Measuring SANReN Performance: An Internal and External View

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***Abstract*—Internet systems in developing regions experience various performance challenges due to inadequate infrastructure and resources. In this study, we conduct measurements using Speedchecker and perfSONAR to determine network performance when accessing the South African Research and Education Network (SANReN) from within the network and from outside the network. Our analysis finds that SANReN has performance challenge in and around Port Elizabeth (PE), as universities in these cities experienced the highest delays and page load times. We find that PE uses circuitous routes for traffic flows to Johannesburg and Pretoria, causing high delays and high page load times.**

***Index Terms*—NRENs, Active Measurements, Delay, Page Load Time**

I. Introduction

Network scalability, reliability, performance, and quality of experience (QoE) are among the most common issues faced by network administrators [1], [2]. These issues are amplified in the context of developing regions such as Africa, with many ISPs having low inter-connectivity between each other, resulting in high round-trip times (RTT) [3]. In addition, Chetty et al. [3] showed that South African broadband users regularly do not achieve the bandwidth speeds that are expected on their respective internet connections. The Covid-19 pandemic added extra stress on the networks, resulting in an increase in latencies as well as a decrease in video streaming quality as perceived by Facebook users [4]. Previous research on Africa's National Research and Education Networks (NRENs) showed that over 75% of traffic between African universities used primarily circuitous routes [5]. In this study, we focus on exploring performance issues faced by the South African National Research Network (SANReN). We employ active network measurements to investigate performance challenges and factors that impact performance for users of the network.

The main contribution of the study is to find the performance issues within SANReN and evaluate the reasons. We carry out network performance tests to analyse the quality of service (QoS) when accessing zero-rated websites hosted in SANReN. More specifically, active measurements focus on performance disparities when accessing these educational websites from different locations and networks in South Africa. Active measurements also focus on the performance of accessing these educational websites from within SANReN, compared to accessing them from outside the network. One of the key metrics used for the comparison is page load time (PLT) – which is the average time taken from the time the user enters the URL in the browser, until the page is completely loaded. The other metrics used are end-to-end packet delay, and throughput. The location of web servers, inter-connection between network operators and SANReN, and consequently, the network paths followed by packets from source to destination are among the factors that are investigated.

II. Background and Related Work

A. SANReN

SANReN is the South African nation-wide network that supplies universities, science councils, science projects such as the Square Kilometre Array (SKA), and various other projects and institutions with broadband internet connectivity [6]. It is operated by the Tertiary Education and Research Network of South Africa (TENET) [7], and primarily funded by the Department of Science and Technology (DST) [8]. Figure 1 shows the topology of SANReN, a nation-wide network that spans across multiple universities around South Africa. Most universities are connected via either 100 Gbps, 10 Gbps, or 1 Gbps links across the land, supplied by telecommunication companies such as Telkom, Neotel, and DFA. There are multiple 10 Gbps undersea cables supplied by West Africa Cable System (WACS), SEACOM, and Eastern Africa Submarine Cable System (EASSy) that link universities via London and Amsterdam [6]. Universities within close proximity are linked wirelessly or share a metropolitan network.

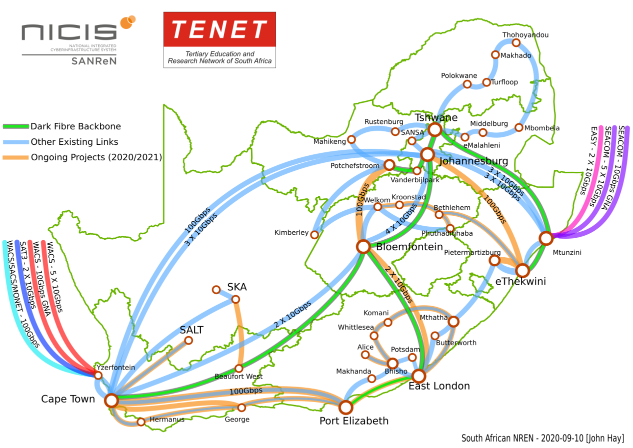

Fig. 1. SANReN backbone map [6].

B. Active Measurements

Active network measurements consists of injecting packets to assess network performance in terms of delay, packet loss and bandwidth capacity [9], [10], [11], [12]. Our study carries out the active measurements using existing tools, leveraging the advantages of both Speedchecker [13] and perfSONAR [14] to target specific source and destination combinations.

