eVLBI Development in TIGO*

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Abstract. Very Long Baseline Interferometry (VLBI) is a geometric technique which measures the time difference between the arrivals of a radio wavefront emitted by a distant quasar to at least two Earth based radio telescopes. Because the time difference measurements are precise to a few picoseconds, VLBI determines the relative positions of the cooperating radio telescopes to a few millimeter and the positions of the quasars to a few milliarcseconds. The transfer of the collected data from the radiotelescopes to the correlation centers is made through physical shipment of data discs which implies a delay of weeks in the turnaround. eVLBI is a technique which allows the direct transmission of the data to the correlators through Internet with multiples advantages. TIGO is a VLBI station located in Concepción, Chile with a limited bandwidth of few Mbps which must be increased in order to achieve an usable speed to work as an eVLBI station. The challenge and approaches to dodge the difficulties of achieving eVLBI in TIGO are explained in the present paper.

Keywords: Astronomy, Geodesy, VLBI, Network, Internet, Multipath Routing.

1 Introduction

Global reference systems are realized by measuring platforms, which represent reference points in the universe or on the Earth. Measurements between reference markers contain information about the relationship between them. This relationship can be expressed as directions or distances at a given epoch.

The existing reference frames are used in a hierarchical manner. The geodetic principle *from the big to the small* is applied here. Therefore quasars at the edge of the known universe form a quasi-inertial celestial reference frame (CRF) in which the position of the Earth is determined. On the next hierarchy level

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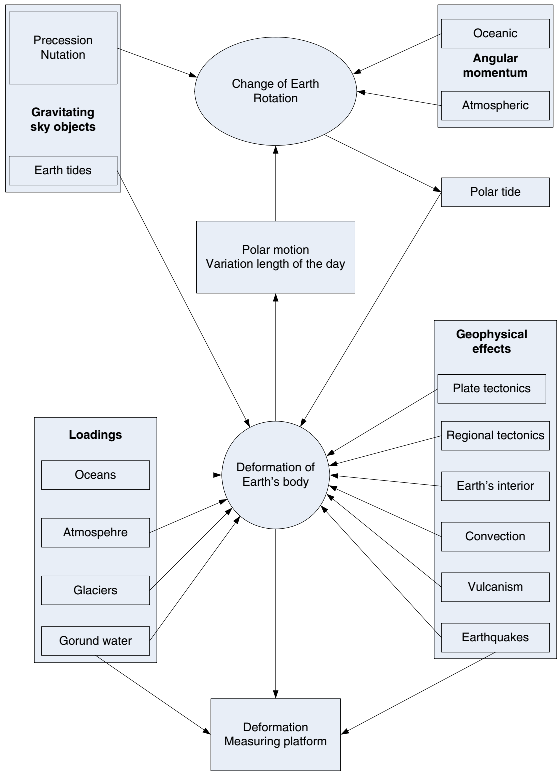


Fig. 1. Geodynamic phenomena with significant signals in measurements with geodetic space techniques. A proper modelling of the phenomena allows the determination of precise global reference frames [10].

comes the terrestrial reference frame (TRF). Any other continental, national, regional or local geodetic network appears in subsequent steps in the hierarchy of reference frames and makes use of reference points of the preceding level as an outer large scale frame. It is therefore mandatory that the most precise measuring techniques are applied at geodetic observatories, which have to supply data for the generation of the celestial and terrestrial reference frames. The reference points at different continents require measurements with techniques, which provide the relation between them. These techniques are summarized as geodetic space techniques.

The measurements of geodetic space techniques are biased due to geodynamic phenomena which vary the observation conditions at individual network stations. These local effects must be monitored in local surveys in order to complement the geodetic space techniques. The correct modeling of the geodynamic phenomena (Figure 1) allows finally the determination of precise reference frames.

The most remote objects in the universe are quasars in a distance of about 3-15 billion light years. Those objects can be detected with very sensitive radiotelescopes. With the Very Long Baseline Interferometry (VLBI) technique it is possible to relate the position, orientation and rotation of the Earth to the quasi-inertial reference frame realized by quasars. Due to the large distance of the quasars the gravity field of Earth is not predominant in the VLBI measurements.

eVLBI is a technique which allows to analyze the data for the correlators as long as they are captured. TIGO (http://www.tigo.cl) is a VLBI station located in Concepción, Chile, with a limited bandwidth of few Mbps. This paper deals with the challenge and approaches for achieving eVLBI in TIGO.

