# Analysis of Bottlenecks in International Internet Links†

Technical Report TR-98-24

December 10, 1998

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† Work supported by Intelsat and by NSF NCR-9627922

# Contents

# Abstract

We report on preliminary results of analysis into the sources of congestion in international Internet routes from the United States to several countries: Brazil and South Africa. Using the *pathchar* and *traceroute* tools, we identified which links in a variety of routes are a bottleneck. The measures used were throughput, round trip delay, and router queueing delays. Measurements with *ping* were used to validate the round trip times obtained with *pathchar*.

# 1 Introduction

Internet users that communicate with a machine in another country often experience poor performance. "Poor" may different things to different users:

- The latency, or round trip time (RTT), of sending a singe packet from one machine to another might be unreasonably long.
- The variance in RTT experienced may be large.
- The bandwidth to move a large file across the Internet may be unacceptably small.
- The rate at which packets sent between the machines are lost may be high enough to cause packet retransmissions to noticeably degrade latency or bandwidth.

What causes poor performance? This report identifies examines two sources of bottlenecks:

- links, and
- routers.

Bottlenecks due to links in an Internet route depend on the link properties. Obviously the physical media (e.g., fiber, satellite) and protocol (e.g., FDDI, ATM) limit the RTT and maximum bandwidth of a link. Furthermore the load on the link (the number of users whose packets are being multiplexed on the link affect the RTT and bandwidth that an end user sees.

There are several reasons why a router may be a bottleneck. If a router has insufficient buffer space or processing speed then it will discard packets. Packet loss will ultimately lead to high RTT.

Sometimes the packets may have to wait for a long time in the router queue, which also increases RTT. The router throughput (e.g., number of packets per second that can be routed) may cause a bottleneck: the lower the throughput of a router, the longer the average queue length and hence the RTT for a given offered load from users.

Sometimes routing algorithms may be a headache, especially in international routes. The route chosen may be inefficient (e.g., introduce extra hops an hence increase RTT), or the router's throughput is reduced by the time it spends on the routing algorithm.

The study presented has a limitation: It pinpoints *where* bottlenecks are in various international routes. However it is often difficult to understand *why* the bottleneck exists. For example, in the study we often identify a certain router as a bottleneck. But it is difficult to get information from the organization that owns the router as to the characteristics of the device and the traffic the device handles.

# 2 Overview of Experiments

## 2.1 Definition of Segments

To trace paths from the U.S. to Brazil and South Africa, an entire path from source to destination machine is divided into several segments. Normally the segmentation is done based on network domains. We try to keep one network domain within one segment. The segments selected follow:

- *Virginia Tech (VT):* This segment consists of internal links of VT. A packet experiences exactly three hops to go from the source computer within VT to the network boundary where it leaves the VT campus, so there are three links in this segment.

- *Network Virginia (NetVA):* This segment has only one link, which connects VT to Sprint.

- *Sprint:* In all cases in this study, the VT traffic goes to the Internet through Sprint. So, Sprint's Internet has great impact on the resuls in this study. The number of hops within Sprint that packets make vary from trace to trace.

- *Exit North America (ExitNA):* This segment consists of rest of North America. North America is used instead of the U.S. because a packet sometimes goes to Canada before going to the remote country. Both the U.S. and Canada have the same type of properties, so both are considered as a single segment. This segment typically consists of several hops.

- *Overseas:* This segment represents the link connecting North America to remote countries. This segment is always a single link.

- *Remote Country:* This segment represents the network that packets traverse within remote countries (Brazil or South Africa). This segment normally has several hops.

## 2.2 Routes within Segments

Each of the above segments may have one or more links. A packet may follow different routes within each segment. Table 1, Table 2, and Table 3 list statistics about how many links a packet traverses when it goes through the each segment, for three different ExitNA segments: Gip.net, Teleglobe.net, and UUNET's Alter.net, respectively.

| Link | Mean | Median | Min | Max | StDev |
|---|---|---|---|---|---|
| VT | 3 | 3 | 3 | 3 | 0 |
| NetVA | 1 | 1 | 1 | 1 | 0 |
| Sprint | 2.6 | 2 | 1 | 8 | 1.53 |
| ExitNA (Gip.Net) | 1 | 1 | 1 | 1 | 0 |
| Overseas (Gip2Embr) | 1 | 1 | 1 | 1 | 0 |
| Brazil (Embr.net.br) | 4.04 | 4 | 1 | 6 | 1.65 |

**Table 1. Number of hops a packet traverses in each segment for traffic routed from the U.S. to Brazil via Gip.net.**

| Link | Mean | Median | Min | Max | Stdev |
|---|---|---|---|---|---|
| VT | 3 | 3 | 3 | 3 | 0 |
| Net VA | 1 | 1 | 1 | 1 | 0 |
| Sprint | 5.92 | 6 | 5 | 6 | 0.28 |
| ExitNA (Teleglobe.net) | 3.31 | 4 | 2 | 5 | 1.18 |
| Overseas (Tlgb2Embr) | 1 | 1 | 1 | 1 | 0 |
| Brazil (Embr.net.br) | 2.92 | 3 | 1 | 8 | 1.75 |

**Table 2. Number of hops a packet traverses in each segment for traffic routed from the U.S. to Brazil via Teleglobe.net.**

| Link | Mean | Median | Min | Max | Stdev |
|---|---|---|---|---|---|
| VT | 3 | 3 | 3 | 3 | 0 |
| Net VA | 1 | 1 | 1 | 1 | 0 |
| Sprint | 3.13 | 3.5 | 2 | 5 | 1.13 |
| ExitNA (Alter.net) | 6.73 | 6 | 5 | 8 | 1.08 |
| Overseas (Alter2SA) | 1 | 1 | 1 | 1 | 0 |
| South Africa | 2.77 | 3 | 2 | 4 | 0.81 |

**Table 3. Number of hops a packet traverses in each segment for traffic routed from the U.S. to South Africa via Alter.net.**

## 2.3 Experiment Trials

Before each experiment trial is conducted, a list of URLs with unique servers representing various Internet Service Providers within Brazil and South Africa were selected. For Brazil, 100 URLs were used. For South Africa, 60 URLs were used.

In each experimental trial, paths from a host connected to domain vt.edu by switched 10 Mbit/sec Ethernet to the 100 or 60 servers in the URLs are identified using *pathchar*. *pathchar* is a tool to trace paths hop by hop developed by Van Jacobson, at Berkeley. In an experiment trial, a driver program is executed that runs *pathchar* multiple times, each time on a distinct URL in the list that is supplied to the driver.

Multiple trials for each URL are recorded. Sometimes it takes several hours to complete a single trial, and a network failure or congestion somewhere in the Internet causes the trial to fail. In this case the trial is restarted from the beginning. Thus the data recorded only represents traces for which data on the entire path was recorded.

The paths are traced at different times of a day and also from different network of Virginia Tech. The data are analyzed and results are discussed in the next section.

# 3 Experiments Results

All graphs are presented and results are discussed in this section. At first paths are identified. Then Bottleneck Bandwidth (BB) and RTTs are measured and plotted per segment basis.

## 3.1 Path Identification

A limited number of paths were observed from Virginia Tech to hosts in Brazil and South Africa. These are illustrated in Figure 2.

All paths start from VT. Then all paths go through NetworkVirginia, and then to a Sprint router. The Sprint router is in Northern Virginia (NOVA), specifically Herndon Virginia. Within Sprint a variety of routes are followed. When the paths leave Sprint they become different; a packet leaving Sprint goes to one major network domain: gip.net, alter.net, or teleglobe.net. Gip.net (previously named gsl.net) is in Reston, VA. Alter.net is UUNET WorldCom, formerly UUNET Technologies, Inc. UUNET WorldCom is in Fairfax, VA, also in NOVA. Teleglobe.net is in Quebec, Canada. When a packet goes from Sprint to teleglobe.net it goes from NOVA to Canada. After gip.net, UUNET, or Teleglobe, the path leaves North America. So the complete path is from VT to NOVA then to the destination country or from VT to NOVA then Canada and then to the destination country.

## 3.2 Bottleneck Bandwidth

We use the term *bottleneck bandwidth* (BB) to denote the lowest bandwidth experienced in any link in a path. In this experiment BBs are calculated on a per-segment basis. One segment may have more than one hop, so BB means the lowest bandwidth obtained in the segment. Thus BB represents the lowest bandwidth obtained throughout a path. BB inside VT varied little over all experiments performed. But in Sprint BB varies a bit from time to time. We are mainly concerned about the ExitNA segment. RTT is always high in this segment. As the packets always follow VT, NetVA, and Sprint, the results are categorized based on the major network domain inside North America.

The data is collected for different ISPs inside Brazil. Some of the cases are traced more than one time. So, among all data mean, max standard deviation (stdev) are calculated. As sometimes one or two data are unusually high, thereby substantially increasing the stdev, the median is also calculated. The median gives a value very close to the most frequently observed value.

### 3.2.1 Through gip.net to Brazil

Figure 3 shows the bandwidth for each segment when the packet goes through gip.net. Figure 4 shows the median values of all collected data. This figure gives a close estimate to what users typically experience.

Figure 3 also shows mean values, along with stdev. In case of VT, gip.net and inside Brazil stdev is very low, and users experience little variance in BB. But in NetVA, Sprint, and Overseas stdev is quite high. Thus users experience large variations in BB in these three segments. The lowest BB obtained was in gip.net, and the second lowest was in Brazil (Embratel.net). Figure 4 shows that NetVA and Sprint both have a high capacity network.

### 3.2.2 Through teleglobe.net to Brazil

Figure 5 and Figure 6 show the same type of information as Figure 3 and Figure 4. But in this case the packets follow teleglobe.net.

Here the stdev of NetVA is little bit more than the previous case and a little bit less in case of Sprint. The noticeable thing is that inside segments teleglobe.net and Overseas stdev is quite high. Inside Brazil it is same as the previous case. Figure 6 shows the median values. NetVA is quite high and Sprint is lower than the previous values. The bandwidth inside teleglobe.net is remarkably high. Inside gip.net bandwidth is around 1.5 MB but inside teleglobe.net it is around 19 MB. In the Overseas segment it is better than through gip.net.

### 3.2.3 Through alter.net to South Africa

Most of time the path followed by a packet to South Africa (SA) goes through alter.net. Sometimes it also follows gip.net and teleglobe.net. But they are very much infrequent. Thus we only consider the case of reaching South Africa via alter.net, whose overseas router is in Northern Virginia.

