Analysis of internet latency : the reunion island case

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ABSTRACT

Internet connectivity is not fairly distributed around the world, in particular for islands or isolated areas. An example, the internet connection of Reunion Island is mainly based on links to France located about $10,000$kms away. This situation generated a particular connection which induced high delays and degraded internet service. Typically, the minimal delay between France and Reunion Island is around $180ms$. In this paper, we investigate the performance of the Internet connection by analyzing delay and path properties from and to Reunion Island mapped to continent IPv4 spread. With two experiments, based on 27 local probes and $7,860,000$ traces, we propose a correlation analyzing between delay and path properties. One particular finding is that the delay is more dependent of the chosen path as the geographical distance, compared to models in literature.

Categories and Subject Descriptors

C.2.3 [**Computer-Communication Networks**]: Network Operations—*Network monitoring*

General Terms

Measurement, Performance

Keywords

Active measurement, RTT, End-to-end delay

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1. INTRODUCTION

The Internet was first designed to carry applications data that had no real time constraint and limited user interaction. It now differs greatly as several applications are based on users' interactions and timely content delivery has become a critical parameter. As the internet connectivity is expected to improve, the user experience of such applications was also expected to improve. Counter intuitively, it has been shown that the internet end-to-end connectivity actually got worse [16, 8] within the last decade due to changes in the internet path and bufferbloat issues that further impact TCP's congestion control [12]. Beyond bandwidth, low latency is required for these applications. This is considered as an important issue on which the RITE project is now focusing. Their members recently wrote a survey [7] that describes the factors of latency and proposes some solutions to reduce it. It includes exploiting path diversity to select the shortest path and load-balancing to prevent congestion. They are only applicable if the internet topology is highly meshed.

However, there are some geographic areas where the topology is poorly meshed or even connected to the Internet with a single cable which may increase the risk of outages and congestion. We investigate the main causes of delays in such areas and focuses on the case of Reunion Island. In this article, term latency referrers to *Round Trip Time* (RTT). Among the known latency factors we focus on the geographic distance and path properties. We collected a total of $7,860,000$ *traceroute* traces through two measurement campaigns to study the routes from (resp. toward) Reunion Island using a set of 27 local probes (resp. the atlas [19] measurement platform).

The analysis of internet routes from and toward Reunion Island revealed high path distortion i.e. routing politics is far from the shortest physical path available as 99% of the traffic is routed through a country that is $10,000$km away from Reunion Island. We show evidence that more efficient paths exist but they are rarely used. We also studied the delay as a function of the geographic distance. Our most interesting finding is that routing politics have such a high impact that the delay is inversely proportional to the geographic distance between the source and destination. The remainder of this paper is organized as follows. Section 2 describes the topology of the submarine cables connecting Reunion Island to the Internet as well at the *Internet eXchange Point* (IXP). It also reviews the findings of the previous study related to the case of Reunion Island. Section 3 presents our measurement setup deployed to measure path and latency. The results are analyzed in section 5. Section 6 reviews the related work.

2. DESCRIPTION

As seen on Figure 1, there exist two cables that connect Reunion Island to the Internet. The SAFE cable spans from Asia (India and Malaysia) to South Africa. The SAFE is extended by the SAT3-WASC cable which connects countries in West Africa to Europe. The LION and LION 2 cables connect the lower part of the Indian Ocean to a range of submarine cables in East Africa. This means that Reunion Island is connected to four landing points namely West Africa and Europe, East Africa and Asia. There is also an IXP [2] in Reunion Island as well as in the nearby Mauritius Island. As a result, it should be enough to experience a fairly good connection toward theses areas and as well as the entire Internet.

However, most of the residents of Reunion Island experience a slow internet connection with frequent outages[1]. In 2012, the author of [4] compared the internet latency observed from Reunion Island and Paris. Figure 2 represents the probability density function (PDF) of the RTT. The RTT was evaluated with the `ping` command on a sample of IPv4 addresses distributed over the world. The two curves have the same trend with a $200ms$ shift. This latency difference suggests that Reunion Island traffic is tunneled or routed toward exit points that add $200ms$ to the RTT. This is probably one of the main reasons for the sensation of slowness. In [22], Vergoz studied the internet connectivity of the local ISP and found high performance variation between the ISP. To the best of our knowledge, [4] and [22] are the only attempts to characterize the internet connectivity of Reunion Island. In this work we aim to find the cause of the poor user experience as well as the shift in the delay distribution.