PerfSONAR is a global network measurement framework that operates within NRENs. PerfSONAR has dedicated tests for delay (ping), page load time, traceroute, and throughput. PerfSONAR includes tools such as Bandwidth Test Controller (BWCTL) [15], One-Way Ping (OWAMP) [16], and Network Diagnostic Tool (NDT) [17], and these allow perfSONAR to conduct tests for specific types of traffic such as bulk data transfer and video transfer. A *big data* study done by Zurawski et al. [18] shows the potential of perfSONAR in applying it to determine the source of congestion between Brown University (in the United States) and the Large Hadron Collider at the European Organization for Nuclear Research (CERN). Another project making use of perfSONAR for network monitoring is the US ATLAS [19], [20].

Speedchecker [13] is a global network measurement in which software probes are installed on end-user devices, including home routers, PCs, and wireless devices. The Speedchecker platform exposes an API that allows one to issue measurements such as ping, traceroute, and HTTP GET. The measurements can be launched from specific locations (countries and cities), and this allows measurement of internet quality of service from the vantage point of those locations. Recent studies [21], [22] have used Speedchecker to study Africa's internet infrastructure. Chavula et al. [22] studied the effects of cross-border infrastructure and logical interconnections on intra-country and cross-border latency in Africa. They conducted Speedchecker ICMP pings between countries using Speedchecker and applied a community detection algorithm to group countries based on round trip times (RTTs) between countries. The study was expanded in Formoso et al. [21] who carried out a large-scale mapping of inter-country delays in Africa. Their analysis further revealed clusters of countries with lower delay interconnectivity among themselves. Arnold et al. [23] conducted a study using Speedchecker to measure the impact of a private WAN on cloud performance.

III. Methodology

We used two platforms to conduct active performance measurements: Speedchecker [13] and perfSONAR [14]. We undertook a 2-week active measurements study, runnting test both from within SANReN (internal performance) and from outside SANReN (external performance).

A. Network Delay and Page Load Time

Network delay is one of the key metrics used to assess network performance because it directly impacts user experience. In this study, we conduct delay (ping) tests to various zero-rated websites[1] that are hosted within SANReN. We also conduct Page load time (PLT) test to measure the total time it takes to load a page from when the user enters the URL in a browser. PLT is a key metric in finding the QoS of websites because it shows the network performance when actual data is requested by an end-user [24]. We load the same websites from different cities, both within and from outside SANReN. This is done to observe the performance from different locations, and compare performance from outside SANReN and from within [25].

We also conduct traceroute tests to the websites and use the results to explain the delays and PLTs. We attempt to find gaps in the network and identify congestion prone paths. The traceroute also helps to identify if the routes that are used are circuitous. The dependent variable for these tests is the number of IP hops it takes to travel from each source to the specified destination. We only consider successful traceroutes as being the ones that reach the target websites' ASNs. We use MaxMind's ASN database [26] to lookup the ASN of each target website, as well as the last IP hop reached by a traceroute.

B. Throughput

Throughput tells us how fast the network transfers data between two points [27], [28]. For external tests, we calculate throughput from the page load time tests by using the total number of bytes downloaded for each test. We define throughput for these tests as the number of total downloaded bytes (TDB) divided by the result of total page load time minus time-to-first-byte (TTFB), i.e.: $Throughput = \frac{TDB}{PLT-TTFB}$. For the internal tests, we use Iperf3 [29] to measure the throughput.

We run tests from Cape Town, Johannesburg, Durban, Port Elizabeth, and Pretoria to websites at the universities as listed in Table I. The universities were chosen because they are seven of the biggest universities in South Africa and are spread out across the country. The websites that we used as destinations are zero-rated websites from each of the universities, and their locations were checked using IP-API [30] and IPWHOIS [31].

TABLE I
DESTINATION UNIVERSITIES USED IN THIS STUDY.