2 VLBI

Very Long Baseline Interferometry (VLBI) is a geometric technique which measures the time difference between the arrivals of at least two Earth based radio telescopes of a radio wavefront emitted by a distant quasar as is shown in Figure 2. Because the time difference measurements are precise to a few picoseconds, VLBI determines the relative positions of the cooperating radio telescopes to a few millimeter and the positions of the quasars to a few milliarcseconds [1]. The very distant quasars provide an inertial reference frame which is two orders of magnitude more accurate than the well-known fundamental catalog of fix stars FK5. Since the radio telescopes are fixed on the rotating Earth, VLBI tracks instantaneously the orientation of the Earth in an inertial reference frame, indispensable information for any kind of satellite orbit determinations and space navigation.

VLBI observations, as a microwave technique, can be performed under all meteorological conditions. The elements of a geodetic VLBI station consists in general of:

– A radio telescope with a cryogenic dual band S/X-band receiver.
– A data acquisition terminal for bandwidth frequency synthesis
– A hydrogen maser as very precise frequency standard to which all local oscillators in a VLBI-system must be phase-locked.
– A data formatting and a recording device for the temporary storage of digitized quasar noise.

Usually the VLBI-data are acquired during 24h on about 30 quasars in about 300 different directions. The VLBI-data consists of digitized noise from the quasar and is recorded with a time stamp on magnetic tapes or hard disks arrays at the stations. After the completion of the observations within an experiment, the magnetic tapes or disc arrays must be shipped from all co-observing stations to a VLBI correlator. After the arrival of these tapes the interferometer is setup at the correlator. The correlation process plays back the recorded data from all the station simultaneously and the processor searches for the maximum of the cross-correlation function. The correlator output are the fringe phase and the fringe amplitude from which the delay and delay rate of the wavefront can be derived. The delay is the primary observable in geodetic VLBI. Radioastronomers

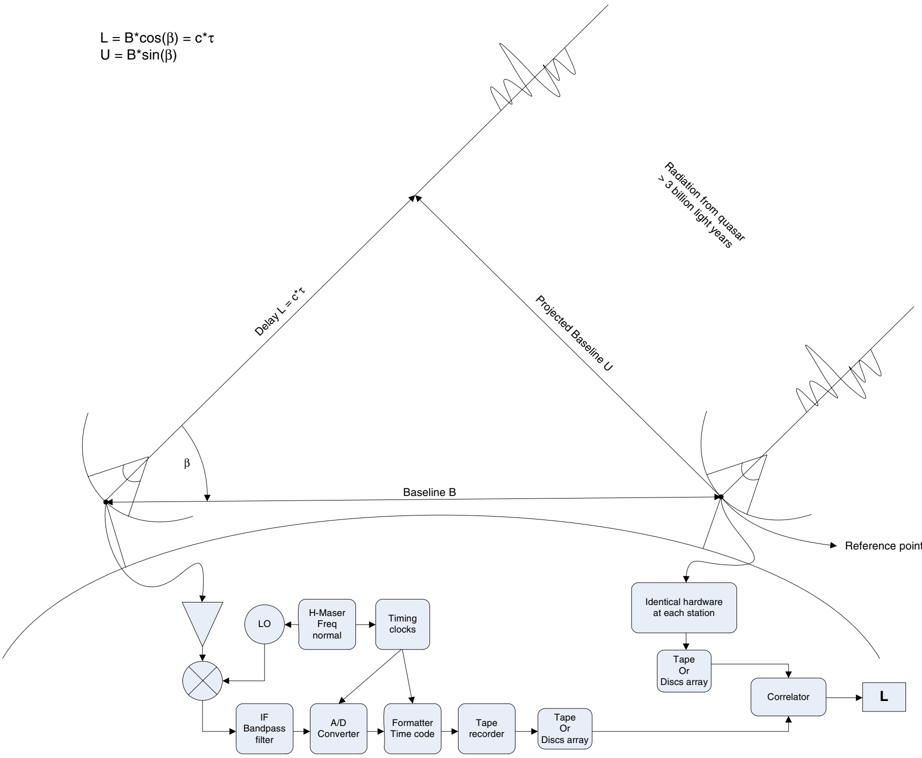


Fig. 2. Principle of Very Long Baseline Interferometry shown in a tape recorder correlation interferometer [10]

are using from the VLBI data the fringe phase and amplitude of the correlation process to derive images of the radio objects.