[1]According to the ISP, most of these outages are not induced by the local infrastructure.

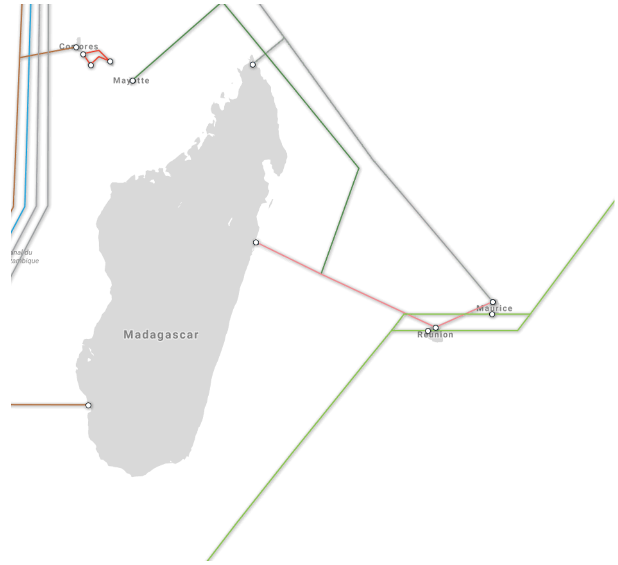

Figure 1: Mascarene Islands submarine cables.

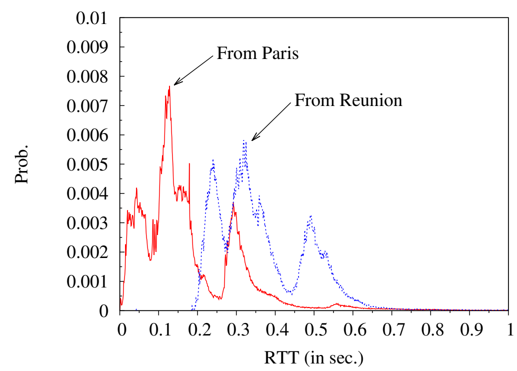

Figure 2: Comparison between Paris and Reunion Island access.

3. MEASUREMENT OPERATIONS

We chose to study the internet connectivity of Reunion Island according to the delay and the network paths. To do so we collected *traceroute* traces between Reunion Island and $10,000$ destinations distributed worldwide (section 3.1). As the internet routes are known to be asymmetric, we also performed *traceroute* executed from worldwide distributed probes toward destinations located in Reunion Island (section 3.2).

3.1 From Reunion Island

Our active measurements made from Reunion Island involve 27 raspberry pi [1] probes distributed over the 5 local ISPs : 13 hosted at Orange, 4 at SFR, 5 at ZEOP, 2 at RENATER, and 3 at CanalBox. Our trace includes measurements performed from July 3^{rd} 2016 to August 3^{rd} 2016. We created a random set of $1,000,000$ public IPv4 addresses among which only $83,850$ responded to

ICMP Echo request.

This new set was geo-referenced by country. The second column of Table 1 shows the geographical distribution of these IPv4 addresses and the third column shows the actual distribution of the IPv4 addresses provided by the website `https://www.countryipblocks.net`[2]. The two distributions are distant from one another. To respect the actual representation, we have decided to use the second one. Among these $83,850$ IPv4 addresses, we selected a subset of $10,000$ addresses that fits the actual geographical distribution. Each of our

Table 1: Geographical distribution of our $83,850$ randomly obtained IPv4 addresses and the actual geographical distribution provided by the *CountryIpBlocks* website.

Continent	Random	CountryIPBlocks
Africa (AF)	0.95%	2.59%
Asia (AS)	32.96%	23.34%
Europe (EU)	28.99%	20.7%
North America (NA)	8.89%	47.55%
Oceanie (OC)	0.7%	1.55%
South America (SA)	6.30%	4.27%
Other (bogons)	21.19%	0.0%

local probes was configured to perform a *traceroute* toward all of the IP of our data set within one day. A probe started a new measurement every 8.64s which lasted for an average of 28s. The number of *traceroutes* running simultaneously has been limited to 4, resulting in a maximum bit-rate of $5,06Kb/s$, which is negligible compared to the available bandwidth which is at least of $128.33Kb/s$ (see [22]). To further prevent the congestion induced by our measurements on the destination, the sequence of destinations to visit was randomized on each probe. Our final data set contains a total of $7,560,000$ *traceroute* traces.