Figure 7 and Figure 8 show the graphs corresponding to the previous four figures. The VT, NetVA and Sprint parts are very similar of previous cases. Standard deviation inside alter.net is very low. As it does not change a lot, it is more stable. The standard deviation of the Overseas segment is a little bit higher but reasonable.

The bandwidth of VT is little bit higher now, and this is the highest BB we observed in our experiments. The bandwidth inside alter.net is better than gip.net but worse than teleglobe.net. The

Overseas segment bandwidth is lowest in this case. Inside South Africa it is the lowest of all, only around 0.15 MB.

## 3.3 RTT

Round trip time is a very important measure to identify the bottleneck of a path. In our experiments, RTT excludes delay time in a router's queue. It includes propagation delay, input delay and the router queues on the far hop. For each router in a path, *pathchar* gives RTT from the source computer to that router. Using these values we could obtain the portion of total RTT due to individual segments. Thus if we add the values reported here for the RTT due to each segment, we get the RTT of the entire path.

### 3.3.1 Through gip.net to Brazil

Figure 9 shows that RTT is very low in the NetVA and Sprint segments. NetVA has only one link but within Sprint a packet goes through several hops. Both are very good because of taking low time. The stdev in these two segments are also very low. Stdev is also very low inside gip.net. But gip.net takes a very high RTT. In the Brazil segment, overall RTT is around 225-250ms, whereas ingip.net alone takes around 140-145ms. Thus gip.net is the bottleneck for RTT. We will summarize some more characteristics of this bottleneck later.

Figure 10 shows the median value and represents the most realistic one. VT RTT takes around 7-8ms. Inside VT, there are three hops. RTT is less than 1ms in both NetVA and Sprint. Most of time is wasted in gip.net and then inside Brazil. The RTT of the Overseas segment is reasonable.

### 3.3.2 Through teleglobe.net to Brazil

In this case the RTT of VT and NetVA are very similar to those of gip.net. Here Sprint takes some more time than previously. The standard deviation is also high. It makes Mean-Stdev negative (see Figure 11). This may happen due to one or two high samples observed. It may also happen because the traffic increases suddenly and raises the RTT to a very high level.

Like gip.net, inside teleglobe.net RTT is very high (both are marked as Exit NA). The stdev is low. Thus, it means inside teleglobe.net RTT is always high. But Figure 6 shows that bandwidth of teleglobe.net is high. It is higher than that of gip.net and alter.net. But RTT is highest of all in here. It may be due to higher traffic in teleglobe.net or poor routing than can not use the advantage of higher bandwidth. Figure 12 shows that inside Brazil is very high. It is higher than the previous case (gip.net). It can not be easily compared to the previous value because the URLs used for measurement in the two cases are different. We did not get any URL for which the packets sometimes go through gip.net and in the next trial go through teleglobe.net. The longer time may be due to a packet traveling a longer or busy path.

### 3.3.3 Through alter.net to South Africa

Figure 13 shows that RTT through VT, NetVA and Sprint are very similar to the previous values (gip.net and teleglobe.net). The RTT inside Sprint is more similar to that of teleglobe.net than that to that of gip.net. Here stdev is higher because of some high RTT samples. Inside alter.net RTT is very high. This value is very close to the value of teleglobe.net. But stdev inside is little bit higher. Thus, the RTT in this segment varies a lot. The Overseas segment RTT is also high. In case of gip.net the value was 9ms, and in teleglobe.net it was 5ms. But here it is 22 ms (Figure 14). Inside South Africa RTT is also high. Inside Brazil RTT varies a lot. Sometimes it is low and sometimes it is high. But in South Africa RTT is high most of the time.

# 4 Discussion and Some Hypotheses

In previous section some data and graphs are presented. Now we want to analyze the result and try to develop some hypotheses about what causes the bottlenecks. There are two types of bottleneck:

<u>Lowest Bandwidth:</u>

> In all paths, the lowest bandwidth is always observed in the Remote Country. It is assumed that inside remote countries bandwidth will be lower than that of U.S.. So we are not very interested about this kind of bottleneck.

<u>Highest RTT:</u>

> This type of bottleneck always happens inside Canada and the U.S., specifically in the ExitNA segment. It is our primary concern why ExitNA segments exhibit a very long RTT. Sometimes Overseas produces a high RTT, but that is always lower than the RTT of ExitNA. We identified the links that account for most of the long RTT. We call these links *busy links*. The links and some of their properties are described below.

## 4.1 Busy Link

Table 4 shows the end to end routers that are connected with the busy link, the bandwidth of the links and their RTT. These busy links have some properties common. The properties are:

- Each link is in Canada or the U.S..
- Each link is entirely in one network domain. Both routers at the endpoints of the link are either in the same network domain (e.g., gip.net or alter.net).
- The routers are in very close considering physical proximity, so they are not connected by a satellite link.
- In most of the cases the first of the two routers uses FDDI.
- In most of the cases the link is the final network link before traffic leaves the U.S. or Canada to the overseas link.

| Remote Country | Links (Router to Router) | Link BW | Link RTT |
|---|---|---|---|
| Brazil | gip-dc-3-fddi0-0.gip.net (204.59.144.197) to 204.59.224.202 | 1.5 Mb/s | 140 ms |
| | gip-penn-3-fddi0-0.gip.net (204.59.136.197) to 204.59.192.22 / 204.59.192.100 | 1.5 Mb/s | 145 ms |
| | gip-ftworth-2-fddi1-0.gip.net (204.59.120.194) to 204.59.121.14 | 1.5 Mb/s | 150 ms |
| | gin-mtt-bb2.Teleglobe.net(207.45.223.61) to embratel-gw4.Teleglobe.net(207.45.206.178) | 20~70 Mb/s | 315 ms |
| South Africa | 195.ATM-0-0.Gw1.DCA1.ALTER.NET (146.188.161.17) to telkom-gw.customer.ALTER.NET(137.39.128.14) | 483 Kb/s | 325 ms |
| | Fddi0-0.New-York4.NY.Alter.Net(137.39.126.10) to satelkom-gw.customer.ALTER.NET(137.39.245.238) | 1~4 Mb/s | 300-325 ms |
| | gip-dc-3-fddi0-0.gip.net (204.59.144.197) to 204.59.225.86 | 1 Mb/s | 250 ms |
| | gip-dc-2-fddi1-0.gip.net (204.59.144.194) to 204.59.145.14 | 1 Mb/s | 240 ms |

**Table 4.** Routers that connect busy links, their BW and RTT

## 4.2 Causes of Bottleneck (Some hypothesis)

Based on the data, graphs and discussion above the causes of bottleneck can be hypothesized:

- *Busy link router either has insufficient processing capacity or insufficient outgoing link capacity*

Table 5 and Table 6 show the total queuing delay at routers along the paths to Brazil and South Africa. The segmentation in the tables is little bit different than that used previously in the paper. Because the queuing delay is very low in U.S., except in the busy link, all U.S. segments except the busy link are considered a single segment named “US Link.”

| | Min | Median | Std | Mean | Max |
|---|---|---|---|---|---|
| US Link | 0.00 | 5.27 | 6.90 | 6.18 | 32.45 |
| Busy Link | 0.00 | 12.50 | 39.02 | 27.56 | 141.00 |
| Overseas | 0.00 | 1.61 | 25.38 | 12.39 | 125.00 |
| Brazil | 0.00 | 115.00 | 351.67 | 256.83 | 1281.00 |

**Table 5.** Queuing delay for each segment from US to Brazil

| | Min | Median | Std | Mean | Max |
|---|---|---|---|---|---|
| US Link | 1.00 | 5.83 | 47.83 | 21.75 | 163.58 |
| Busy Link | 0.00 | 42.60 | 24.58 | 36.96 | 61.20 |
| Overseas | 0.00 | 23.80 | 29.88 | 30.54 | 80.00 |
| SA | 4.48 | 64.75 | 209.29 | 148.68 | 635.00 |

**Table 6.** Queuing delay for each segment from US to South Africa

It shows that the queuing delay for routers within the remote country is an order of magnitude higher than the rest of the path. This is explained because the network with the remote countries has smaller capacity. But what is more interesting is that if we look at the other three segments (US Link, Busy Link, and Overseas), we see that the queuing delay at the *single router* at the entrance to the busy link is more than the *entire* queuing delay at all routers within either the US Link segment or the Overseas segment. Thus improving this single router is critical to improving the RTT up to the entry of packets into the remote country.

The high busy link router queuing times observed in the previous bullet are due either to outgoing links with insufficient capacity or to routers with insufficient processing power to keep up with the arrival of packets.

- *Metropolitan Area Exchange (MAE)*

MAEs use an FDDI ring interconnecting routers from subscribing ISPs. The MAE East Internet network access point handles more than 60% of all worldwide Internet traffic. ISPs are bypassing MAEs, instead using NAPs due to the poor performance of MAEs (packet drops, etc.) Currently there are three MAEs, in the east, central and west U.S. MAE East is in Vienna, Northern VA. Our bottlenecked routers are also in NOVA (Reston, FairFax). We cannot identify from the router names in the paths we observed if the paths are affected by MAE East.

# 5 Packet Loss Statistics

Connection-oriented traffic, such as TCP, requires lost packets to be retransmitted. Retransmission consumes bandwidth and increases network load, thereby increasing RTT. The tables presented in this section assess what percentage of packets from the U.S. to Brazil and South Africa are lost. The analysis further identifies where the loses occur.

Table 7, Table 8, and Table 9 report statistics on the percentage of lost packets for each segment in three paths, two to Brazil and one to South Africa. First, packet loss can be a very large problem: Brazil's embr.net.br looses 7% to 9% of all packets. The Overseas segment links from Teleglobe to Brazil and from alter.net to South Africa experience 13% to 17% packet loss. Within the U.S., Sprint experiences a 2% to 4% packet loss rate, but the standard deviation can be quite high: up to 10, or about a 3% swing. In addition Sprint's worse-case behavior is bad indeed: its maximum loss rate is 12% to 46%!