Usually the VLBI operation is scheduled within the International VLBI Service (IVS). The main program is the continuous observation of the rotation of Earth (CORE) in which a VLBI station observes in different global VLBI networks one to three times a week for 24 hours. Each 24 hours experiment consists of about 300 quasar observations about 3-5 minutes each.

3 eVLBI

Every year near 3 Petabytes of VLBI data are recorded on magnetic tapes or hard disks and physically transported to one of the few VLBI correlator sites (3 in The U.S., 2 in Europe, 2 in Japan and 1 in China). It's expected that this data volume will increase rapidly in the coming years. Disks and/or tapes are erased and re-cycled to between the telescopes and the correlation centers after correlation processing. This means that the data is ready to be used by the correlator near one week after the data is captured. This fact and other technical reasons had pushed to develop research about e-VLBI implementations.

e-VLBI has been developing rapidly in past 2-3 years, with increasing amounts of data transferred electronically, around 50 TB transferred in 2004 and 300 TB were transferred in 2005.

e-VLBI technique offers many advantages over the current operation:

- Bandwidth growth potential for higher sensitivity. VLBI sensitivity (SNR) is proportional to square root of bandwidth resulting in a large increase in number of observable objects. The only alternative is the use of bigger antennas but this is a more expensive alternative.

$$\Delta S \approx \frac{1}{\sqrt{B \times T}} \frac{T_{sys}}{A} \tag{1}$$

  where ΔS is the noise in flux density, T_{sys} is the noise expressed as system temperature, B is the bandwidth, T is the integration time and A is the radiotelescope area.
- Rapid processing turnaround. In astronomy it gives the ability to study transient phenomena with feedback to steer observations. In geodesy higher precision measurements for geophysical investigations can be achieved and better earth-orientation predictions can be obtained, particularly UT1, important fact for military and civilian navigation. The growth of the bandwidth will produce a need of growth of storage capacity therefore a near real-time processing will be necessary at the correlator side.
- Lower costs. The media pool represents a great cost that can be removed. Big bandwidths make possible to lead the VLBI stations to an automated operation eliminating manual handling and shipping of storage media.
- Increased reliability. Removal of recording equipment and tapes or disks shipping will increase the robustness of the process. The use of high speed networks will allow at the same time remote performance monitoring and control capability in near real-time which can lead the station to a full automation.

4 Current Status

The international Internet connection of TIGO can be divided in 3 sections as is shown in Figure 3:

- The path from the TIGO facility to the University backbone.
- The link between the University and the REUNA (Red Universitaria Nacional) academic Chilean network.
- The REUNA International link.

The current configuration has a total speed of 5Mbps. In the last mile connection from TIGO to the University there is an optical path with a monomode optical fiber with a speed of 100Mbps. The connection between the University and REUNA has a speed limited to 15 Mbps for national traffic with a capacity