3.2 Towards Reunion Island

Our second data set was collected with the aim of determining if asymmetrical path exists toward Reunion Island. Asymmetric routes are frequent in the Internet. They are mainly created due to routing policies and traffic engineering. Mechanisms such as load balancing, *hot potato routing*[3] or *BGP* convergence can lead to such an asymmetry. To verify the existence of asymmetric paths, we used the RIPE NCC Atlas platform [19]. It is a global network of probes that measures internet connectivity and reachability. Atlas has around $10,000$ probes distributed over the world. For our experimentation, and in agreement with the General Condition of Uses (GCU) of the platform, we selected the maximum of probes authorized $(1,000)$. This selection was made so as to keep the same geographic distribution as the previous experiment (see Table 1, column 3). The Atlas probes would reach ten of our raspberry pi deployed over Reunion Island. This set of raspberry-pi covers all local ISPs. Note that this distribution results from the Atlas credit limitation on the number of source and destination pairs. As we found no difference in the characteristics of the internet path of the raspberry-pi located in a same local ISP, it was more important to devote the Atlas credits on the increase of the source diversity instead of the destination diversity. This platform was in use during the same time frame as the first experiment. The raspberry pi were connected to a *setup box* whose IP address might periodically change. The raspberry-pi used *DynDNS* to remain reachable by the remote atlas probes.

To be sure that we would not induce congestion on our raspberry pi, we divided our experimentation in $10,000$ smaller measurements. One measurement consists in one probe joining one destination. Between two experimentations, we created a delay of 8.64s to make sure that all our experimentations were equally distributed on each day. Our final data set includes the results of $300,000$ *traceroute*.

3.3 Summary

Table 2 summarizes Section 3. All the data are available on the following website `http://t.univ-reunion.fr/167`

Table 2: Summary of data-set characteristics

	From	Towards
Probes	Raspberry Pi	Atlas RIPE NCC
Destination	$10,000$ IP	10 raspberry-pi
Sources	27 raspberry-pi	$1,000$ Atlas probes
Tool	Paris-traceroute	
Raw Data	$7,560,000$	$300,000$
Sanitized Data	$1,015,180$	$38,714$

4. TOOLS INVOLVED

4.1 Traceroute

The original *traceroute* [18] developed by Malkin is known to produce inconsistent results in the context of load-balancing.

[2]The distribution was retrieved from the *countryipblocks* website on the 4^{th} of May 2016

[3]`http://t.univ-reunion.fr/168`

To circumvent this issue, *Paris-Traceroute* was created by the authors of [5]. It can send TCP packets instead of ICMP. In [23], the authors compared the ICMP and TCP techniques. While they found that in most of the cases the results are similar, when the ratio between the mean RTT and the minimum RTT tends to be large (beyond 20), the results of the TCP variant tend to be less stable.For this reason, we use the ICMP version of *Paris-Traceroute* protocol in our experiment.

4.2 Geo-localization

The coordinate of the IPv4 address were obtained with the database of *RIPE NCC*. We used their API [3] to retrieve information (country, latitude, longitude and AS) about each the $83,850$ IPv4 addresses and each of the routers found during the *traceroute* measurements.

We found out that some of the IPs were not properly geo-localized. We inferred an approximate geo-localization of the node according to the minimum delay from several probes distributed worldwide. An IP was considered to be part of the same continent as the probes with which it had the closest delay.

4.3 Data sanitization

Our two measurement campaigns lead to a raw data set of $7,860,000$ *traceroute* traces. After sanitization the data set shrinks to $1,053,894$ *traceroute* traces. To obtain this data set, we removed traces that met one of the following criteria :

- the destination has not been reached;
- 3 following stars are present in the traces;
- the presence of '!N' (network unreachable) or '!H' (host unreachable) marks due to *Paris-Traceroute*;
- the presence of IP whose countries are not present in the *RIPE NCC* database; This criterium was only applied for the geographic path analysis performed in section 5.4.