It is not difficult to see why connections to international hosts often do not respond. In the worst case, Table 9, a packet lives a dangerous life: at worst NetVA looses 1/3 of its packets, Spring nearly ½, then loss rates of 14%, 40%, and 34% in ExitNA, the Overseas segment link, and within South Africa.

| Link | Mean | Median | Min | Max | StDev |
|---|---|---|---|---|---|
| VT | 0 | 0 | 0 | 0 | 0 |
| NetVA | 0.04 | 0 | 0 | 1 | 0.2 |
| Sprint | 2.04 | 0.5 | 0 | 16.8 | 3.69 |
| ExitNA (Gip.Net) | 4.80 | 2 | 0 | 36 | 8.87 |
| Overseas (Gip2Embr) | 4.96 | 4 | 0 | 19 | 5.39 |
| Brazil (Embr.net.br) | 7.34 | 6 | 0 | 34 | 8.36 |

**Table 7. Percentage of packets lost in each segment of path from U.S. to Brazil via Gip.net**

| Link | Mean | Median | Min | Max | StDev |
|---|---|---|---|---|---|
| VT | 0 | 0 | 0 | 0 | 0 |
| Net VA | 0 | 0 | 0 | 0 | 0 |
| Sprint | 2.50 | 0.67 | 0 | 12.2 | 3.77 |
| ExitNA (Teleglobe.net) | 4.89 | 2.5 | 0 | 12 | 4.53 |
| Overseas (Tlgb2Embr) | 13.15 | 8 | 0 | 41 | 14.83 |
| Brazil (Embr.net.br) | 9.04 | 3.75 | 0.67 | 28 | 10.07 |

**Table 8. Percentage of packets lost in each segment of path from U.S. to Brazil via Teleglobe.net**

| Link | Mean | Median | Min | Max | Stdev |
|---|---|---|---|---|---|
| VT | 0 | 0 | 0 | 0 | 0 |
| Net VA | 1.86 | 0 | 0 | 32 | 6.83 |
| Sprint | 4.33 | 0.5 | 0 | 46 | 9.94 |
| ExitNA (Alter.net) | 4.61 | 3.35 | 0.2 | 13.62 | 3.59 |
| Overseas (Alter2SA) | 17.8 | 15.75 | 0 | 40 | 11.72 |
| SA | 18.07 | 19.96 | 1 | 34 | 9.852 |

**Table 9. Percentage of packets lost in each segment of path from U.S. to South Africa via Alter.net**

# 6 Validation of *pathchar* RTT Measurements by *Ping*

We validated our RTT measurements from *pathchar* using the well-known tool *ping*. To do this *ping* was executed just after each execution of *pathchar*. Normally *ping* performs 128 trials measurements of RTT. *Ping* reports the minimum, average, and maximum values of RTT. Most of the time the RTT of *pathchar* falls in between minimum and average values reported by *ping*. Occasionally *pathchar* reports an RTT that is slightly higher than *ping*'s average value. Very rarely is *pathchar*'s RTT higher than *ping*'s maximum value. Because we run *ping* after *pathchar* the network conditions vary slightly, and this could account for the rare observations.

The packet drop percentages reported by *ping* are more meaningful. *Ping* gives the packet drop of the whole path whereas *pathchar* gives drops on a per-hop basis. Thus it is difficult to compute the overall packet drop in *pathchar*. The packet drop percentage also depends on time. In one trial we observed that the percentage of packet drop was always higher than that of South Africa. In another trial the percentage in South Africa was higher than Brazil. The overall packet drop percentage from *ping* most of the 0%. Sometimes it is 5-10%. Only rarely is it higher than 20%.

# 7 Conclusions

- RTT to foreign countries is on the order of hundreds of msec, the same order as a geosynchronous satellite. Thus a geosynchronous satellite may offer service competitive with that of today's terrestrial links.

- In terms of RTT, the bottleneck router is usually one hop before the Overseas segment link; furthermore that bottleneck router usually uses FDDI.

- In terms of bandwidth, the bottleneck is in foreign country.

- Brazil or South Africa packet loss rates are surprisingly high (as much as 40% for single hop).

- We did observe an anomaly in measuring packet loss percentages: *pathchar*'s loss percentage was higher for one link than the *ping* loss percentage for the entire path.

- Teleglobe's network was unusual in that it has high bandwidth, but also high RTT.

# Appendix. Tools Used in this Study

- *pathchar* from Van Jacobson

- Traceroute fromVan Jacobson

- NeoTrace from Neoworx

- *Ping* from UNIX system

- Host name to Latitude/Longitude from UIUC

- Some tools from Global one sites. (Whois, Dig, etc. from gip.net )

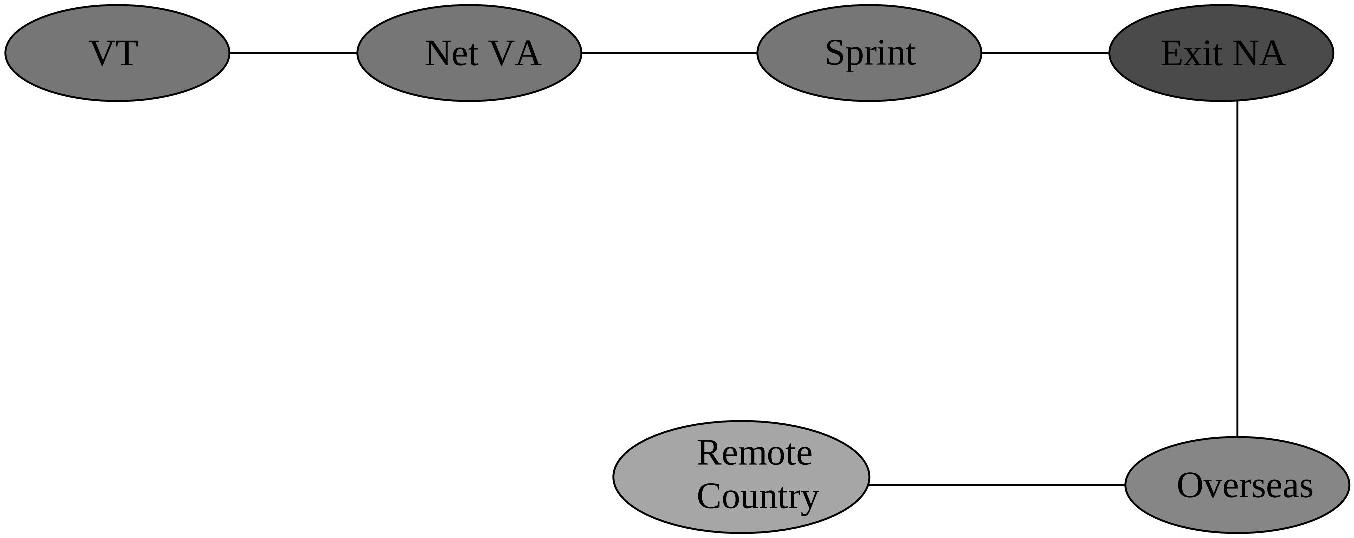



**Figure 1. Segmentation of link**

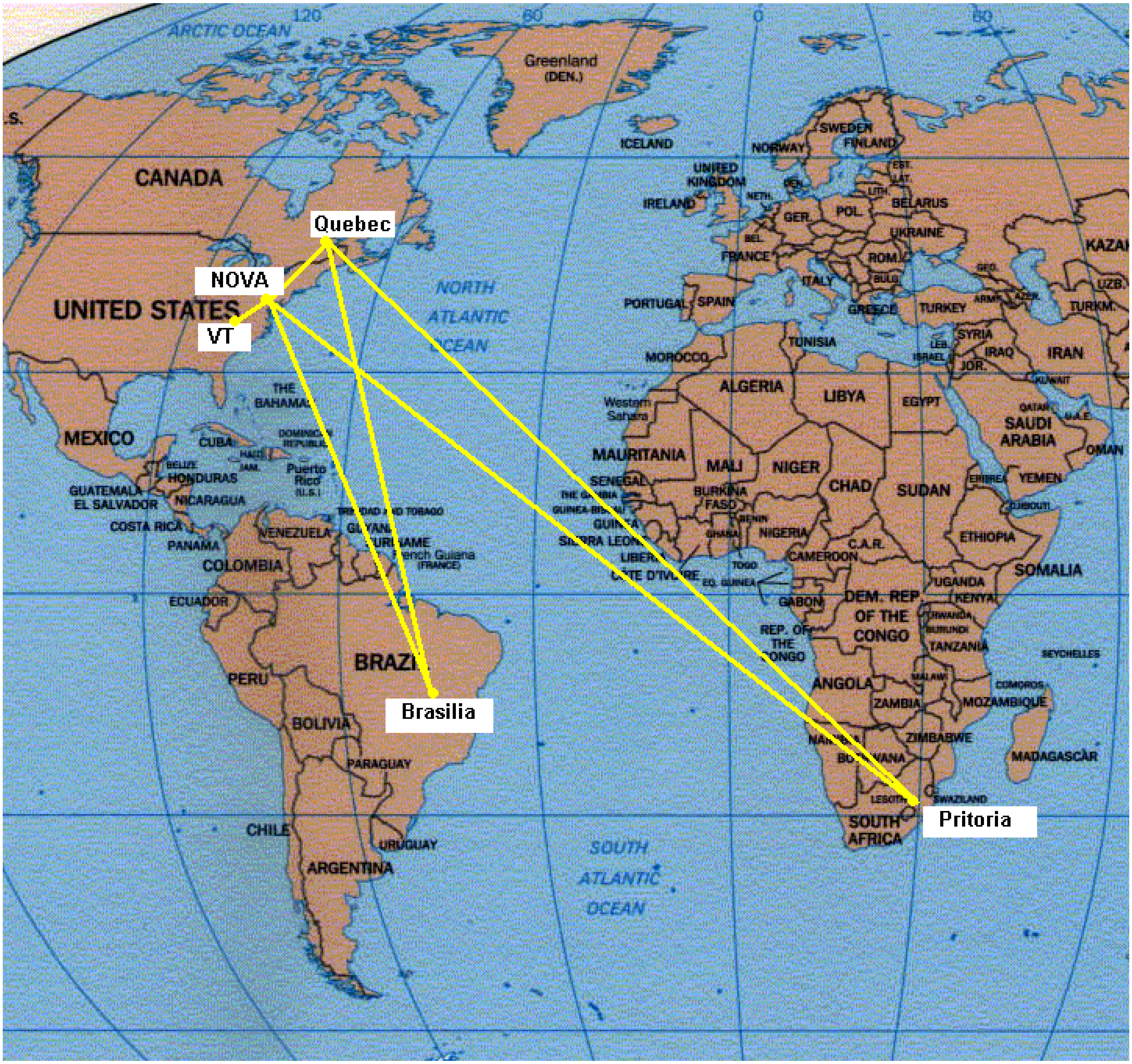
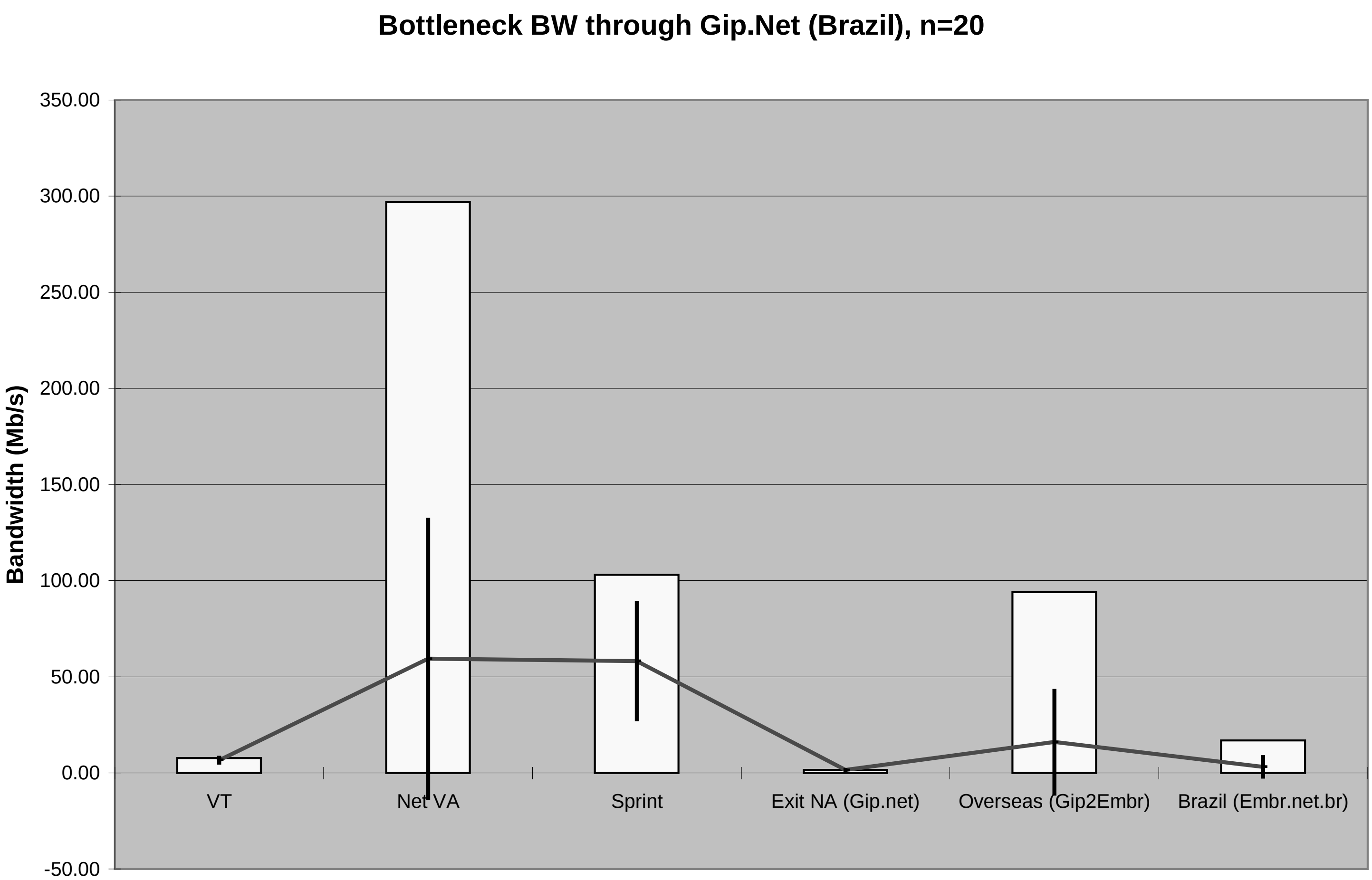



