A GUIDE TO EVALUATE THE NETWORK REQUIREMENTS AND CONDITIONS TO ORGANIZE A NETWORK MUSICAL PERFORMANCE

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Abstract

This paper is based on the authors' experience on providing technical support for networked music and arts performances. It presents a guide to verify the network requirements and conditions before planning a distributed performance. It also presents a questionnaire to help diagnosing network problems. Lastly, the paper discusses the importance of Research and Academic Networks (NRENs) on supporting artistic performances over networks.

Keywords:

RNP, network conFiguretions, telematics dance, distributed music performance

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1. Introduction

In October 2005, the Brazilian National Research and Educational Network (RNP) promoted a telematic dance demonstration created especially to celebrate the inauguration of the 5th generation of its research and education network. Given the name "VERSUS", the show brought together dancers and musicians from three cities more than 2,000 km apart from each other (Salvador, Brasília and João Pessoa) in cyberspace. The main stage was set up in Brasília, where the audience could watch local dancers interacting with dancers in Salvador through multiple high-definition video projections. Music for the show was generated and transmitted from João Pessoa (Santana, 2010).

VERSUS also inaugurated a successful partnership between artists, video application developers and network engineers, which was duplicated in many other telematic events supported by the RNP over the years.

One of the most recent and challenging performances occurred in 2013 during the 36th APAN (Asian-Pacific Advanced Network Association) conference held in the city of Daejeon, South Korea. The show, entitled "Dancing Beyond Time", highlighted the large geographic distances and time zone differences between the participating locations: Prague (Czech Republic), Barcelona (Spain), Salvador (Brazil) and the conference location in Daejeon. The dancers were distributed between Barcelona, Salvador and Daejeon. The music was performed by a trio of musicians in Prague, and transmitted in 4K resolution (4096 × 2160 pixels) resolution video to the main stage in Korea.

Dealing with the great distances between the locations involved is one of the most challenging aspects of distributed music and dance shows, as it involves delays in audio and video transmissions. Having a "fast internet", with a sufficiently large bandwidth in all show locations is not enough to ensure good transmission fluidity. In many cases, it is advisable to deploy tailored network conFiguretions, which is not commonly provided by commercial internet providers.

This article presents a guide to assist in verifying if network conditions are sufficient to put on a distributed music or dance shows. The information presented is based on best practices accumulated by the RNP and other partner networks in supporting telematic performances.

2 - Bandwidth is not everything

When planning a distributed dance or music show, it is recommendable to have a computer network specialist involved at each location, typically an IT professional responsible for network support at the campus/laboratory/studio where the artists are to perform. It is common not to include such a professional and form the technical team only with specialists in software and audiovisual equipment.

Another common error is to only check the contracted bandwidth in the show's locations (capture and display points), without verifying the actual available bandwidth. Network bandwidth, which is the data transmission capacity over the network, is important for telematic shows, but is not the only network characteristic that needs to be verified. Having ample bandwidth at all locations does not ensure a problem-free audio and video transmission.

In order to explain why bandwidth is not the only network aspect which should be taken into account, the reader must understand that all information transmitted over the Internet, whether audio or video, is divided into parts known as "packets", which are sent separately and asynchronously. When each packet arrives at its destination, it is used to reproduce part of the audio/video generated at the source and contained in the packet. With this concept in mind, it makes it easier to understand other important characteristics of a computer network, such as:

• Delay: it is the time needed for each packet to travel through the network from origin to destination. There are several factors affecting delay, such as the distance a packet needs to travel from end to end, the equipment used to transmit data/audio/video, the medium through which the packet is transmitted (cable, air, etc.) and, principally, other data flows sharing the same connection as the telematic performance. Knowing the amount of the delay is important in order to coordinate the event between the multiple locations, because the packet may take a significant amount of time to be transmitted from origin to destination. In live events with an audience present in a given location, for example, one location may have to begin its part of the transmission before another one, with the advance time being the delay between the endpoints. The shorter the delay, the better.

• Delay Variation (Jitter): delay is not constant over time, as it is affected by many factors. Jitter is more of a problem in having a good show than delay in itself. If delay t were constant (in other words, zero jitter) , it would be simple to manage, because the only task would be to determine the delay between communication points, and begin one time interval t after the other, and, from then on, both points would operate normally, without having to worry about the network. However, as delay is variable, some packets may arrive at their destination before others, and a packet could even arrive at its destination before another one which was generated before it at the origin, in other words, out of chronological order. Another problem which can happen is a packet arriving, and the ones which follow taking longer to arrive (for example, due to traffic congestion on the network), creating a "blank space" with no packet with content to be reproduced. To minimize this problem, reproduction at the destination must use a memory space known as a reproduction buffer to store packets before use. This buffer minimizes the problem of jitter by "inserting an artificial delay" at the destination. Even so, the lower the jitter, the better.