Abbreviation	Name	Location
UCT	University of Cape Town	Cape Town
UWC	University of the Western Cape	Cape Town
WITS	University of the Witwatersrand, Johannesburg	Johannesburg
UJ	University of Johannesburg	Johannesburg
DUT	Durban University of Technology	Durban
UNISA	University of South Africa	Pretoria
NMU	Nelson Mandela University	Port Elizabeth

We ran daily tests for two weeks between each city and university. In order to comply with Speedchecker's fair-usage policy, we limited our tests to 14 per day per destination

[1]South African Zero-rated Content: https://docs.google.com/spreadsheets/d/1d3HciexwZQndqHULEILwk_g4F1RRwUMlQjVVPc80BsI/edit?usp=sharing

university. Tests were conducted in the morning (9AM), afternoon (3PM), and night (9PM) to get a measure of the network performance.

IV. Results

We group our active measurement results by experiment type and split them into external Speedchecker experiments conducted from outside of SANReN, and internal perfSONAR experiments conducted from within SANReN. We present the data as box plots and show the distribution of data for each city and each university. We use scatter plots to display the relationship between page load time and delay. We also show the number of IP hops taken by the traceroute to reach each destination from the source cities. After presenting the internal and external results, we present a comparison thereof.

A. Packet Delay Results

1) Packet Delay from Outside of SANReN: Figure 2 presents a box plot of the delay from the five cities that were used as sources for testing. The cities with the lowest median delays to universities are Johannesburg with a median packet delay of 29ms, and Pretoria with a median delay of 35ms. Durban had a median delay of 47ms, Cape Town: 48ms, and PE: 53ms. In terms of the destination websites, WITS (which is within Johannesburg) had the lowest median delay: 37ms, followed by UNISA (in Pretoria) at 37.5ms. NMU, which is located in Port Elizabeth, had the highest median delay of 57ms, followed by UCT and UWC with 46ms and 43ms respectively. Both UCT and UWC are located in Cape Town.

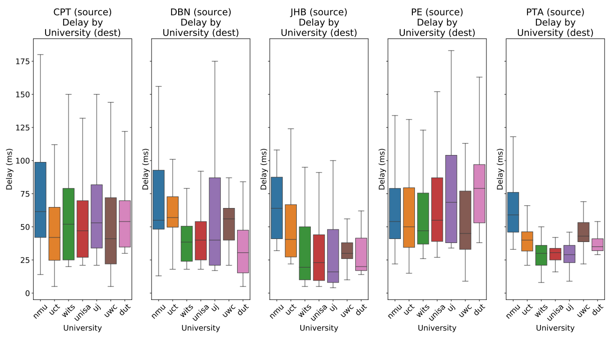

Fig. 2. External delay by destination university.

Overall, the delays appear to be in line with the distances between the universities and cities. For example, the delay from Durban to Cape Town universities was higher than the delay from Durban to universities in Johannesburg, Pretoria, and Durban. The median delay from Durban to UWC is 56 ms and Durban to UCT is 57 ms. Delay between Durban and the universities in Johannesburg, Pretoria and Durban is lower, with Durban to UJ: 40 ms, Durban to UNISA: 40 ms, Durban to WITS: 38.5 ms, and Durban to DUT: 30.5 ms.

2) Packet Delay from within SANReN: Results from the internal delay tests are presented in Figure 3. Here again we see that the delays follow the distance pattern. For example, the median delay from Cape Town to DUT is 27.05 ms, and from Durban to UCT and UWC, the median delays were 26.82ms and 27.35ms respectively.

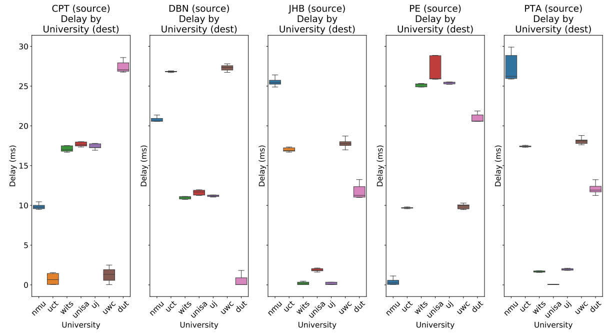

Fig. 3. Internal delay by destination university.

There is higher delay from Port Elizabeth (PE) to UJ and WITS, with median delays of 25.47 ms and 25.26 ms respectively. We also observe higher delays from Johannesburg to NMU (25.42ms). Similarly, we see relatively high delays between Pretoria to NMU (Port Elizabeth) of 26.24ms. In comparison, we see relatively lower median delays of 10ms between Cape Town and PE (and vice-versa).