**Figure 2. Trajectory of a packet from VT to Brazil and South Africa**




| | VT | Net VA | Sprint | Exit NA (Gip.net) | Overseas (Gip2Embr) | Brazil (Embr.net.br) |
|---|---|---|---|---|---|---|
| Max | 7.80 | 297.00 | 103.00 | 1.70 | 94.00 | 17.00 |
| Min | 3.70 | 4.60 | 14.00 | 0.68 | 0.76 | 0.30 |
| Mean+Std | 7.90 | 131.68 | 88.50 | 1.71 | 42.65 | 8.33 |
| Mean-Std | 5.41 | -12.98 | 27.96 | 1.22 | -10.62 | -1.85 |
| Mean | 6.66 | 59.35 | 58.23 | 1.46 | 16.01 | 3.24 |

**Figure 3**

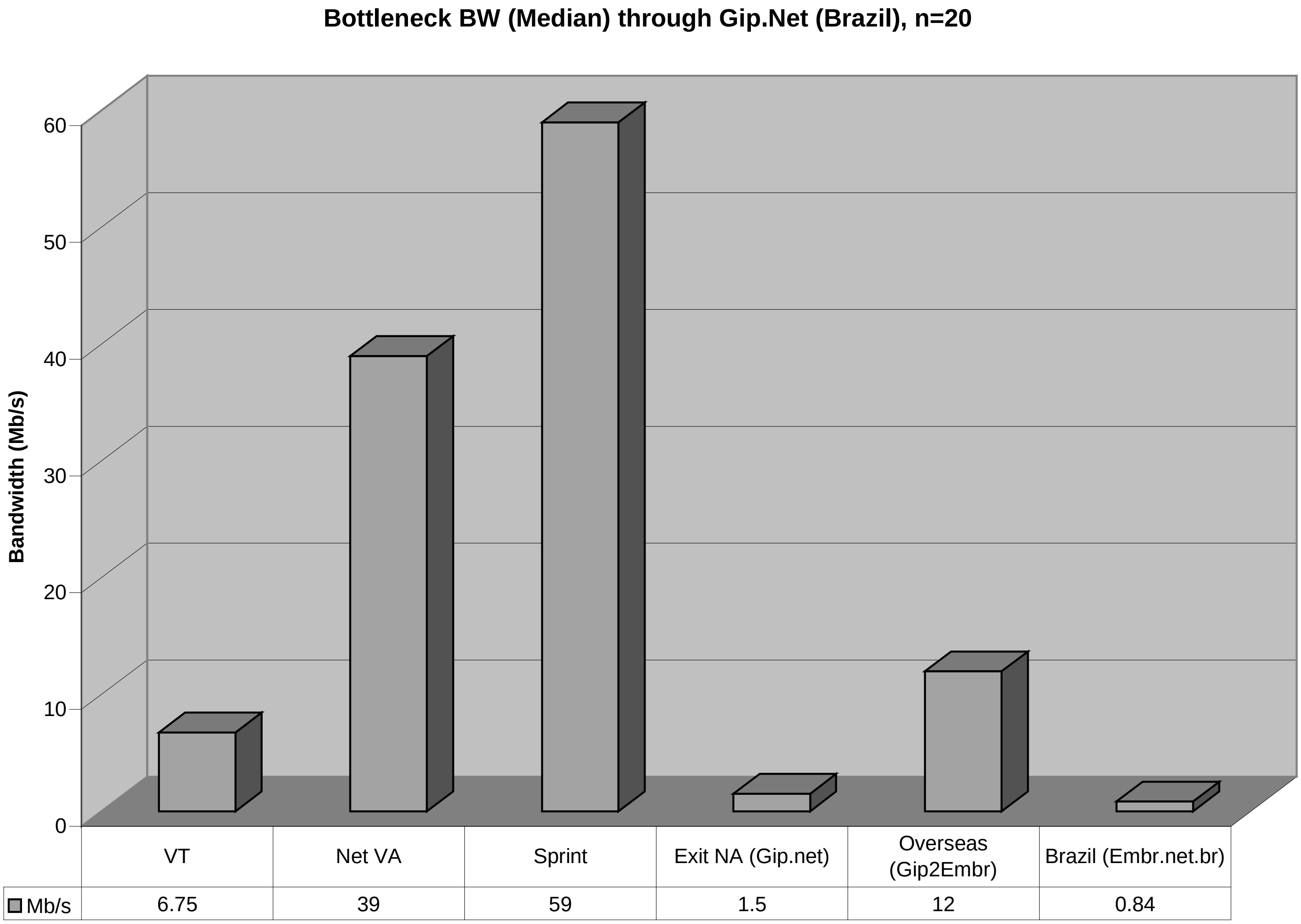
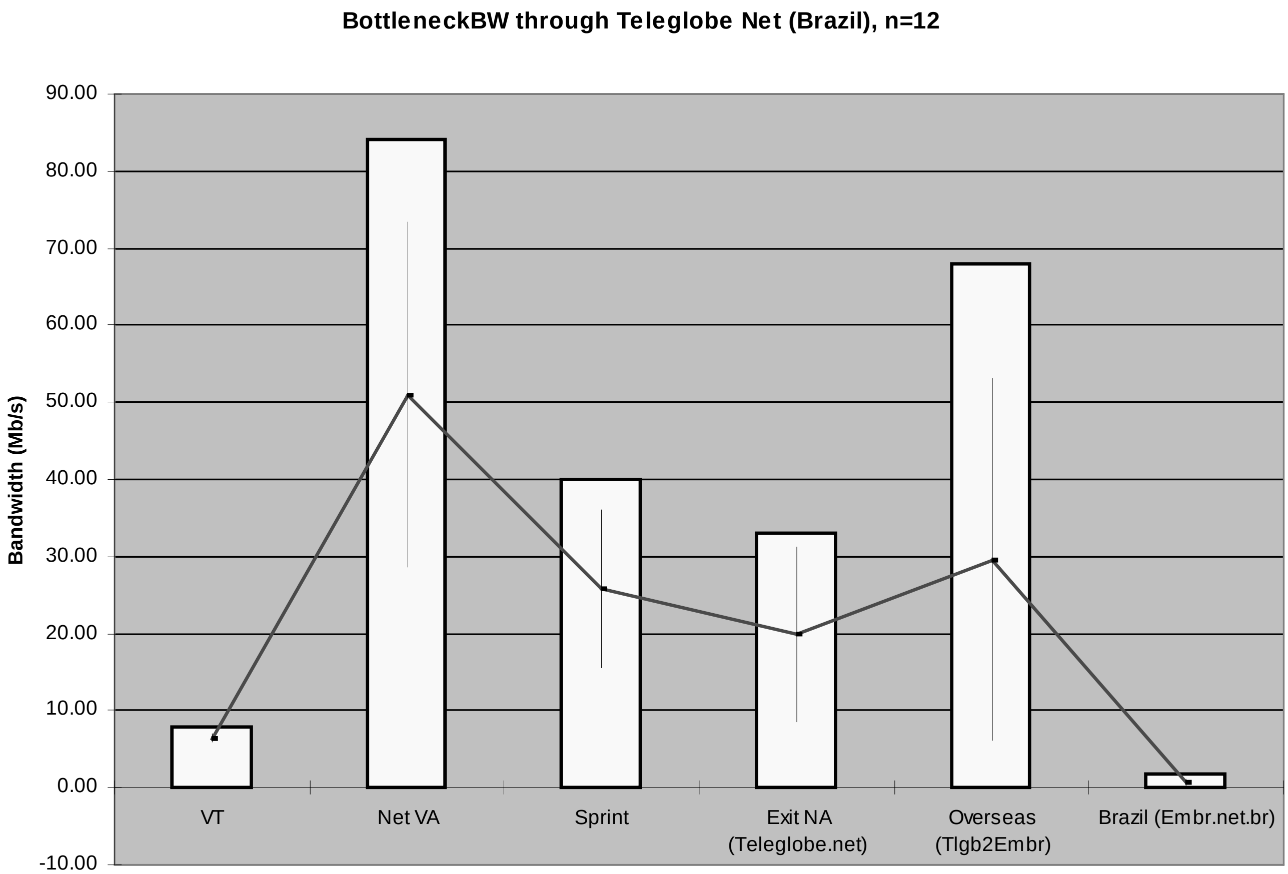