• Packet loss rate: it is the percentage of packets lost during a network communication between two points. The network is unstable, to the point that a packet may even be completely lost on the way between points. It is normal to lose a few packets, as millions of packets travel on the network over time. If a communication packet between telematic performance points is lost, it can be recovered using packet loss recovery techniques, such as FEC (Forward Error Correction) or simply ignored. The problem is when a large group of packets is lost together, exceeding the recovery capacity used, generating a blank space with no packets with content to be reproduced, leading to reproduction problems. Not even the reproduction buffer can solve this problem, as there are no packets to arrive. Thus, it is important to use a network path with a minimum packet loss rate, ideally zero.

• Network path or route: it is the path that a packet uses to go from origin to destination. Telematic performance locations are connected to each other logically, but not physically. To go from origin to destination, the packet passes through several intermediary network points. There are several paths between origin and destination. Then, if part of the path has problems, or is congested, the choice of best path for packet transmission changes, thus different packets in the same origin-destination connection may travel over different paths. It is important to be familiar with the network path in order to perform tests also involving the intermediary points.

Given the network concepts above, it is highly recommendable to put together a checklist of network characteristics before organizing a telematic performance, as presented below.

3 - Understanding and verifying network performance

In order to put on a telematic performance, firstly the network, hardware and software requirements must be evaluated. A non-comprehensive guide is presented in this section to help in organizing a dance or music show on the network.

3.1 - Align expectations

In organizing a telematic performace, the first thing to do is to understand the expectations the users (artists) have regarding the usage of the available network. To achieve this, there need to be discussions between users and network operators/technicians at each location. These discussions must seek to identify some network metrics, such as minimum required bandwidth, maximum acceptable delay and jitter and maximum tolerable packet loss rate supported by the software to be used for the telematic show.

This information should be gathered based on the local connectivity at the show display points, as well as the infrastructure capacity of the networks to be used to provide the end-to-end connectivity between the participating show locations. This connectivity involves the campus networks, access networks (e.g. metropolitan networks), regional as well as international networks.

After determining network requirements, the next step is to verify if what was defined as expected is actually available for use, in other words, the current standard network utilization must be known in order to estimate the impact the telematic performance may have.

Finally, after all this analysis, some realistic and achievable objectives need to be defined, such as, if there is connectivity with sufficient bandwidth over the entire network path. For example, if the locations are interconnected by a network with capacity of 1 Gbps, however, this network has a maximum utilization of around 300 Mbps, it is reasonable to expect that there are no more than 700 Mbps available for use. In addition, if the required delay has to be below 100ms (milliseconds) and the show display points are on different continents, this could make the show unfeasible, as the delay between continents is usually greater than 100ms, thus being a serious restriction to holding the show.

3.2 - Obtain information about the capture and display points

It is important to be familiar with the equipment and software used in the capture and display points, as often the use of improper software tools and low-performance hardware may mean that network use expectations are not attained. Regarding the hardware used, it is important to know characteristics such as the processor performance, quantity and access time of the installed memory, disk performance and usage and performance of the network and media capture cards and associated software. From the point of view of software, it is important to be familiar with the type and version of the operating system and installed applications, if network parameters have been optimized on the operating system and what network addressing is being used at the show locations. For example, if the systems are set up with public IPs addresses and what is the support IP version. With this information in hand, potential bottlenecks and localized restrictions in the capture and display points involved in the show can be identified.

Transmission bottlenecks can be caused by excessive consumption of processor capacity by the application, full use of memory capacity, lack of available disk space (sometimes the disk may be full) and also from improper conFiguretion of the equipment network conFiguretion.

3.3 - Obtain information about the network

The end-to-end connectivity of the show locations should be documented, for example, using diagrams and maps (see example in Figure 1). In these diagrams there should be markings highlighting the limits of the local networks, campus and metropolitan networks and the long-distance national and international connections. In addition, it needs to be shown which equipment is on the path starting from each show participation point until the edge of the campus network, such as routers, network switches or firewalls.