3) External vs Internal Packet Delay: We combined and compared the results from the external and internal delay experiments. Figure 4 shows the overall delay to each university. We observe, as expected, that the internal tests have lower delays when targeting each of the universities. We also observe that NMU has the highest median delay from both external and internal sources, while WITS has the lowest median delay from both external and internal sources. UJ has the biggest IQR (53) and the highest value for the maximum delay from external sources (154 ms). The biggest difference between external and internal median is experienced by NMU with the difference being 36.4 ms (57 ms - 20.6 ms).

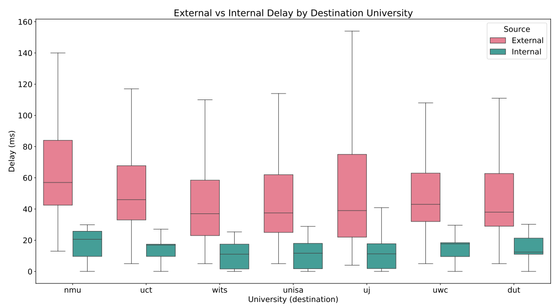

Fig. 4. External vs internal delay by destination university.

B. Page Load Delay Results

1) Page Load Delay from outside SANReN: Results from the page load time tests conducted by Speedchecker (external vantage points) to SANReN-based websites are presented below. In Figure 5, we observe that results are similar for four of the source cities, with again PE being the outlier. PE experiences higher PLTs for SANReN websites than the rest of the cities, with a median PLT of 1727 ms. In contrast, Johannesburg had the lowest median PLT of 315ms, followed by Durban with 472ms, Cape Town with 496ms, and Pretoria with 534ms.

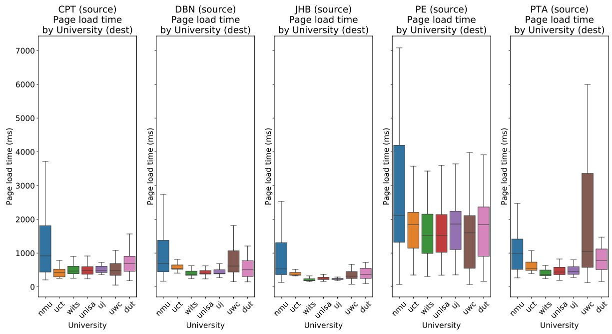

Fig. 5. External page load times by destination university.

In terms of target websites, NMU (again Port Elizabeth) has the highest PLTs with an overall median of 899ms from all cities. In comparison, DUT, UWC, and UCT have median PLTs of 594.5ms, 527ms, and 516ms respectively. WITS, UNISA, and UJ had the lowest overall median PLTs of 387ms, 404ms, and 426ms respectively. When focusing on specific pairs of source city and target university, we see that although NMU resides in Port Elizabeth, the highest median PLT of any source and target pair is experienced when trying to reach NMU from Port Elizabeth, with 2112.91 ms. Moreover, PE has an overall IQR of 1244.5, showing that the PLTs are inconsistent to all the universities targeted. For comparison, Cape Town has an IQR of 322, Durban: 312, Johannesburg: 193, and Pretoria 526.

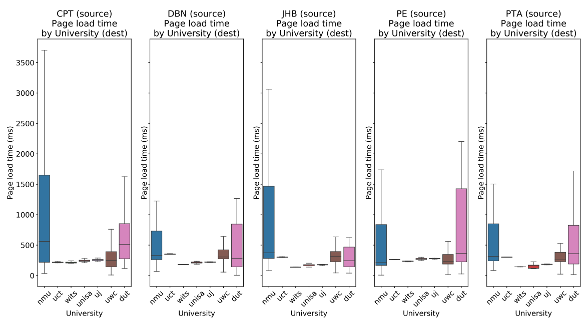

Fig. 6. Internal page load time by destination university.

2) Page Load Delay from within SANReN: Figure 6 presents the results for page load times from within SANReN. We see that NMU and DUT have the highest median PLTs across all the source cities, with NMU having a PLT of 329.75 ms and DUT having a PLT of 341.82 ms. The rest of the universities experience lower PLTs, with UCT having an overall median PLT of 300.8 ms, UWC: 275.48 ms, UJ: 223.11 ms, UNISA: 215.68, and WITS: 179.55 ms. The next highest median PLT to DUT is 362.75 from Port Elizabeth.