5. RESULTS

This section analyzes the collected data and shows the characteristics of internet connection in Reunion Island through delay and path properties. The accuracy of the results is dependent on the results of the geo-localization of the IP.

5.1 Path length and geographical distance

In our data set we found a mean path length of 17.11 hops which is close to 15.57 hops, the mean value for the whole Internet described in [17]. A much more interesting behavior is that we found no correlation between the geographical distance and the path length. Figures 3 and 4 plot the distribution of the path length as function of the distance of the end hosts. The area drawn by the ellipses contain 95% of the samples that belong to a given continent. The error bars represent the mean and standard deviation of the path length for each continent.

The figures show that the path does not increase with geographical distance. Even the paths toward local and regional destinations are as long as the most remote ones. The figures also show $PL(d) = \alpha \times d + \beta$ the fit of the linear function of the path length as a function of the distance. We found the value of alpha to be 1.58×10^{-5}. This clearly shows that the geographical distance does not affect the path length.

5.2 Impact of path length on Round Trip Time

Figures 5 and 6 plot the distribution of the RTT as a function of the path length as well as the median and the density functions. It also plots the probability density function of the path length.

The figures show that for each added node, the delay increases. The figures also plot $D(d) = \alpha \times d + \beta$ the fit of the linear function of the delay as a function of the path length. The obtained value of α is 6.22 which means that for each additional hop, we can expect an increase of $6.22ms$ in the RTT. This behavior doesn't seem to exhibit any property specific to the context of Reunion Island.

5.3 Correlation between delay and geographical distance

In [14], Krajsa et Al. found that geographical distance has an impact on the value of RTT. They determined that a linear function with a slope of 0.0128 allows to predict the internet RTT for a given geographic distance (see Table 3). They evaluated the accuracy of their prediction with the coefficient of determination R^2 which had a value of 0.9794. In this section, we study the relevance of this linear model in the context of Reunion Island.

We referred to the results obtained by this model as the *Expected Internet RTT for a given geographical Distance* (EIRD). But to the best of our knowledge, this is the only study we can compare with.

As the *EIRD* model of [14] is not accurate in the context of Reunion Island, we fitted $ER(d) = \alpha \times t + \beta$ the linear function of the distance as a function of the delay. The coefficients are shown in Table 3.

Figure 7 (resp. fig 8) plots $ER(d)$ for the case *From* (resp. *To*) and *EIRD*. In addition to the figures, we have represented the 5, 10, 25, 75, 90 and 95 percentiles. The points on the error bars represent the 50 percentile. It also plots the probability density function of the geographic distance.

The coefficient of determination between the fitted $ER(d)$ and our data indicate that this isn't an accurate prediction model. However, the negative slope indicates

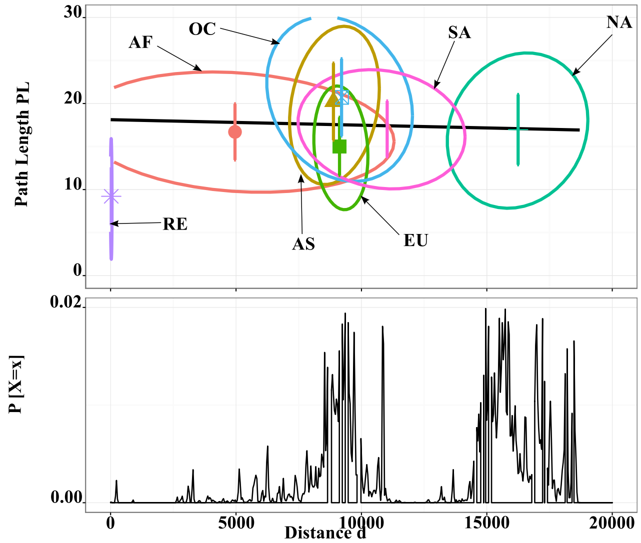

Figure 3: Geographical distance and path length from Reunion Island. The ellipses contain 95% of the samples that belong to a given continent.The errors bars represent the mean and standard deviation of the path length for each continent.