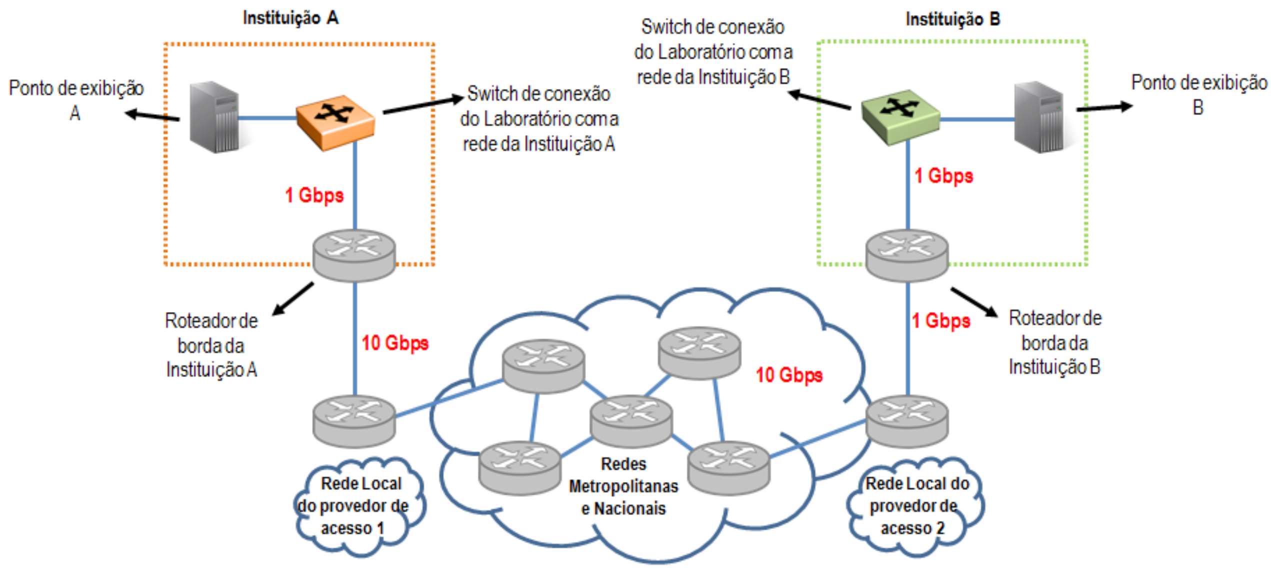

Figure 1. Example of a network diagram showing connectivity between capture and display points.

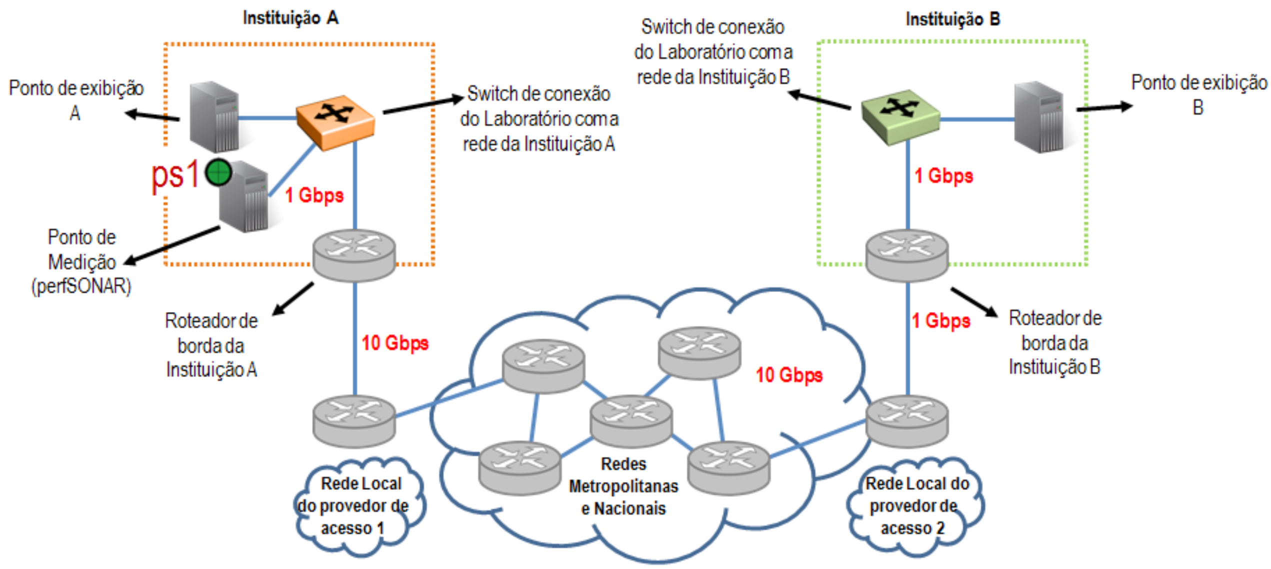

Figure 2. Temporary installation of a perfSONAR measurement point close to the capture and transmission point to perform network measurements.

3.4 - Perform measurements on the end-to-end network path

Using measurement tools, such as the perfSONAR mentioned earlier, there is a need to try and measure the reachable bandwidth, delay, jitter and packet loss ratio between points. To better understand the tests, an effort should be made to understand the network route(s) over which the data will be transmitted (Fig. 3).