Bottleneck BW (Median) through Gip.Net (Brazil), n=20
Bandwidth (Mb/s)
60
50
40
30
20
10
0
VT
Net VA
Sprint
Exit NA (Gip.net)
Overseas (Gip2Embr)
Brazil (Embr.net.br)
Mb/s
6.75
39
59
1.5
12
0.84

**Figure 4**




| | VT | Net VA | Sprint | Exit NA (Teleglobe.net) | Overseas (Tlgb2Embr) | Brazil (Embr.net.br) |
|---|---|---|---|---|---|---|
| Max | 7.80 | 84.00 | 40.00 | 33.00 | 68.00 | 1.80 |
| Min | 4.90 | 12.00 | 1.80 | 0.30 | 1.40 | 0.06 |
| Mean+Std | 7.12 | 73.43 | 36.15 | 31.34 | 53.03 | 1.19 |
| Mean-Std | 5.84 | 28.57 | 15.45 | 8.50 | 6.17 | -0.01 |
| Mean | 6.48 | 51.00 | 25.80 | 19.92 | 29.60 | 0.59 |

**Figure 5**

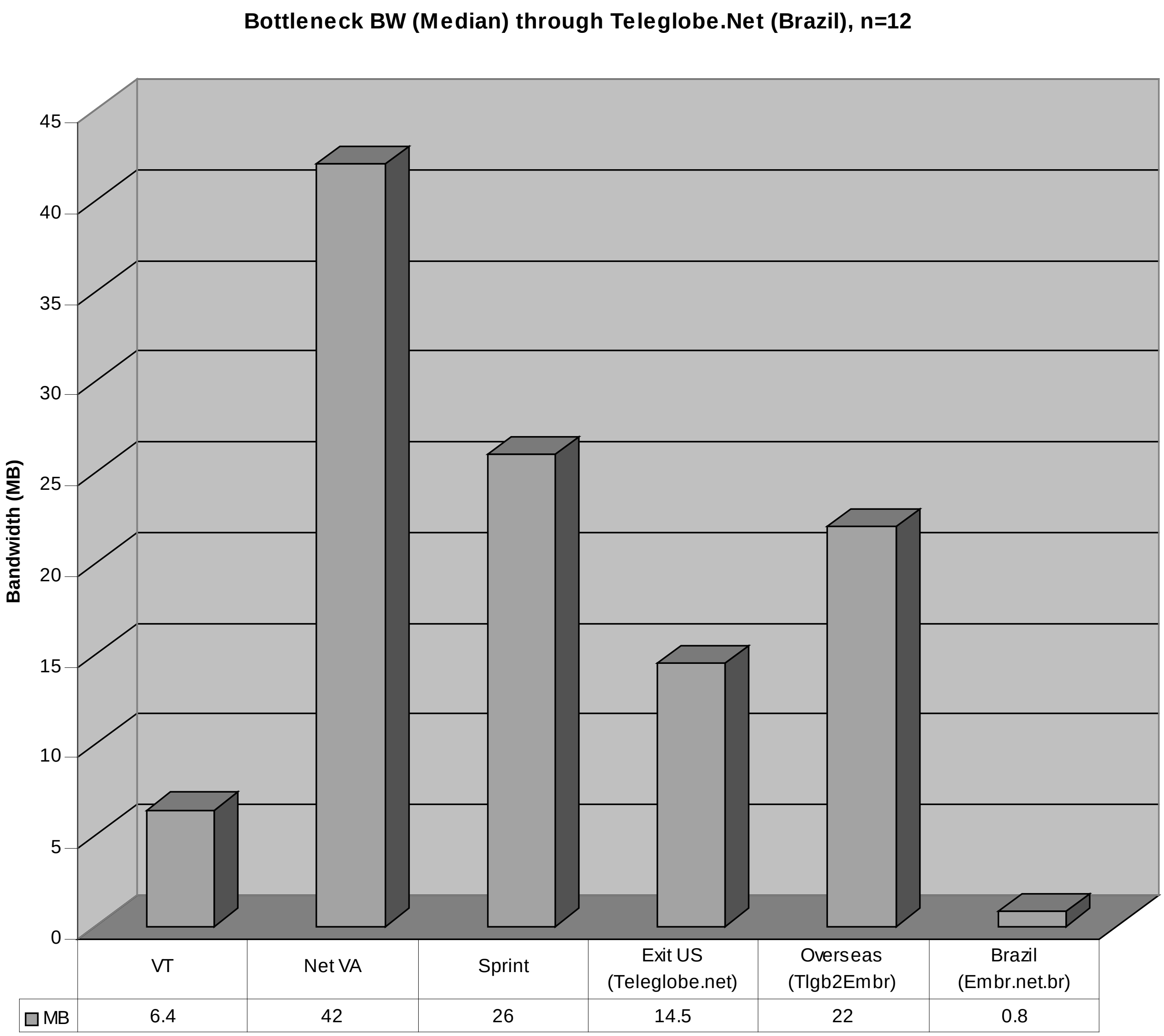
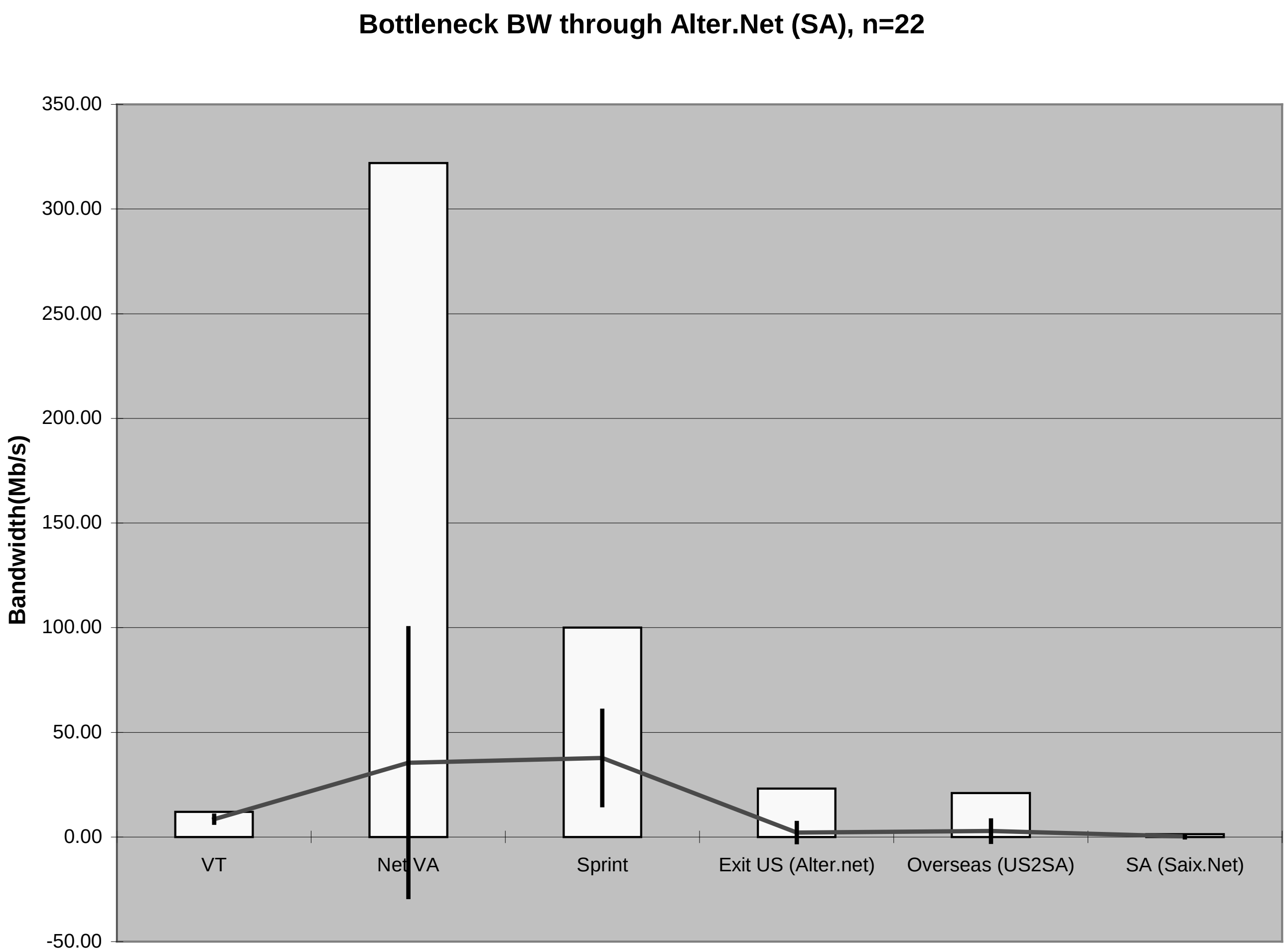