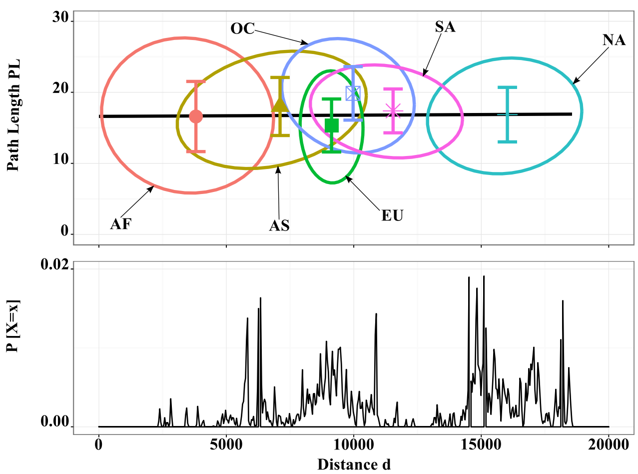

Figure 4: Geographical distance and path length toward Reunion Island : Same as Figure 3.

that the closer a destination is, the higher the expected delay. This is the exact opposite of what EIRD and common sense suggest for the Internet.

5.4 Path Analysis

While there exist direct links toward the near-by countries and continents, this doesn't reflect on the results from 5.1 and 5.3. It suggests that the routes used by the ISP are far from optimal. To investigate this issue, this section studies the routes used to reach the various destinations.

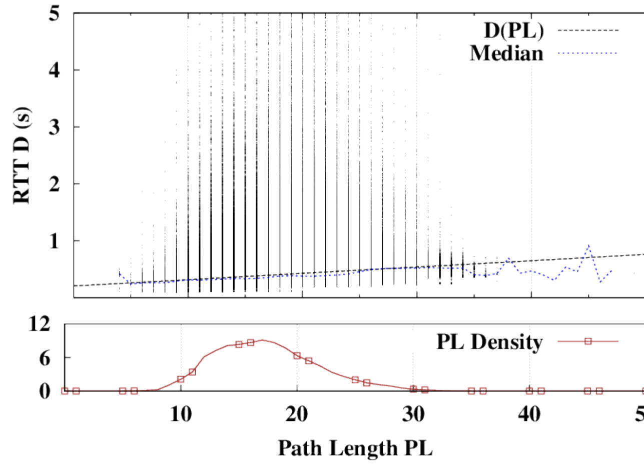

Figure 5: Dependence of the RTT and the path length (From Reunion).

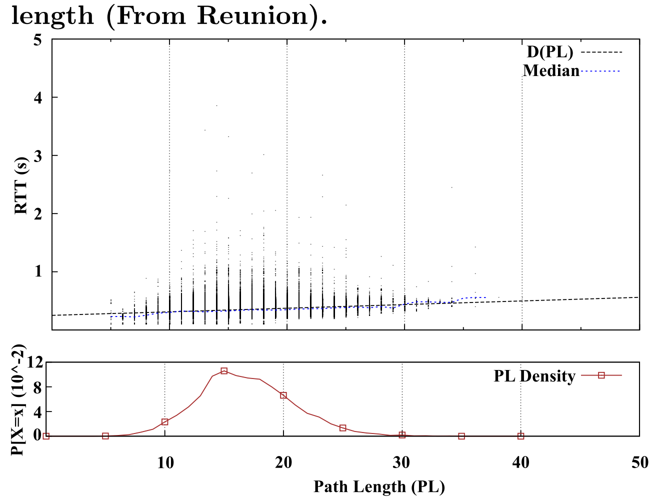

Figure 6: Dependence of the RTT and the path length (toward Reunion).

From our traces, we extracted the country of the first router of the path located outside Reunion Island. The results are plotted on Figure 9. The width of the link is proportional to the proportion of the total samples that goes through this country. We are aware that while a direct path to the Asian continent exists, but zero percent of the traffic destined to this country goes through this direct path. Most of it is routed through France. The same observation holds for East and West Africa. In Figure 10 we show the country of the last router not located in Reunion Island for the destination located in Reunion Island with sources distributed worldwide. Similarly to the previous case, the major part of the traffic is coming from France. We can notice that a very small fraction of the traffic destined to Reunion Island goes through the direct path from the Asian continent or South Africa.

Table 3: Dependence of RTT on geographical distances Formula.