It is important to check if the routing is symmetrical, that is, if the same route is used in both directions between the pair of points, otherwise measurements to be performed could be very different and undergo dynamic changes as a result of congestions or problems in some part of the network. Network engineering techniques may be adopted to determine a fixed route between points. More details are discussed in the conclusions to this article.

Finally, it is important to know the level of network utilization along the route, to have an estimate of the amount of capacity available to be used by the show (Fig. 4).

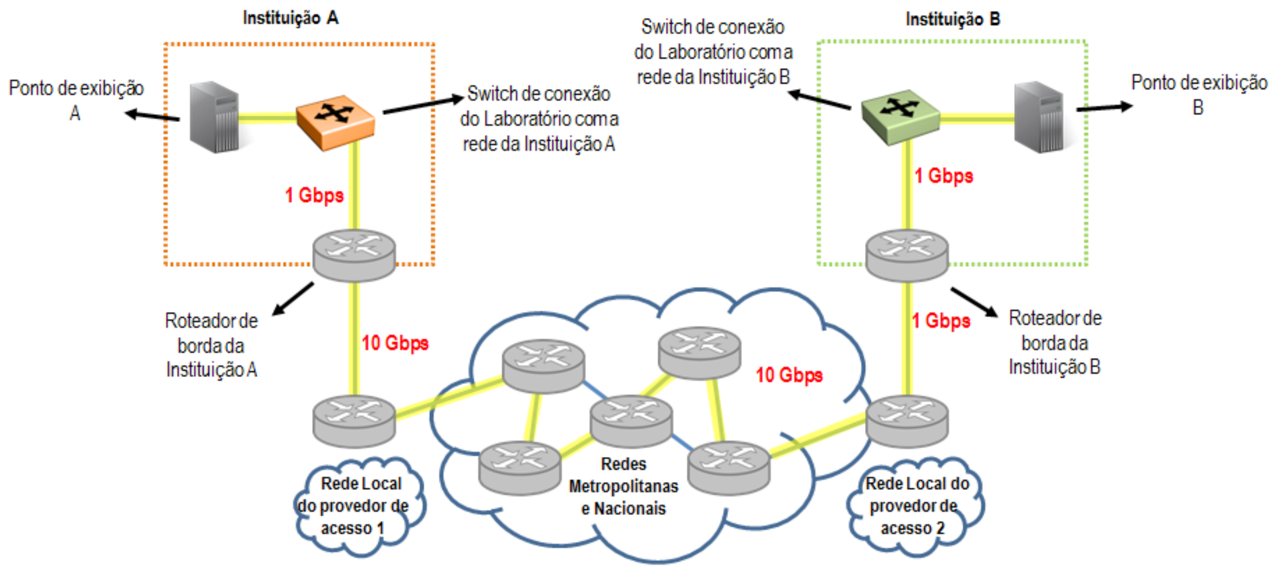

Figure 3. Discovery of the complete path between capture and display points.

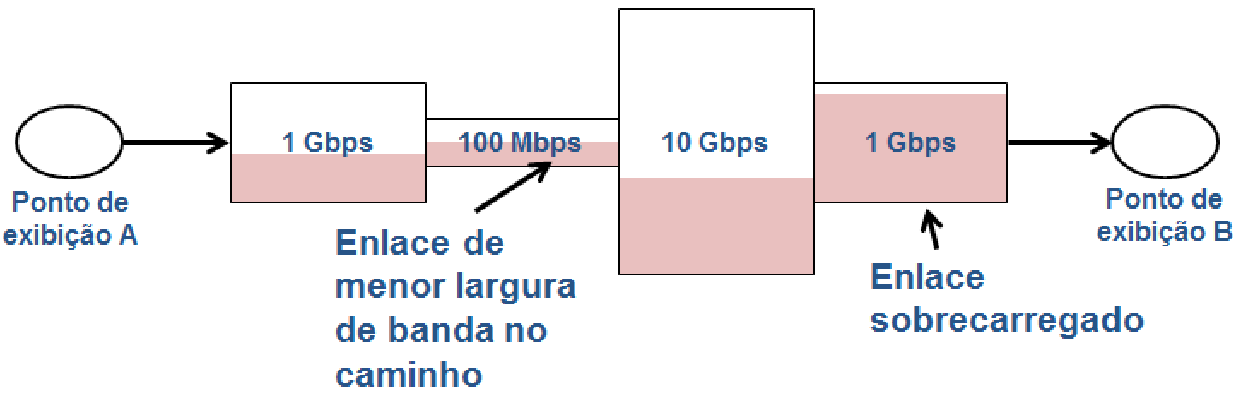

Figure 4. Diagram showing network capacity and utilization, and possible bottlenecks

