographical locations) on the sphere. This mapping has more spaces to visualize the data than the 2D geographic maps. Overall, this visualization maps the routers as nodes onto a 3D sphere and links are mapped as arcs [4].

However, there are challenges when visualizing such data because there are so many nodes and links that are connected to each other. This can cause the display of the visualization to be cluttered and it can also lead to occlusion of nodes or links [13]. One of the solutions for this issue is to aggregate the nodes and links together. Although, this may solve the issue, another problem arises from this solution. Beker et al. [1995] believes by doing so will leave out important information. To solve this problem, the visualizations should have an interactive feature to filter certain data [13].

3.4 Visualizing AS level maps

A 3D hyperbolic visualization was used to represent the AS level map of the internet. This visualization has a 3D hyperbolic view where objects become smaller as they go further away from the origin of the sphere [4]. The Euclidean points are mapped onto the interior of the sphere. The centre of the sphere is represented as the origin of the coordinate system [4]. The visualization is generated in a 3D space by using a 3D hyperview program called Walrus which is created by CAIDA. The AS level map of the African internet was visualized using Walrus [4].

This visualization shares the similar issues as the 2D and 3D geographical visualizations where many nodes and links are connected to each other and cause display clutter and occlusion of nodes or links. The 3D hyperbolic visualization looks complicated which makes it difficult to comprehend and evaluate it. Various cluttering reduction techniques can be used to minimize such issues [5].

4. Discussion

4.1 Router level topology modeling

Previous work on internet topology modeling by Faloutsos et al. [1999] relied on the collected traceroute data which contained router level paths and it had been used to produce router level topology. One of the findings was the scale-free structure of the inferred router level topology which is the power-law degree distribution of routers. This finding implies that there is a large number of low-degree edge routers and a small number of high-degree core routers [14].

However, many experts argued that this finding is indeed erroneous [16]. The first reason is there are no publicly available router level topologies that exhibit the scale-free structure. The second reason is due to technology constraints which proves that the existence of high-degree core routers in real-world network is nearly impossible. Lastly, it has been shown that the errors in the router level topology modeling by Faloutsos et al. [1999] are a result of a limitation of the alias resolution method [14].

4.2 AS level topology modeling

Most of the studies proposed graph-based network models from a graph-theoretic perspective, but most of the studied models are neither relevant or realistic due to the incompleteness of the inferred AS level topologies. In the paper by Zhou et al. [2004], it proposes a model which tries to reproduce many AS level topologies. The model uses traceroute dataset to infer the AS level topology. However, the dataset suffers from the limitations of traceroute measurement which can cause the AS level topology to become inaccurate or incomplete [14].

The resulting graphs from the AS level topologies that were inferred from multiple data sources such as BGP and traceroute measurement, showed the peculiarities in data collection techniques. Therefore, after a various study of different inferred AS level topologies in the past, it has been discovered that a proposed model is only as good as the underlying data [14].

4.3 Results of visualizing router level maps

The graphs that were created by Terrapix tend to be disconnected when they were used to produce 2D and 3D router level maps. Two anomalies were discovered when inspecting the Africa map generated by Terrapix. The first anomaly is that the map consists of several disconnected graphs. The second anomaly is there are routers that don't have any connections on the map [4].

There are several reasons for the first anomaly. Firstly, there is an international entry point where the packets are sent to a destination and returns to Africa over international routers and links. This will be shown as a bloom effect on the map, where it has a starting point with links spreading outwards [4]. Another reason involves the functions of traceroute. Many traceroutes probes were sent to many random IP addresses in Africa. It is not feasible to send traceroutes to every IP address, but it should map most of the networks in Africa. However, IP addresses in a given range might not be near to each other because national companies run different networks throughout the country. As a result, traceroute cannot discover other networks and will not be able to discover the network router [4].

The reason for the second anomaly is that Terrapix removed all the routers' international links which is why the routers do not have any connections. Therefore, tracer cannot find local links because of broken links or routing policy which route packets through a certain link [4].

4.4 Results of visualizing AS level maps

The 3D hyperbolic visualization is drawn by using a MST (Minimal Spanning Tree) representation of a graph. The root of MST is important because it is used to highlight the tree structure of the graph. The router of the network was used to compute MST. A graph is created when sending probes from a single location where the first routers detected are the routers from where the traceroute traffic originates. Therefore, the generated graph will have the first routers as the root of the graph [4].

In addition, the MST is computed by using the first node as the root of the tree. The first node which is picked by Walrus will need to have as many connections as possible, but it will also need to generate as few non-tree links as possible. Although it is ideal to have no non-tree links, it is still important to note that non-tree links form as a part of the MST structure and should be included in the final representation of the network [4].

4.5 Comparison between 2D or 3D geographic and 3D hyperbolic mappings

Geographic maps are used to present the router level maps. The geographic maps can display the physical locations of the routers in the network and geographical positions of the countries. The main purpose of this mapping method is to show the locations of the key infrastructure [4].

However, the geographic method cannot be used to present AS level maps because using geographic methods to present the structure of the AS level of internet is very difficult and challenging. The reason to this is that an AS cannot be confined to one specific location. Instead, a graph visualization called 3D hyperbolic mapping was used to show the connection properties of the AS level internet [4]. This visualization is useful when large graphs need to be viewed. Although it is useful, the 3D hyperview algorithm should not be used if the graph has no tree structure. Thus, this 3D hyperbolic map is used to obtain connection-based information regarding the underlying structure of the AS level internet [4].

5. Conclusions

For the main purpose of the internet topology discovery, this paper is concerned with the use of data collection techniques that were used to collect the data at each internet topology level (Router level and AS level topology). Based on the previous work, the most commonly-used techniques are in the form of traceroute measurements and BGP information. The data collection techniques along with its limitations and the issues that these techniques create when using the resulting data for internet topology modeling at each level were discussed in detail. This paper also showed how these known problems were dealt with from the previous studies by presenting innovative approaches and solutions to address these problems.

In addition, two methods of mapping the African internet and different visualization methods were introduced from the previous work. When using these methods various issues may arise from it, but solutions to each of these methods were also discussed. Overall, the structure of physical links is shown by the router level maps and the AS level maps can be used to show the relationships between the internet service providers (ISPs). The geographical locations of Africa are shown using 2D and 3D visualizations and the AS structure of the African internet is visualized using a 3D hyperview program (Walrus).

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