3) External vs Internal Page Load Delay: We combine the results from our external and internal page load time experiments and present them in Figure 7. We observe that parts of the external and internal quartiles for NMU, DUT, and UWC overlapping. We see high page load times to universities even from within the cities in which they are located, indicating possibility of congestion in the paths used to transfer data.

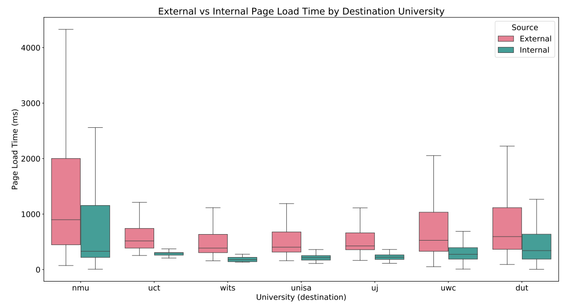

Fig. 7. External vs internal page load time by destination university.

More specifically, we see a difference of 569.25 ms when comparing the external and internal median PLTs to NMU, a difference of 252.68 ms when comparing DUT's external and internal PLTs, and a difference of 251.52 ms when comparing UWC. We observe a difference of 215.2 ms between UCT's median PLTs, 207.45 ms between WITS', 188.32 ms between UNISA's, and 202.89 ms between UJ's median PLTs. With the exception of WITS, all the universities have a difference of over 200 ms between their external and internal PLTs.

4) External and Internal Page Load Delay vs Packet Delay: We combined and compared the results from our external and internal page load time experiments. Figure 8 shows the overall results compared to one another. We notice that high delays are common when using external sources, with 20.53% of the data points having delays higher than 75 ms. We also observe that the page load times are similar for a large number of tests, with 93% of internal tests having PLTs under 1000 ms, whereas only 77.42% of external tests have PLTs under 1000 ms. This suggests that delay from external sources could be improved, and that throughput in the network is sufficient as page load times from inside the network are similar to that of external sources.

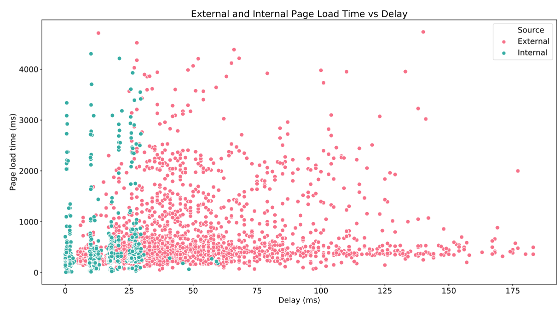

Fig. 8. External and internal page load time vs delay.

C. Traceroute Results

We conducted traceroute tests from the source cities to each target website, and we make the following observations. The highest median number of hops among the target universities when using PE as the source is 17 from PE to NMU. We observe that the overall median number of hops to universities from PE is 14. We observe that from our external experiments, DUT is the university with the biggest difference between external and internal median values, with external tests taking 14 hops and internal tests taking 6 hops. NMU's internal and external results have a big difference in their median values as well, with the internal and external tests taking 8 and 15 hops respectively. PE is the only city where the university with the highest median number of hops is located in the source city itself. Figure 9 presents a comparison of number of hops to each university.

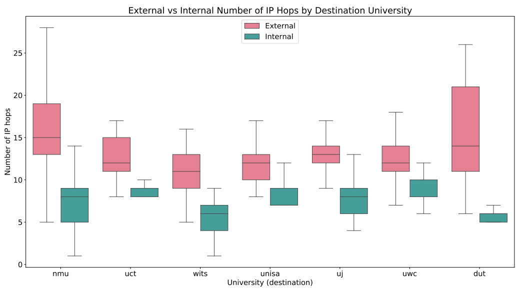

Fig. 9. Number of IP hops for traceroute by destination university — external vs internal sources.

We observe that, for the external tests, the highest number of hops of any source and target pair is 17 from PE to NMU. For the internal tests, the highest number of hops for a source and target pair is 11 from PE to UNISA and from Pretoria to UWC.