To find the available bandwidth on the end-to-end path (in both directions) the following measurements can be made using two tools available in perfSONAR - nuttcp e iperf3 - both using display point A as reference:

Outbound (INSTITUTION_A → INSTITUTION_B) using **nuttcp**

```
bwctl -T nuttcp -f m -t 30 -i 2 -x -c $INSTITUTION_A
-s $INSTITUTION_B
```

For example:

```
root@dpd-rj-note04: ~
root@dpd-rj-note04:~# bwctl -T nuttcp -f m -t 30 -i 2 -x -c perfsonar.ampath.net -s ps-bw.sdmz.rnp.br
bwctl: Using tool: nuttcp
bwctl: 286 seconds until test results available

RECEIVER START

RECEIVER END

SENDER START
nuttcp-t: v7.2.1: socket
nuttcp-t: buflen=65536, nstream=1, port=5343 tcp -> 190.103.184.146
nuttcp-t: time limit = 30.00 seconds
nuttcp-t: connect to 190.103.184.146 with mss=8948, RTT=125.077 ms
nuttcp-t: send window size = 94800, receive window size = 87380
nuttcp-t: available send window = 71100, available receive window = 65535
nuttcp-r: v7.2.1: socket
nuttcp-r: buflen=65536, nstream=1, port=5343 tcp
nuttcp-r: interval reporting every 2.00 seconds
nuttcp-r: accept from 200.143.243.4
nuttcp-r: send window size = 4194304, receive window size = 4194304
nuttcp-r: available send window = 3145728, available receive window = 3145728
    0.0000 MB /   2.00 sec =    0.0000 Mbps     4 retrans
    0.0000 MB /   2.00 sec =    0.0000 Mbps     0 retrans
    0.0000 MB /   2.00 sec =    0.0000 Mbps    35 retrans
    0.0000 MB /   2.00 sec =    0.0000 Mbps     0 retrans
    0.0625 MB /   2.00 sec =    0.2621 Mbps     0 retrans
    0.1250 MB /   2.00 sec =    0.5243 Mbps     0 retrans
   11.0000 MB /   2.00 sec =   46.1376 Mbps     0 retrans
   40.7500 MB /   2.00 sec =  170.9177 Mbps    24 retrans
   46.5000 MB /   2.00 sec =  195.0351 Mbps     0 retrans
   99.0000 MB /   2.00 sec =  415.2440 Mbps     0 retrans
   53.4375 MB /   2.00 sec =  224.1331 Mbps   225 retrans
   51.7500 MB /   2.00 sec =  217.0554 Mbps     0 retrans
  108.9375 MB /   2.00 sec =  456.9090 Mbps     0 retrans
  184.2500 MB /   2.00 sec =  772.8079 Mbps     0 retrans
  190.3750 MB /   2.00 sec =  798.4962 Mbps     0 retrans
nuttcp-t: 800.2299 MB in 30.00 real seconds = 27314.48 KB/sec = 223.7602 Mbps
nuttcp-t: 800.2299 MB in 0.24 CPU seconds = 3345153.06 KB/cpu sec
nuttcp-t: retrans = 288
nuttcp-t: 12804 I/O calls, msec/call = 2.40, calls/sec = 426.80
nuttcp-t: 0.0user 0.2sys 0:30real 0% 0i+0d 440maxrss 0+6pf 141+4csw

nuttcp-r: 800.2299 MB in 30.27 real seconds = 27072.32 KB/sec = 221.7765 Mbps
nuttcp-r: 800.2299 MB in 1.30 CPU seconds = 628979.22 KB/cpu sec
nuttcp-r: 111519 I/O calls, msec/call = 0.28, calls/sec = 3684.34
nuttcp-r: 0.0user 1.2sys 0:30real 4% 0i+0d 750maxrss 0+4pf 100970+10csw

SENDER END
root@dpd-rj-note04:~# 
```

To find the network path between capture and display point (round trip) the following measurements may be made, using display point A as a reference:

Outbound (INSTITUTION_A → INSTITUTION_B)

```
bwtraceroute -T traceroute -4 -c $INSTITUTION_A -s
$INSTITUTION_B
```