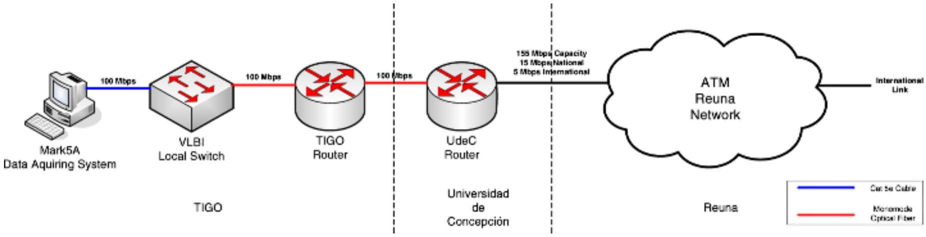
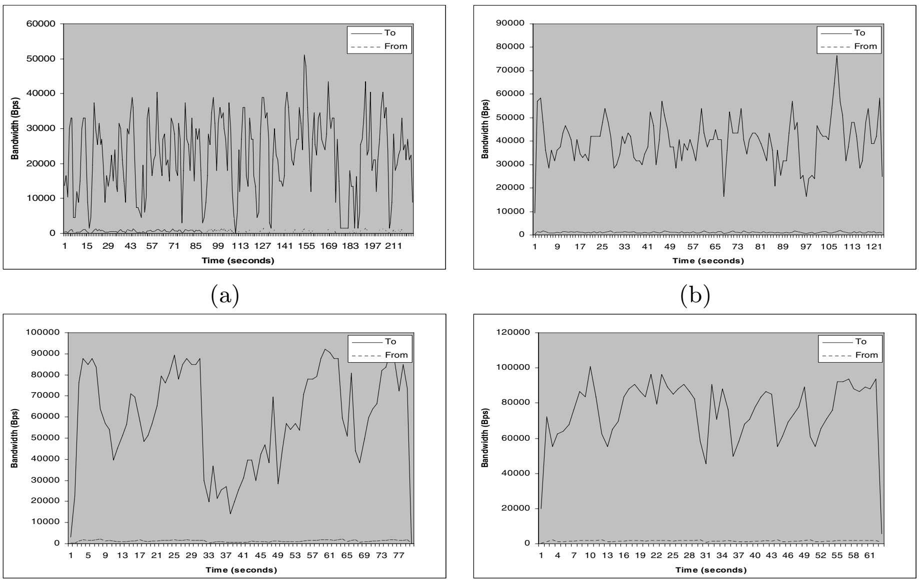


Fig. 3. Current status of TIGO connection



(a) (b)

(c) (d)

Fig. 4. a) Speed results of transferring from Concepción to Boston during working hours. b) Speed results of transferring from Concepción to Boston during non-working hours. c) Speed results of transferring from Concepción to Bonn during working hours. d) Speed results of transferring from Concepción to Bonn during non-working hours.

of 155 Mbps. The international link of REUNA has a capacity of 96 Mbps, but the University has a contract for 5 Mbps only.

A test of the real speed connection from Concepción to United States and Germany is shown in Figure 4. This test was conducted during working and non-working hours sending a 4 MB file to show the influence of the Universidad de Concepción traffics. The results show a clear influence of the difference between working and non-working hours and the destiny. The transmission to United States is slower due to high demand of commercial sites over there. The average speed obtained for a transfer to Boston during working and non-working hours was 21.8 and 38.8 KBps respectively. For a transmission to Bonn the speed was 58.9 and 73.5 Kbps for working and non-working hours, respectively.

5 Approaches

There are two possible solutions to increase the final speed of the connection. It's possible to use Multipath Routing or increase the bandwidth identifying the bottlenecks and upgrading the links and/or equipments.

In 2004 the first world wide eVLBI test was made among Britain, Sweden, Holland, Poland and Puerto Rico with a total speed of 32 Mbps. At the end of 2005 United States, Japan, Sweden and Holland were connected at 512 Mbps in other eVLBI experiment. Therefore a minimal speed of 32 Mbps can convert TIGO into an eVLBI station, however higher speeds will benefit the sensitivity of the station.

5.1 Multipath Routing

eVLBI has special requirements since it needs a fix point to point path between the VLBI station and the correlation facilities. It has been proved that the use of multiple streams can increase the final speed of a connection since it's possible to bypass bottlenecks using alternative routes [5].

A closer look of the Reuna network shows that while the infrastructure can support higher speeds, the final speed of every connected university is limited due the inherent sharing feature of Reuna. Besides the speed achieved for international connections is limited by contract for each university. This scenario gives the opportunity to apply the Multipath Routing as a plausible solution for eVLBI transmissions at high speeds.

In Figure 5 a Multipath Routing scheme is presented. The main route path is what is obtained when a connection is done using default routing algorithms, like OSPF [12] or BGP [13] limited by the constraints described before. The alternative routes can be used to send data as parallel streams to the destination. In the Reuna particular case, Universidad de Concepción has a bandwidth of 15 Mbps for national traffic but the international traffic is limited to 5 Mbps, with the installation of custom eVLBI data routers in other universities it is possible to bypass the international speed restriction of Universidad de Concepción *masquerading* the data to the correlators as national traffic increasing the total speed.

The expected result is a theoretically raise of the transmission speed from 5 Mbps to 15 Mbps. However, the imminent upgrade of Reuna network to 1 Gbps will allow higher speeds.