Bottleneck BW (Median) through Teleglobe.Net (Brazil), n=12
Bandwidth (MB)
45
40
35
30
25
20
15
10
5
0
VT
Net VA
Sprint
Exit US (Teleglobe.net)
Overseas (Tlgb2Embr)
Brazil (Embr.net.br)
MB
6.4
42
26
14.5
22
0.8

**Figure 6**




| | VT | Net VA | Sprint | ExitNA (Alter.net) | Overseas (US2SA) | SA (Saix.Net) |
|---|---|---|---|---|---|---|
| Max | 12 | 322 | 100 | 23 | 21.00 | 1.3 |
| Min | 5.8 | 11 | 3.2 | 0.48 | 0.17 | 0.05 |
| Mean+Std | 10.03579 | 99.59778 | 60.36544 | 6.595858 | 7.88 | 0.457515 |
| Mean-Std | 6.780874 | -28.7644 | 15.21638 | -2.4904 | -2.29 | -0.12297 |
| Mean | 8.408333 | 35.41667 | 37.79091 | 2.052727 | 2.79 | 0.167273 |

**Figure 7**

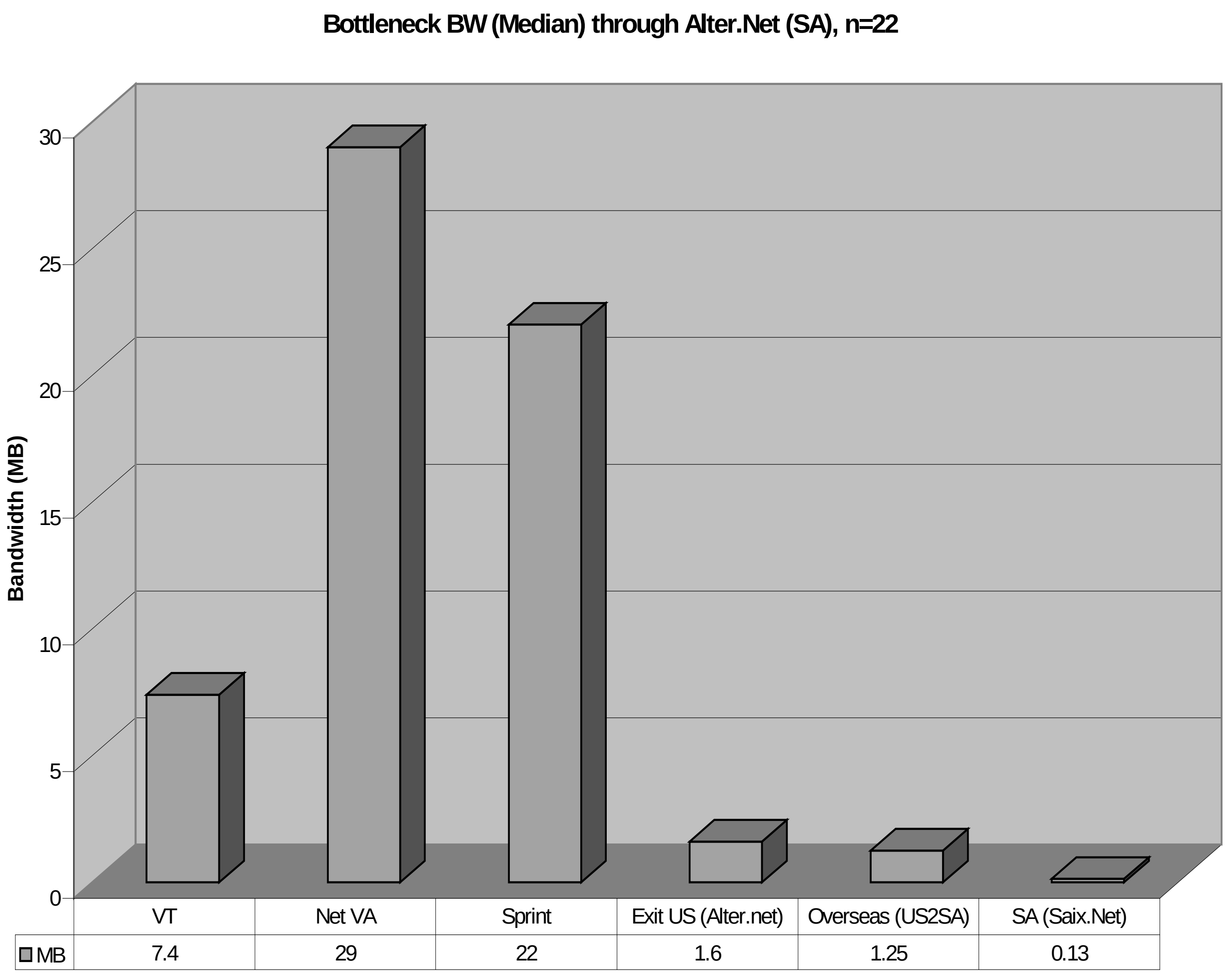
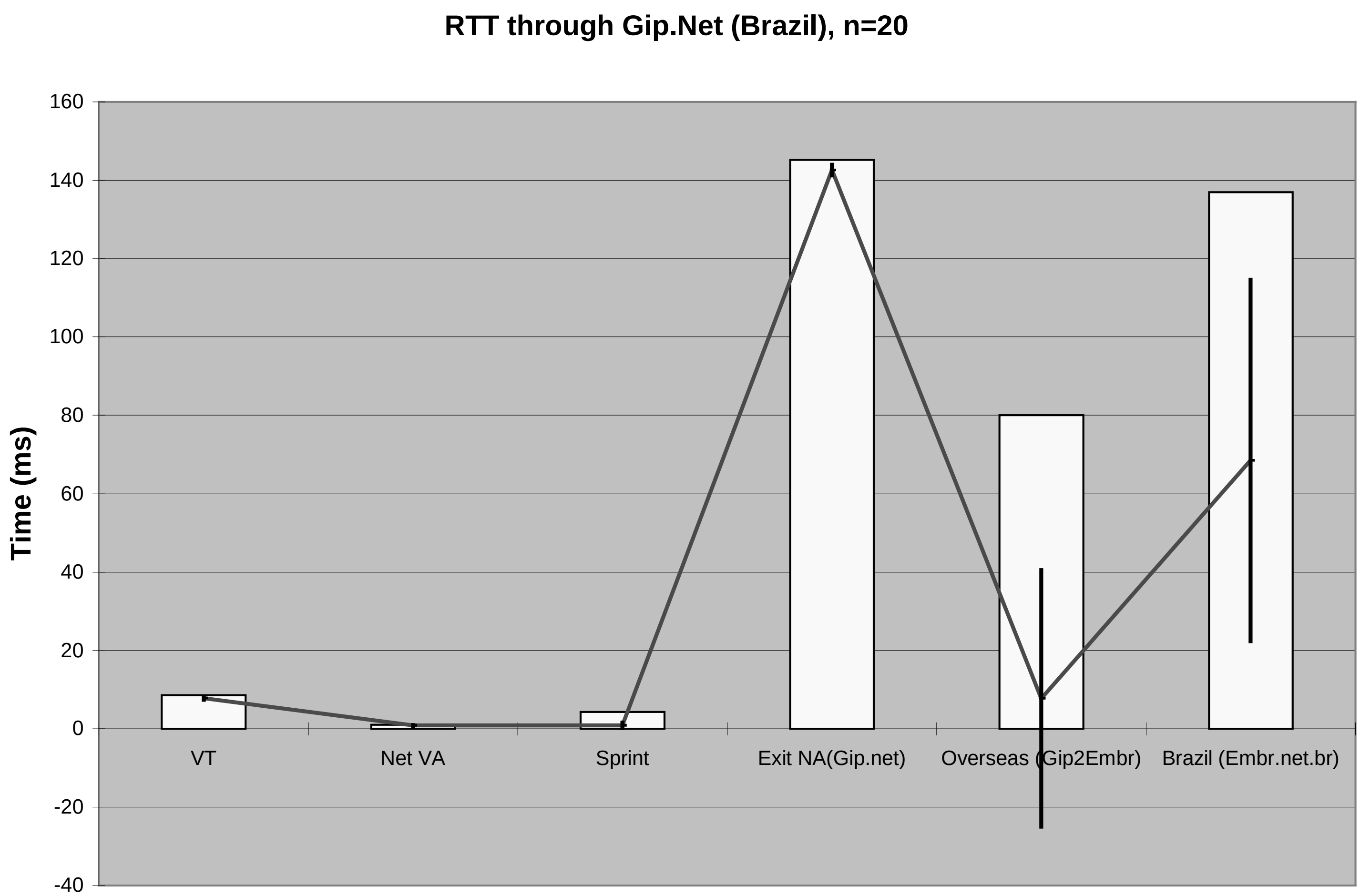

Bottleneck BW (Median) through Alter.Net (SA), n=22
Bandwidth (MB)
30
25
20
15
10
5
0
VT
Net VA
Sprint
Exit US (Alter.net)
Overseas (US2SA)
SA (Saix.Net)
MB
7.4
29
22
1.6
1.25
0.13

**Figure 8**




| | VT | Net VA | Sprint | Exit NA(Gip.net) | Overseas (Gip2Embr) | Brazil (Embr.net.br) |
|---|---|---|---|---|---|---|
| max | 8.55 | 1.03 | 4.25 | 145.20 | 80.00 | 137.00 |
| Min | 7.11 | 0.63 | 0.40 | 140.00 | 6.00 | 27.00 |
| Mean+Std | 8.28 | 0.96 | 1.55 | 144.00 | 40.46 | 114.59 |
| Mean-Std | 7.34 | 0.75 | 0.16 | 141.21 | -24.96 | 22.32 |
| Mean | 7.81 | 0.85 | 0.86 | 142.61 | 7.75 | 68.45 |