For example:

```
root@dpd-rj-note04: ~
root@dpd-rj-note04:~# bwtraceroute -T traceroute -4 -c ps-bw.sdmz.rnp.br -s perfsonar.ampath.net
bwtraceroute: Using tool: traceroute
bwtraceroute: 17 seconds until test results available

SENDER START
traceroute to 200.143.243.4 (200.143.243.4), 30 hops max, 60 byte packets
 1  i2.ampath.net (190.103.184.145)  0.630 ms  0.688 ms  0.828 ms
 2  190.103.184.95 (190.103.184.95)  1.621 ms  1.738 ms  1.865 ms
 3  br-us.redclara.net (200.0.204.8)  117.006 ms  116.981 ms  117.022 ms
 4  rnp-br.redclara.net (200.0.204.214)  117.287 ms  117.310 ms  117.295 ms
 5  rj-sp-nau.bkb.rnp.br (200.143.252.70)  125.066 ms sp2-sp.bkb.rnp.br (200.143.253.38)  117.325
 6  sp2-rj-oi.bkb.rnp.br (200.143.253.222)  125.073 ms lanrj2-rj.bkb.rnp.br (200.143.255.166)  127
 7  200.143.243.4 (200.143.243.4)  124.971 ms  125.046 ms  125.002 ms

SENDER END
root@dpd-rj-note04:~# █
```

Inbound (INSTITUTION_B → INSTITUTION_A)

```
bwtraceroute -T traceroute -4 -c $INSTITUTION_B
-s $INSTITUTION_A
```

For example:

```
root@dpd-rj-note04: ~
root@dpd-rj-note04:~# bwtraceroute -T traceroute -4 -c perfsonar.ampath.net -s ps-bw.sdmz.rnp.br
bwtraceroute: Using tool: traceroute
bwtraceroute: 17 seconds until test results available

SENDER START
traceroute to 190.103.184.146 (190.103.184.146), 30 hops max, 60 byte packets
 1  200.143.243.1 (200.143.243.1)  1.268 ms  1.265 ms  1.259 ms
 2  rj-lanrj2.bkb.rnp.br (200.143.255.165)  0.195 ms  0.215 ms  0.210 ms
 3  rj-sp2-oi.bkb.rnp.br (200.143.253.221)  7.921 ms  7.942 ms  7.937 ms
 4  br-rnp.redclara.net (200.0.204.213)  9.484 ms  9.494 ms sp-sp2.bkb.rnp.br (200.143.253.37)  7.
 5  br-rnp.redclara.net (200.0.204.213)  9.492 ms  9.566 ms  9.641 ms
 6  190.103.184.94 (190.103.184.94)  125.319 ms  125.264 ms  125.368 ms
 7  ps-lt.ampath.ampath.net (190.103.184.146)  125.043 ms  125.264 ms  125.265 ms

SENDER END
root@dpd-rj-note04:~# █
```

Where: $INSTITUTION_A and $INSTITUTION_B are the name and IP addresses of the servers or measurement devices.

Outbound (INSTITUTION_A → INSTITUTION_B) using **iperf3**

```
bwctl -T iperf3 -f m -t 30 -i 2 -x -c $INSTITUTION_A
-s $INSTITUTION_B
```