Experimentation	Equation d(t)	R^2
EIRD	$y = 0.0128 \times x$	0.9794
From Reunion	$y = -62.92 * 10^{-4} \times x + 477.6$	$16,80 * 10^{-3}$
To Reunion	$y = -29.34 * 10^{-5} \times x + 358.1$	$14.81 * 10^{-5}$

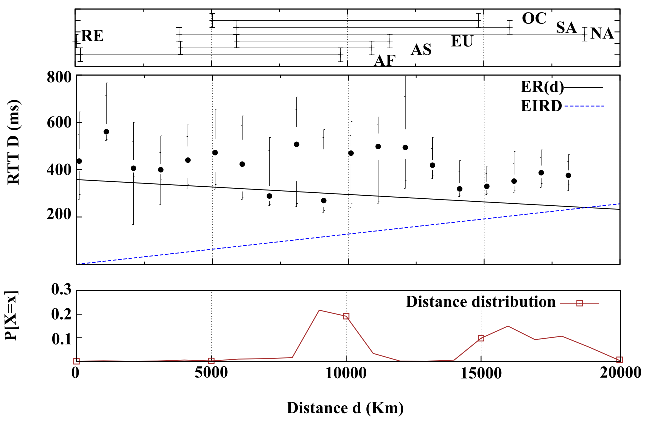

Figure 7: Dependence of RTT on geographical equation (From Reunion)

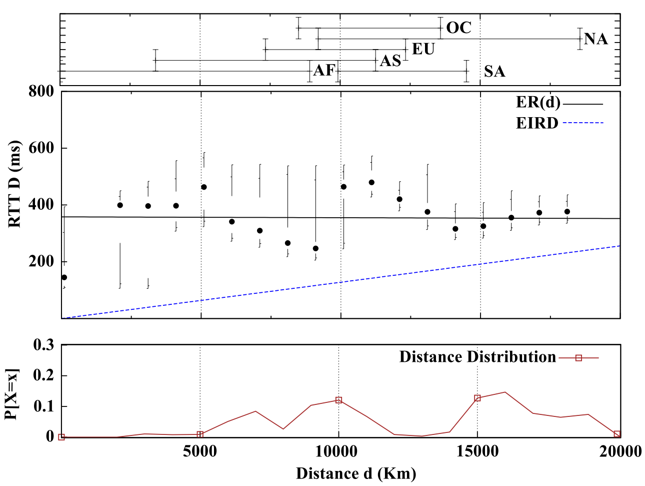

Figure 8: Dependence of RTT on geographical equation (Toward Reunion)

The presence of direct links between Reunion Island and countries more distant countries, such as the USA or Paraguay, without a direct cable between them, are symptomatic of missing information or misled configuration, as stated in the following explanations :

1. The peering agreement has been made with a country before joining the submarine cable. For example, on Figure 10, we can notice a link between Paraguay and Reunion Island. The measurement 4178740 of Atlas [4] shows the existence of a direct link between Paraguay and Reunion Island.
2. The utilization of the set of ISP's IPs allocated by the different organizations. For example, some ISP based in France or Guadeloupe used their IP in Reunion Island, like RENATER with the following IP '`194.167.142.21`'.
3. *MultiProtocol Label Switch* (MPLS) can be used to generate this connection. It is possible for some MPLS configuration to lead to false router-level links in maps derived from raw data. A classification of MPLS tunnel into four classes has been purposed by [10]. In these categories, we can highlight the fourth category, called *invisible*.

These explanations are not the only existing ones, but the most frequently met. In our case, invisible MPLS marks could be the most predominant reason. These marks are due to the split of the cable capacities with numerous ISP and the connection in different points to regenerate the signal.

Despite the presence of two submarine cables to access the Internet, Reunion Island is a slave of France. All our outbound traffic needs to pass through to the mainland France before reaching its final destination. The presence of a local IXP since 2004 has permitted to keep the local traffic inside the island. But with this ISP's politics and a minimal delay of $180ms$ to exit the cable, Reunion Island is penalized in terms of delay, and potentially in terms of Quality of Service (QoS) and Quality of Experiment (QoE). The figure is representative of Reunion Island connectivity. All traffic pass through by France before joining other countries.

The study of [14] showed that the delay increases with the distance. In our results, we have showed that the SAFE cable has numerous points of connection with different countries, but in our case France is the one mainly used. A future work could study the advantage for Reunion Island traffic if the ISP was to use all the exit points that exist along the cable.