D. Throughput Results

It has to be noted that the internal (perfSONAR) throughput measurements reflect the capacity of the core SANReN infrastructure, whereas the external results reflect the throughput when SANReN resources are accessed from outside the SANReN. Figure 10 shows the comparison between the sets of measurements. For throughput measurements conducted from outside SANReN (using Speedchecker), we observe Johannesburg has the highest overall median throughput with a value of 0.01404Gbps, with the highest values being 0.02206 Gbps from Johannesburg to DUT. PE experiences the lowest throughput with an overall median value of 0.00234, with the lowest being from PE to UJ at 0.00104Gbps.

Internal throughput tests conducted using perfSONAR from within SANReN show inter-university median throughput values between 4.91Gbpss and 8.005 Gbps. The lowest throughput was from Durban to UCT at 4.91Gbps. However, Durban experienced the highest overall median throughput of 8.005 Gbps, followed by Pretoria with 7.64 Gbps, Johannesburg with 7.55 Gbps, and PE with 7.53 Gbps.

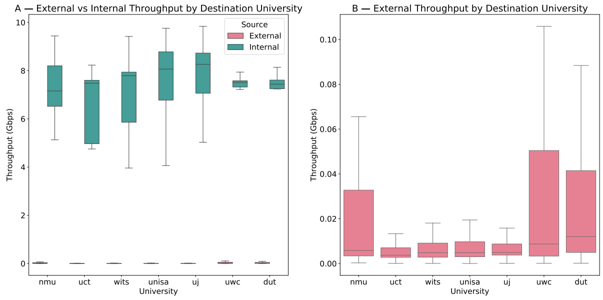

Fig. 10. External vs internal throughput by destination university.

V. Discussion

This study has focused on evaluating network quality of service (QoS) when accessing content hosted in SANReN. We conducted active measurements to study disparities between internal and external access to SANReN, especially when accessing zero-rated educational websites. A key metrics for our comparison was page load time, which is used to represent user's quality of experience when accessing the network. Our results show the difference in the nature of network paths followed by packets from source to destination, and that this is an important factor differentiating delay and page load times between internal and external access. We observe that other ISPs take more circuitous routes to different universities in the SANReN, with 11 as the median number of hops from other ISPs (South Africa based) to SANReN. In comparison, internal SANReN paths have a median is hop count of 6, which is just about 1/3 of number of hops for external access. This indicates sub-optimal interconnection between SANReN and other ISPs in South Africa. This is likely to be a result of the interconnections happening in only one or two locations, and thus traffic being forced to follow circuitous routes through these locations.

The observed performance differences also appear to be different depending on location. For example, the delay to reach a website hosted by NMU from outside of SANReN (57ms) is 35.71% higher compared to the overall median for reaching universities from outside of SANReN (42ms). For the external tests, the overall median delay from PE to the universities tested is 53ms, which is 26.19% higher than the median of all the source cities combined (42ms). For internal delays, PE's delays are 107.59% higher than the overall median. We also see that the delay when targeting NMU is 71.81% higher than the overall median. These high delays seem to be due to circuitous routing, as traceroute analysis shows traffic from Port Elizabeth to Johannesburg travelling via Cape Town, which means that the paths to Johannesburg via East London and Bloemfontein are ignored. Our results also show that PE has higher page load times. The external results when accessing NMU produced a median page load time of 1727 ms, compared to the overall median from cities at 491ms.

The impact of this sub-optimal interconnection is also observed in the differences in median latencies measured from within and from outside SANReN. We observe median latency difference of up to 36 ms between measurements taken from external and internal sources.

We observe a big difference between page load times when accessing webservers from within SANReN compared to accessing them from other ISPs, with the differences being over 500 ms. We observe that the page load times are in general higher for external sources, with up to 23% of external tests having PLTs of over 1000 ms, whereas only 7% of internal tests had PLTs over 1000 ms. This suggests that delay from external sources could be improved through better interconnection with other ISPs.

VI. Conclusion

In this study, we focused on evaluating the internal and external performance differences for SANReN by using active measurements. Our measurements showed a big difference between delays experienced when accessing SANReN webservers from within the network compared to accessing them from other ISPs. Our analysis shows that the high delays and higher page load times experienced outside the SANReN are caused by traffic flowing via circuitous routes, using Cape Town as an interconnection point. This is problematic considering that Cape Town is located far from the rest of the cities in the network, and thus, introduces delays.

For future work, we will expand the number of cities and universities tested. We will also explore and experiment with traffic engineering solutions that could be employed in SANReN.

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