For example:

```
root@dpd-rj-note04: ~
root@dpd-rj-note04:~# bwctl -T iperf3 -f m -t 30 -i 2 -x -c perfsonar.ampath.net -s ps-bw.sdmz.rnp.br
bwctl: Using tool: iperf3
bwctl: 420 seconds until test results available

RECEIVER START
-----------------------------------------------------------
Server listening on 5751
-----------------------------------------------------------
Accepted connection from 200.143.243.4, port 50936
[ 15] local 190.103.184.146 port 5751 connected to 200.143.243.4 port 37666
[ ID] Interval           Transfer     Bandwidth
[ 15]   0.00-2.00   sec  0.00 Bytes  0.00 Mbits/sec
[ 15]   2.00-4.00   sec  0.00 Bytes  0.00 Mbits/sec
[ 15]   4.00-6.00   sec   512 Bytes  0.00 Mbits/sec
[ 15]   6.00-8.00   sec  19.0 KBytes  0.08 Mbits/sec
[ 15]   8.00-10.00  sec  45.7 KBytes  0.19 Mbits/sec
[ 15]  10.00-12.00  sec   128 KBytes  0.53 Mbits/sec
[ 15]  12.00-14.00  sec  1.53 MBytes  6.42 Mbits/sec
[ 15]  14.00-16.00  sec  28.3 MBytes   119 Mbits/sec
[ 15]  16.00-18.00  sec  92.8 MBytes   389 Mbits/sec
[ 15]  18.00-20.00  sec  59.2 MBytes   248 Mbits/sec
[ 15]  20.00-22.00  sec  50.7 MBytes   212 Mbits/sec
[ 15]  22.00-24.00  sec   103 MBytes   431 Mbits/sec
[ 15]  24.00-26.00  sec   182 MBytes   764 Mbits/sec
[ 15]  26.00-28.00  sec   190 MBytes   798 Mbits/sec
[ 15]  28.00-30.00  sec   190 MBytes   798 Mbits/sec
[ 15]  30.00-30.13  sec  11.9 MBytes   798 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[ 15]   0.00-30.13  sec   917 MBytes   255 Mbits/sec  267             sender
[ 15]   0.00-30.13  sec   910 MBytes   253 Mbits/sec                  receiver

RECEIVER END

SENDER START
Connecting to host 190.103.184.146, port 5751
[ 15] local 200.143.243.4 port 37666 connected to 190.103.184.146 port 5751
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[ 15]   0.00-2.00   sec  87.4 KBytes  0.36 Mbits/sec    2   26.2 KBytes
[ 15]   2.00-4.00   sec  0.00 Bytes  0.00 Mbits/sec    1   26.2 KBytes
[ 15]   4.00-6.00   sec   181 KBytes  0.74 Mbits/sec    1   10.0 KBytes
[ 15]   6.00-8.00   sec  0.00 Bytes  0.00 Mbits/sec   35   2.00 KBytes
[ 15]   8.00-10.00  sec  0.00 Bytes  0.00 Mbits/sec    0   5.00 KBytes
[ 15]  10.00-12.00  sec   221 KBytes  0.91 Mbits/sec    0   32.0 KBytes
[ 15]  12.00-14.00  sec  2.60 MBytes  10.9 Mbits/sec    0    624 KBytes
[ 15]  14.00-16.00  sec  33.0 MBytes   138 Mbits/sec    0   3.55 MBytes
[ 15]  16.00-18.00  sec   101 MBytes   425 Mbits/sec    0   8.77 MBytes
[ 15]  18.00-20.00  sec  60.0 MBytes   252 Mbits/sec  228   2.48 MBytes
[ 15]  20.00-22.00  sec  50.0 MBytes   210 Mbits/sec    0   4.48 MBytes
[ 15]  22.00-24.00  sec   104 MBytes   435 Mbits/sec    0   9.44 MBytes
[ 15]  24.00-26.00  sec   185 MBytes   776 Mbits/sec    0   12.1 MBytes
[ 15]  26.00-28.00  sec   191 MBytes   802 Mbits/sec    0   12.1 MBytes
[ 15]  28.00-30.00  sec   190 MBytes   797 Mbits/sec    0   12.1 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[ 15]   0.00-30.00  sec   917 MBytes   257 Mbits/sec  267             sender
[ 15]   0.00-30.00  sec   910 MBytes   254 Mbits/sec                  receiver

iperf Done.

SENDER END
root@dpd-rj-note04:~# █
```

Inbound (INSTITUTION_B → INSTITUTION_A) using **nuttcp**

```
bwctl -T nuttcp -f m -t 30 -i 2 -x -c $INSTITUTION_B
-s $INSTITUTION_A
```

Inbound (INSTITUTION_B → INSTITUTION_A) using **iperf3**

```
bwctl -T iperf3 -f m -t 30 -i 2 -x -c $INSTITUTION_B
-s $INSTITUTION_A
```

Whenever possible, it is important to use intermediary points on the end-to-end path to perform these measurements, in order to make it easier to identify bottlenecks along the path.