**Figure 9**

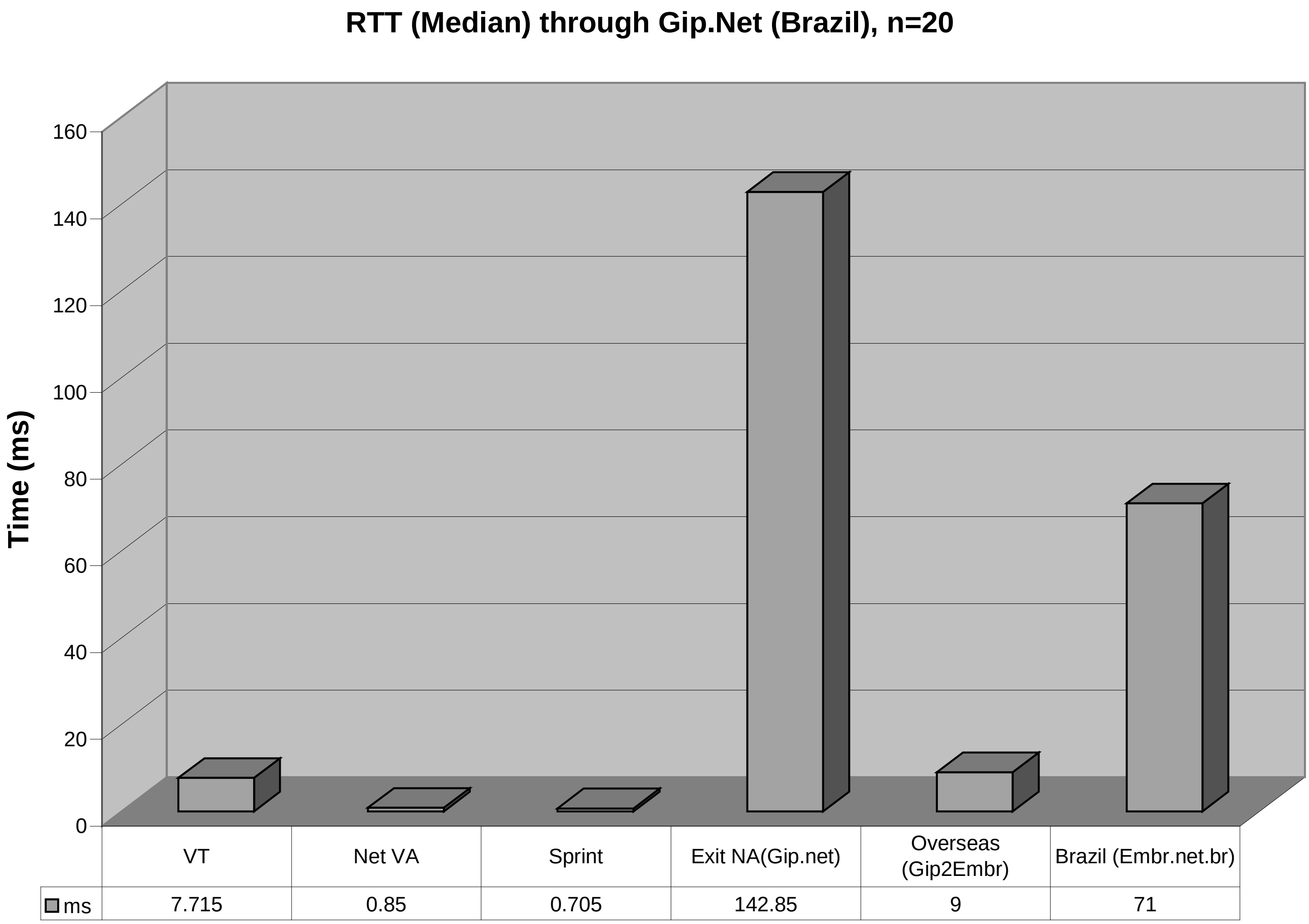
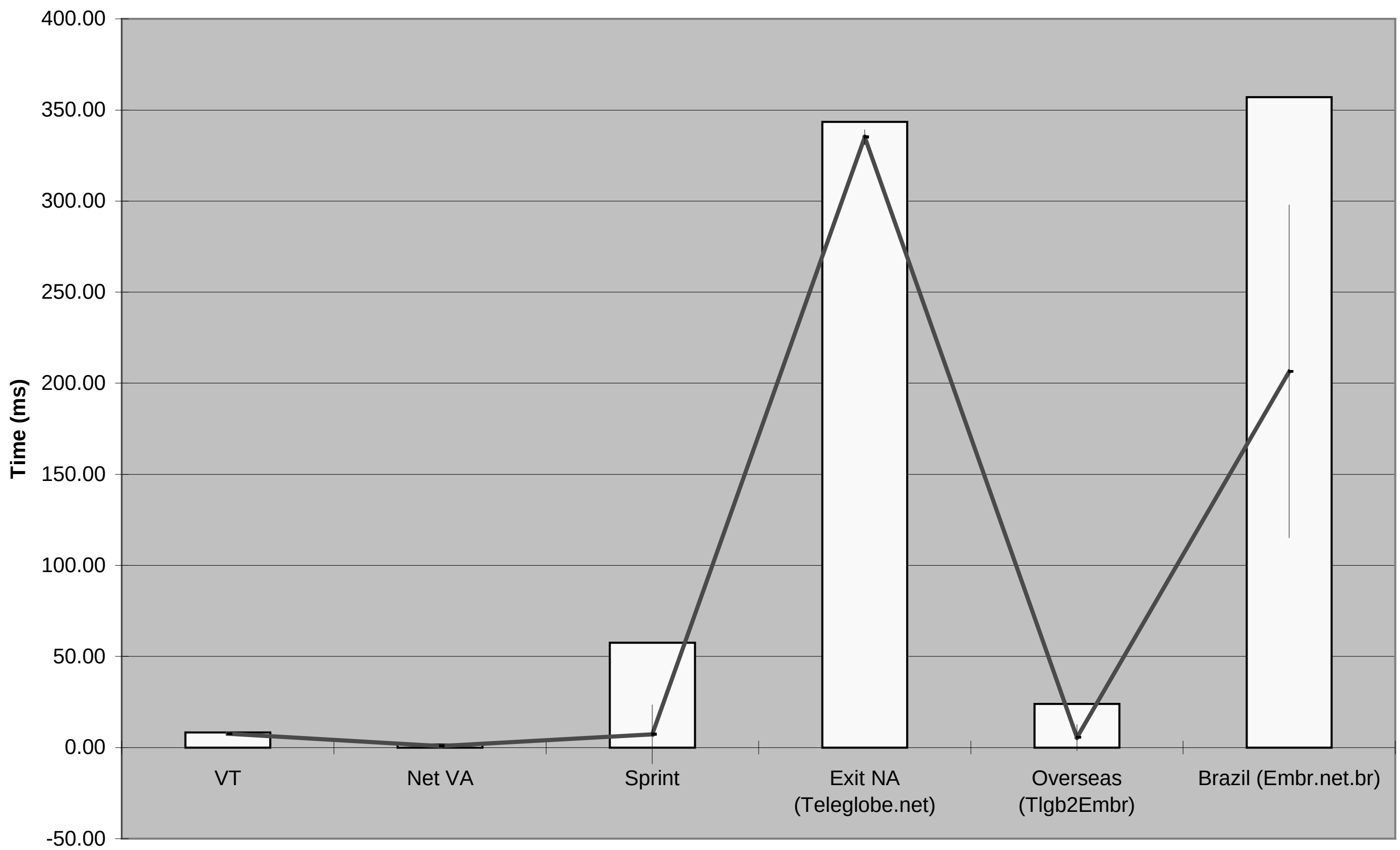

RTT (Median) through Gip.Net (Brazil), n=20
Time (ms)
0
20
40
60
80
100
120
140
160
VT
Net VA
Sprint
Exit NA(Gip.net)
Overseas (Gip2Embr)
Brazil (Embr.net.br)
ms
7.715
0.85
0.705
142.85
9
71

**Figure 10**

**RTT through Teleglobe.Net (Brazil), n=12**




| | VT | Net VA | Sprint | Exit NA (Teleglobe.net) | Overseas (Tlgb2Embr) | Brazil (Embr.net.br) |
|---|---|---|---|---|---|---|
| Max | 8.28 | 1.7 | 57.6 | 343.5 | 24 | 357 |
| Min | 7.31 | 0.73 | 4.26 | 329 | 2 | 21 |
| Mean+Std | 7.890687 | 1.098783 | 23.48609 | 339.1927578 | 12.70243 | 297.9275 |
| Mean-Std | 7.325313 | 0.521217 | -8.91109 | 331.0072422 | -1.50243 | 115.0725 |
| Mean | 7.608 | 0.81 | 7.2875 | 335.1 | 5.6 | 206.5 |
| Stdev | 0.282687 | 0.288783 | 16.19859 | 4.092757831 | 7.102425 | 91.42747 |