5.2 Expres Project

The Expres project [14] aims to identify the bottlenecks of the route from the TIGO VLBI station to a correlator in Europe and expand the bandwidth in order to join the European VLBI network as an eVLBI station. The lowest speed of the path from TIGO to Europe is limited by a contract bandwidth of 5 Mbps

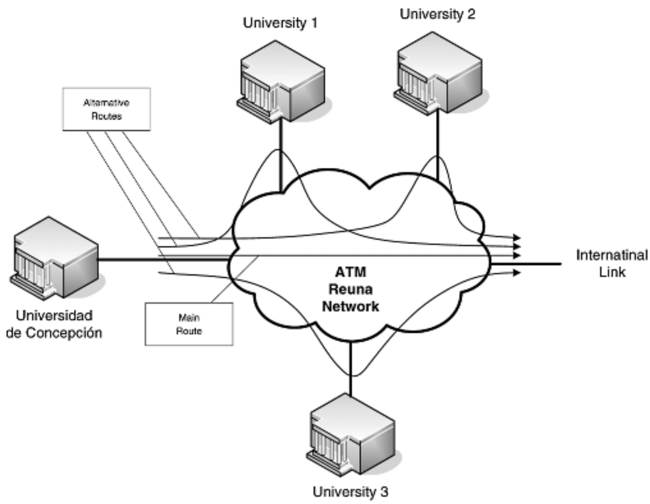


Fig. 5. Multipath Routing in Reuna Network

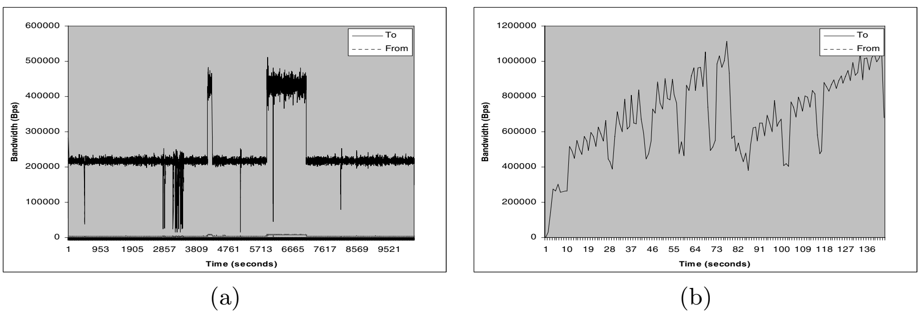


Fig. 6. a) Speed results of transferring from Concepción to Netherlands when Reuna restrictions applied. b) Speed results of transferring from Concepción to Netherlands without any kind of restriction.

provided by Reuna. This speed can be increased buying more bandwidth up to 64 Mbps (96 Mbps are available but $\sim$ 32 Mbps are in use as normal traffic). Besides, in order to achieve this maximum speed it's necessary to release the 15 Mbps constraint of Universidad de Concepción, which can be selectively made by Reuna for the TIGO traffic only. The path from TIGO to Universidad de Concepción has a total speed of 100 Mbps which is not a problem but there are plans to upgrade this path to 1 Gbps. Therefore, 64 Mbps is the expected total speed for the Expres project if no change is made in the Reuna network.

The first step is to find the bottlenecks along the path in order to identify a needed upgrade of the equipments/links involved. According to this, Reuna opened their restrictions with interesting results. Two test were conducted to JIVE VLBI correlator in Netherlands which are shown in Figure 6. The first test was made using two parallel streams with a per flow restriction applied in the Reuna border router linked to Concepción. The first streams was started with an upload speed of $\sim$ 200 KBps, at 68 and 98 minutes of transmission a second stream was started with a resulting total upload speed of $\sim$ 400 KBps. The second test was made without any restriction in TIGO, Universidad de Concepción, Reuna or JIVE VLBI correlator networks showing that a restriction of 10 Mbps exists.

6 Conclusions

The VLBI technique and its contribution to the earth geometry measurements and rotation parameters has been shown. At the present time, the speed achieved by TIGO is not enough to be an eVLBI competent station for the VLBI network. However two approaches were discussed. The use of cooperative nodes from other universities connected to Reuna is a plausible solution. Also, the Expres project in execution can remove the bottlenecks buying bandwidth or upgrading equipments where it's possible. Further, in the near future a creation of custom VLBI data routers software for Linux is planned.

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