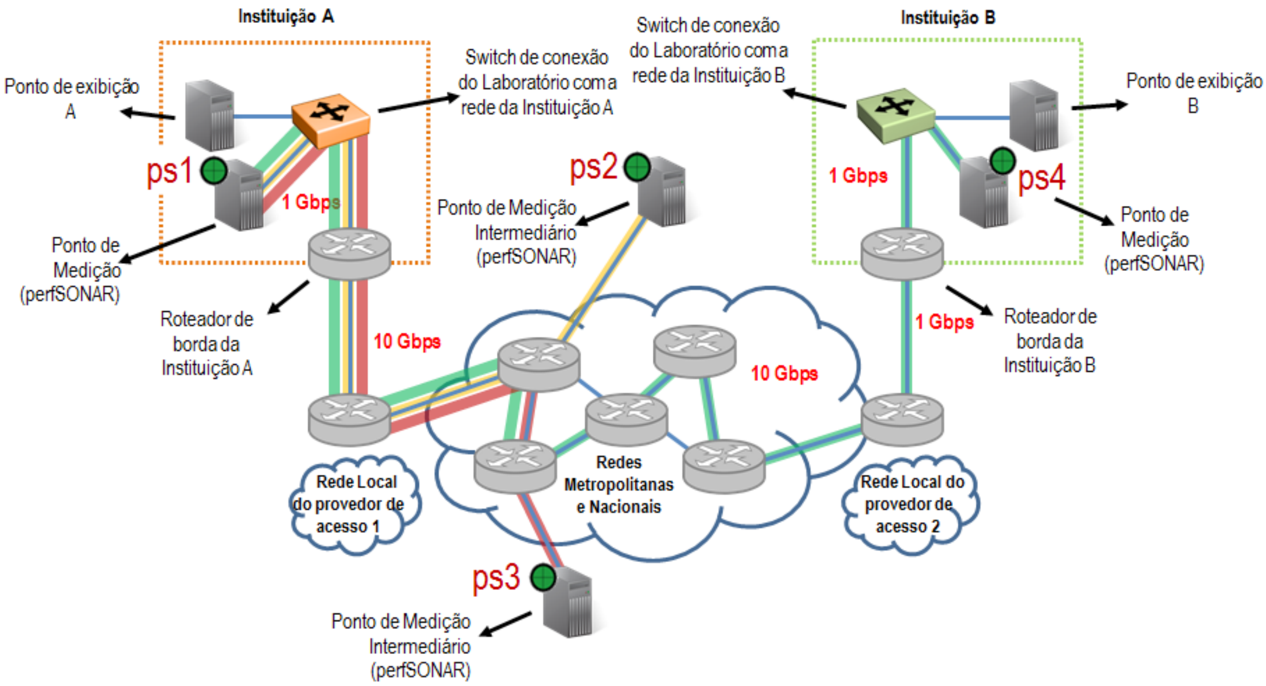

Figure 5. Using intermediary points with perfSONAR for measurements along the end-to-end path.

4 - Questionnaire for problem diagnosis

After analyzing the results obtained by the measurements described in the preceding sections, if network problems are observed, the following questionnaire may help in diagnosis.

1. Is there sufficient bandwidth available on the end-to-end path to meet the demand for the music and dance performance on the network?

a. If yes, ok!

b. If not, what are the points on the network where the available bandwidth is insufficient?

2. Do you have management over these points in the network where the available bandwidth is insufficient?

a. If yes, try to correct the problem.

b. If not, look for someone able to take action depending on whether the network points is inside or outside the administrative limits of your institution.

3. What are the limits of delay jitter and packet loss needed in order to hold the telematic performance? Were these limits obtained using test results?

a. If yes, ok!

b. If not, you should contact the network's technical department, in both institutions and ask: what can be done to attain them?

4. Is the routing symmetrical?

a. If yes, ok!

b. If not, you should contact the network's technical department, in both institutions where the capture and display points are located, to verify network configurations.

5. On the networks which connect the show locations (capture and display points), are there technologies that can guarantee available bandwidth, reduce or eliminate jitter and packet loss, such as configuration of dedicated virtual circuits?

a. If yes, ok! Ask the network providers to use these technologies.

b. If not, look for alternatives discussing with both network technical teams at the institutions where the capture and display points are located and the academic networks (NRENs) involved in the end-to-end path.

5 - Conclusion

RNP is not the only academic network supporting telematic performances. There are educational and research networks in other countries, which also support the development of applications and creation of working groups to assist in putting on cyber-performances (Doyle 2014, Faridah 2006, GÉANT 2015). This occurs because interactive multimedia applications are very sensitive to network quality, as any streaming problems that are not properly corrected during the transmission can be easily perceived by users in the form for of distortions, delays or lack of synchronism in the audio and/or video.

These "problems" affecting multimedia transmissions are inherent to the internet, which is a communication network with several paths for data transmission between two points. Actually, this characteristic was fundamental to the success of the internet. If one segment of the network has problems or is congested, data transmission is dynamically rerouted using another path, which may be longer than the one previously used, modifying delay and increasing its variability.

To avoid the problems of excessive jitter and inadequate bandwidth along the route, the solution is to determine the route to be used and guarantee (overprovision) the bandwidth available for the transmission, a technique also known as defining a virtual circuit with a guaranteed bandwidth. The availability of this resource nowadays is a result of the increased quality and capacity of academic networks, and the high level of collaboration among them to support joint projects. In other words, holding telematic performances is an excellent demonstration of the quality of the global academic networks , formed by the strong collaboration between the different, national and continental networks, serving the global academic community.

It is important to recognize nowadays that it is not practical to ask a commercial provider to create a personalized virtual circuit to serve locations in a telematic performance, except in the rare case where the entire end-to-end route belongs to the network of a single provider, as there is no real collaboration between competing providers to jointly improve service quality.

On the other hand, it is normal for educational networks to collaborate among themselves, at no cost, to provide end-to-end network support for distributed dance/music demonstrations. In the show "Dancing Beyond Time", for example, the High Performance Digital Media Network (HPDMnet) was used for audio and video transmission between locations. HPDMnet is a consortium between some educational networks which provides a dedicated virtual network infrastructure for multimedia transmissions. This is just one of the not uncommon examples of how educational and research networks collaborate among themselves to support distributed network performance.

This article presents a compilation of best practices to determine the necessary network conditions to hold a telematic performance, based on the authors' experience in technical support for this type of event.

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