**Figure 11**

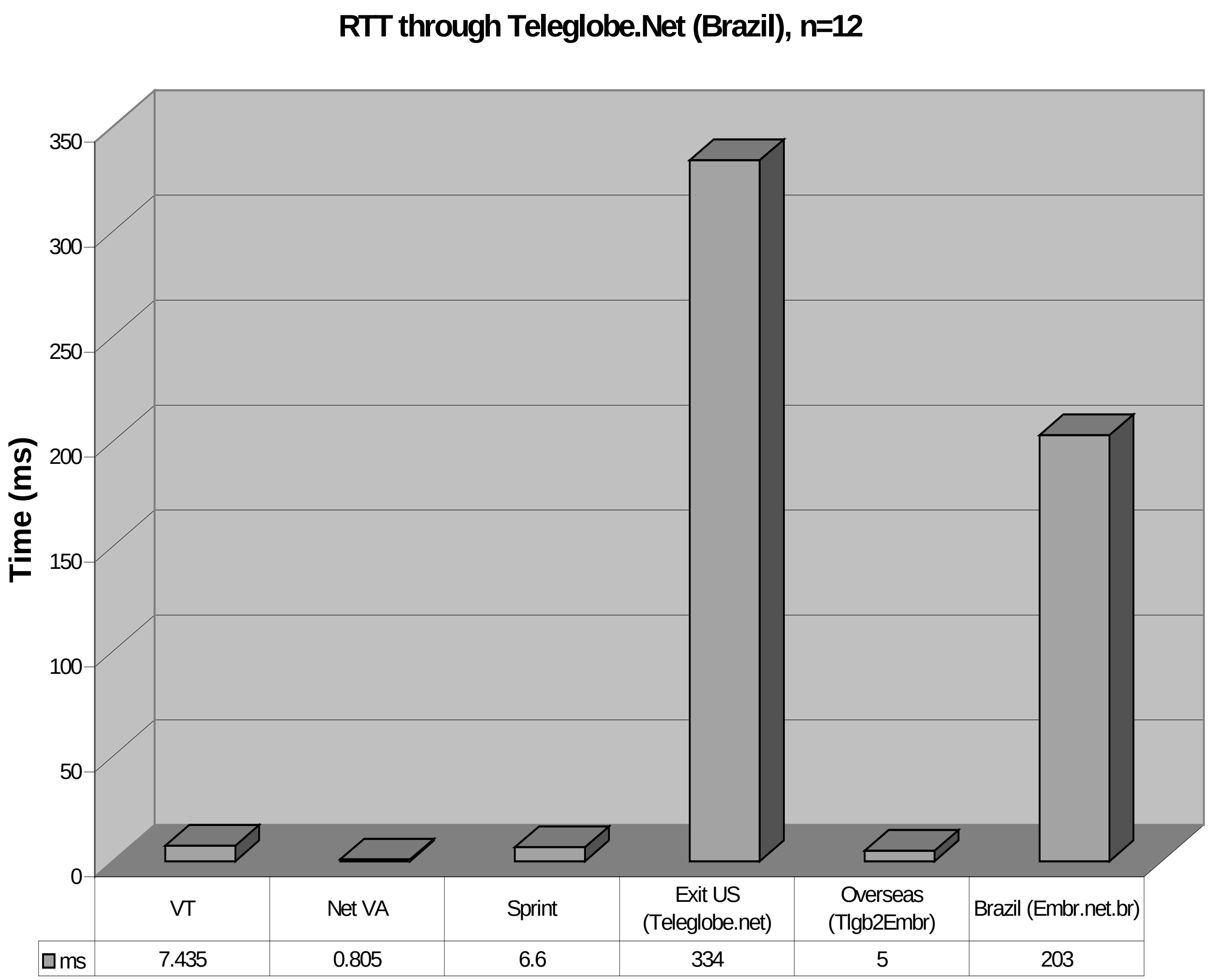
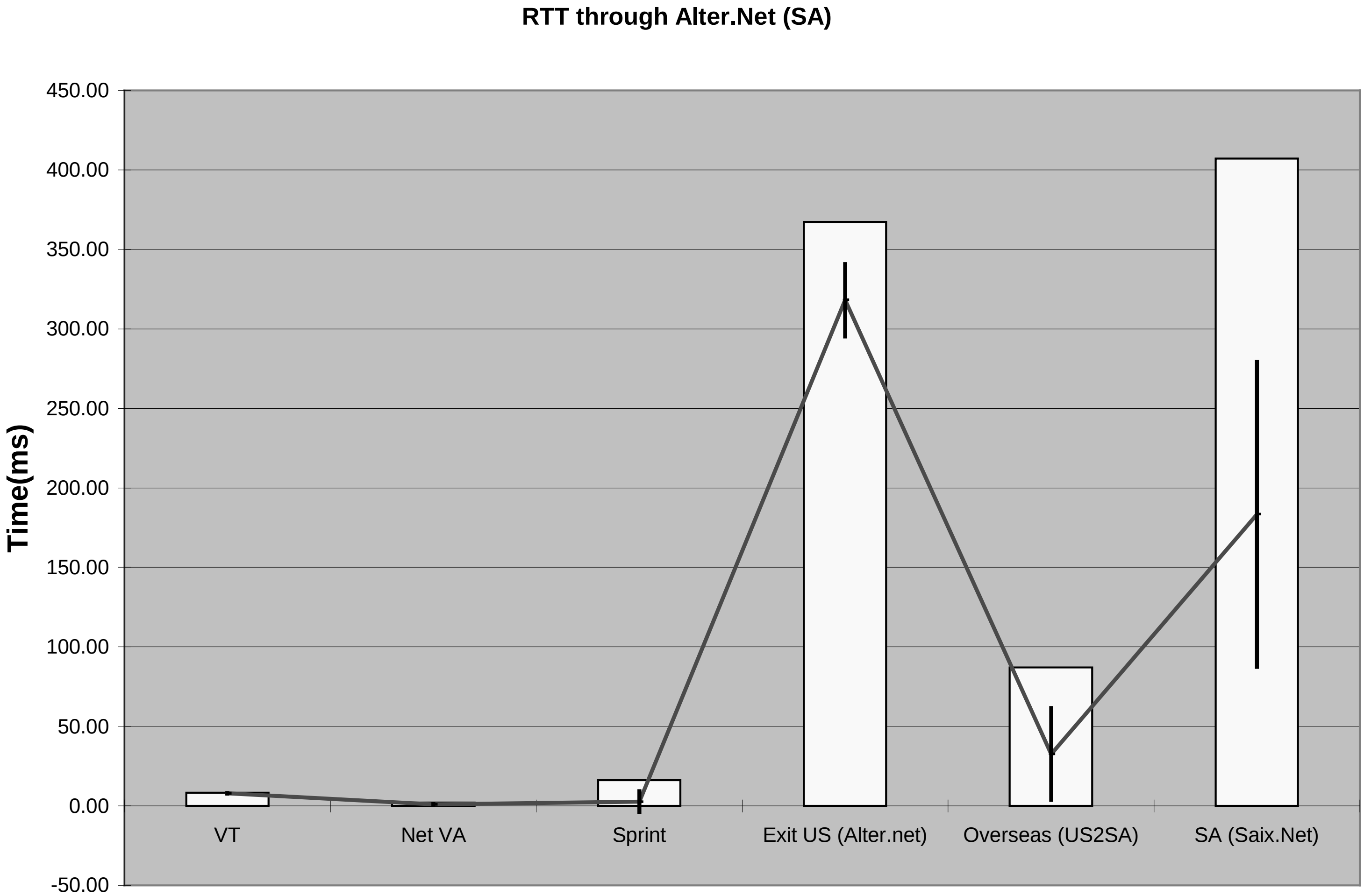

RTT through Teleglobe.Net (Brazil), n=12
Time (ms)
0
50
100
150
200
250
300
350
VT
Net VA
Sprint
Exit US (Teleglobe.net)
Overseas (Tlgb2Embr)
Brazil (Embr.net.br)
ms
7.435
0.805
6.6
334
5
203

**Figure 12**




| | VT | Net VA | Sprint | ExitNA (Alter.net) | Overseas (US2SA) | SA (Saix.Net) |
|---|---|---|---|---|---|---|
| Max | 8.40 | 2.17 | 16.28 | 367.20 | 87.00 | 407.00 |
| Min | 7.86 | 0.66 | 0.70 | 305.00 | 3.00 | 50.00 |
| Mean+Std | 8.15 | 1.30 | 9.39 | 340.80 | 61.55 | 279.20 |
| Mean-Std | 7.85 | 0.51 | -3.94 | 295.37 | 3.88 | 87.53 |
| Mean | 8.00 | 0.91 | 2.72 | 318.08 | 32.71 | 183.36 |

**Figure 13**

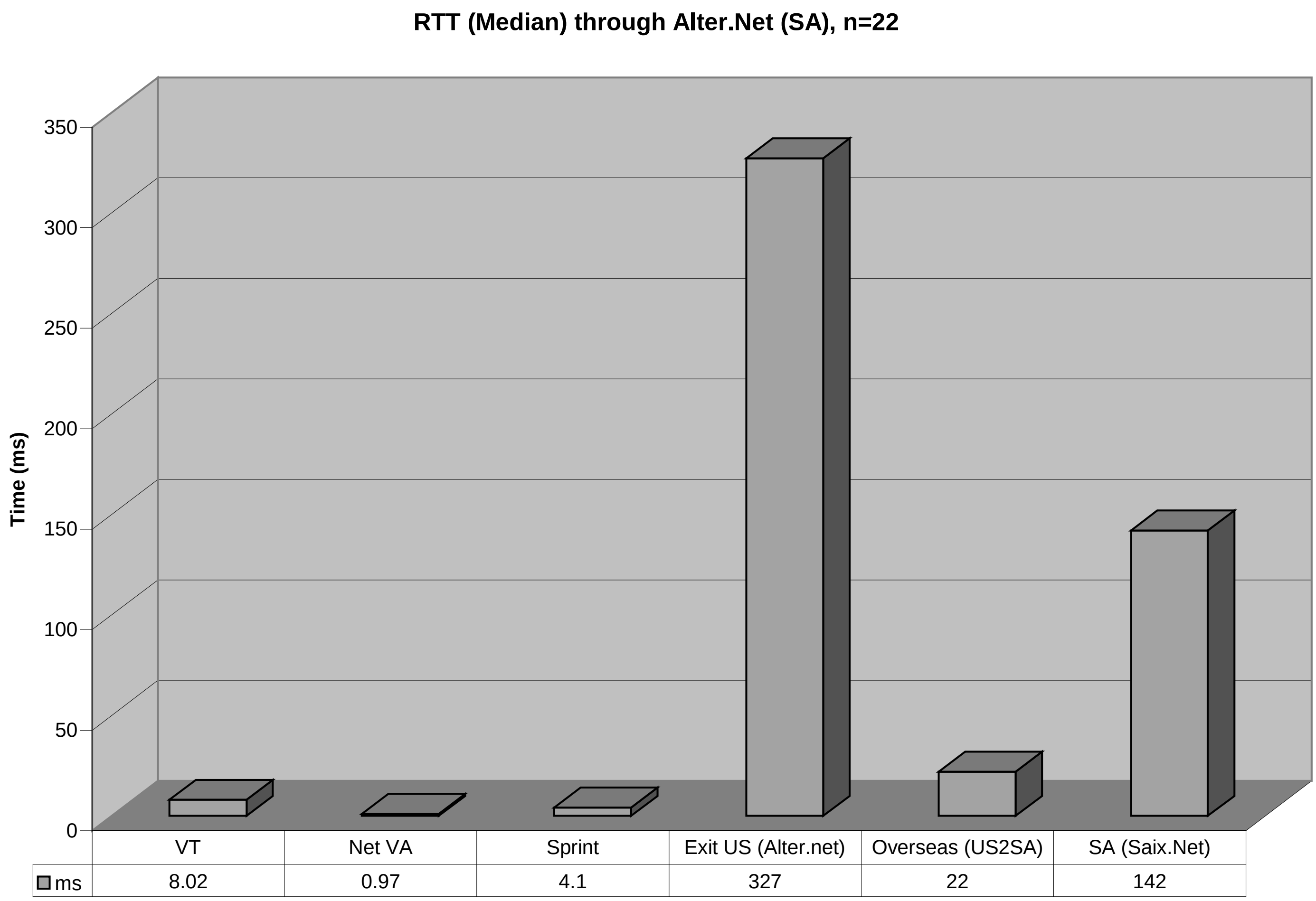

RTT (Median) through Alter.Net (SA), n=22
Time (ms)
350
300
250
200
150
100
50
0
VT
Net VA
Sprint
Exit US (Alter.net)
Overseas (US2SA)
SA (Saix.Net)
ms
8.02
0.97
4.1
327
22
142

**Figure 14**