6. RELATED WORK

Recent studies about routing rules show their impact on the delay. In [24], the authors work on the notion of *Triangle Inequality Violations* (TIV) and its impact on the delay. This notion said that the sum of delay between two nodes of a triangle is necessarily higher as the delay between one of the two previous nodes to the last one. If this rule is not respected, it is the case of TIV. One particular TIV is called *Boomerang routing*. A recent study of this phenomenon [20] as shown

[4] `https://atlas.ripe.net/measurements/4178740/`

Figure 9: Internet path from Reunion Island.

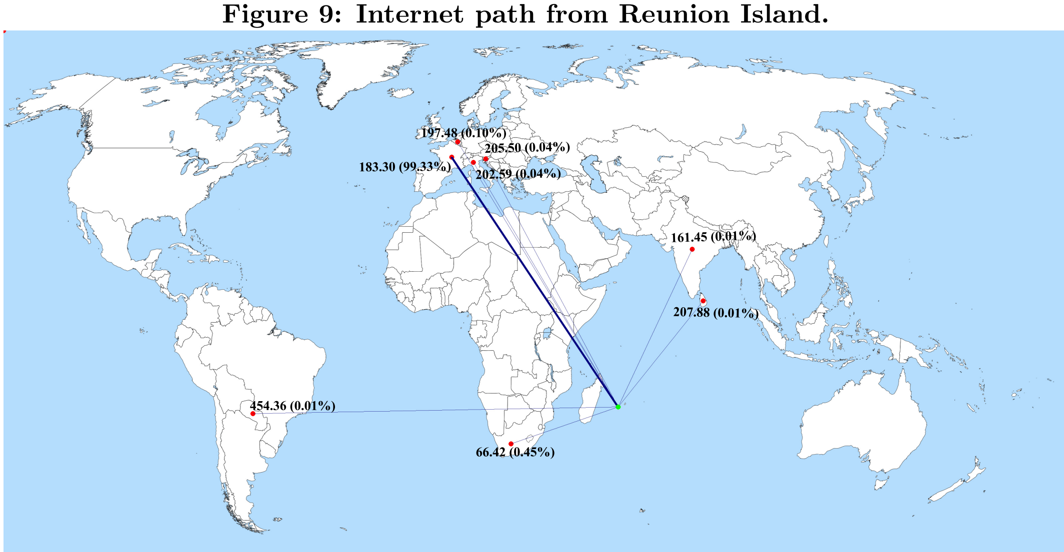

Figure 10: Internet path toward Reunion Island.

that many paths between Canadian ISP's take indirect paths through the USA. This sort of connection is frequent in Africa. For [13] the main reason for long delay in the region is due to peering agreements. Despite the numerous IXPs in South Africa or West Africa, some ISPs preferred to inter-connect in an European or Asian IXP. To bypass this rule, AFNIC and private companies, like Google, Akamai, etc. have made some investments in the African continent. In [11], authors show that new infrastructures have not been correctly used by the African ISP.

These needed to join an IXP based outside of the African continent, and that dependence on submarine cable. [9] worked on the impact of failures in submarine cables, in particularly on the SEA-ME-WE-4. Adding a new submarine cable or increasing their bandwidth will not reduce latency [21, 15]. All the islands around the world are connected to the Internet through a submarine cable or a satellite connection. [6] works on the state of the Internet in Cuba. The situation is similar to high delay, but for political reasons. Of course, some regions in the world have specific difficulties linked to voluntary limitations imposed on the access to the Internet.

7. CONCLUSION

Studying path and delay is a very important task in regions where the internet access is degraded. Our evaluation shows that there does not exist a correlation between path length and geographical distance. Our best results concerned the dependency of geographical distance on delay, which goes against previously obtained results. In the case of Reunion Island, the delay is decreased in function of geographical distance. We have investigated the last (rest. first) node before (resp. after) Reunion Island. The existence of favorite path through the European continent, and more precisely through France with a minimal delay of $182,06ms$, restrain the number of possibilities to find the shortest path to the final destination. The second step of our research about connectivity in the Indian Ocean is the deployment of probes in the different islands and compare the situation. We leave for future work the research of other countries with internet connectivity like Reunion Island and the analysis of the kind of generated traffic

8. ACKNOWLEDGEMENTS

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