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Multipath routing for eVLBI

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ABSTRACT

The very long baseline interferometry (VLBI) technique currently demands data storage resources of about 2 TBytes per day which must be analyzed in correlation centers. The current process involves the physical storing and shipping of magnetic disks to these centers, where up to 5 days are needed for transportation. The need of a fast turnaround opened a new research line where all the collected data of observing radiotelescope stations is sent over the Internet. This technique is called eVLBI. Ideally the station is part of a National Research and Education Network (NREN) where multiple intercontinental routes are available. Under this scenario a new protocol has been developed which allows multiple parallel data flows with important throughput improvements. The unique properties of VLBI data imply the development of a custom load control based on user datagram protocol (UDP). A description of the new protocol and performance comparisons of the first demonstrations for eVLBI performed at the Transportable Integrated Geodetic Observatory (TIGO) are included in the present article.

1. Introduction

The very long baseline interferometry (VLBI) is a geodetic and astronomical technique (Takahashi et al., 1997) with extensive demands of data storage of an average of 2000 GBytes in a regular 24-h experiment. The collected data must be sent to correlation centers where the measurements of all stations related to the International VLBI Service (IVS, Schlüter and Behrend, 2007) network are correlated and the solution of the interferometer is determined. Currently the data are recorded on hard disk modules, which are sent using normal couriers to the correlation centers, often located far away from the observing stations. The fast turnaround among a lot of other advantages achieved using online correlation has opened a new line of investigation called eVLBI (Rushton et al., 2007), which aims to send the data online through a communication infrastructure, such as the Internet.

The network requirements for eVLBI are different compared to the normal traffic found on the Internet, hence new protocols must be developed to achieve a reliable eVLBI technique. The special features and requirements of eVLBI can be summarized as follows:

- It should not be affected by long delay routes.
- It can tolerate a certain packet loss level.
- The data must be delivered in sequential order to the correlation process.
- It needs a large bandwidth over two fixed points: the observing station and the correlation center in order to reach a high signal to noise ratio.

The first three items cannot be satisfied using the well-known transport control protocol (TCP, Postel, 1980), real time protocol, (RTP, Schulzrinne et al., 2003) or user datagram protocol (UDP, Postel, 1981). Therefore, a new load control protocol has to be designed for eVLBI applications. The main purpose of this paper is to describe the development of such protocol and to apply it at Transportable Integrated Geodetic Observatory (TIGO).

The large bandwidth requirement can be met by upgrading links and/or equipments (EXPReS, 2005). However, the connectivity infrastructure of some countries is rather limited and the future investments are unlikely to be sufficient. Therefore, a different approach must be found to obtain sufficient bandwidth using the available infrastructure and make eVLBI feasible in such places. Under the above mentioned conditions, multipath routing seems a good approach to reach the required bandwidth.

Lately multipath routing has turned into an attractive research area, but despite its popularity, and due to several reasons (Löfman, 2005), it has not been widely deployed being limited to intra-domain levels only (Lee and Choi, 2002). Thus, a global solution for multipath routing using the current infrastructure must be developed. The work presented in Andersen et al. (2001)

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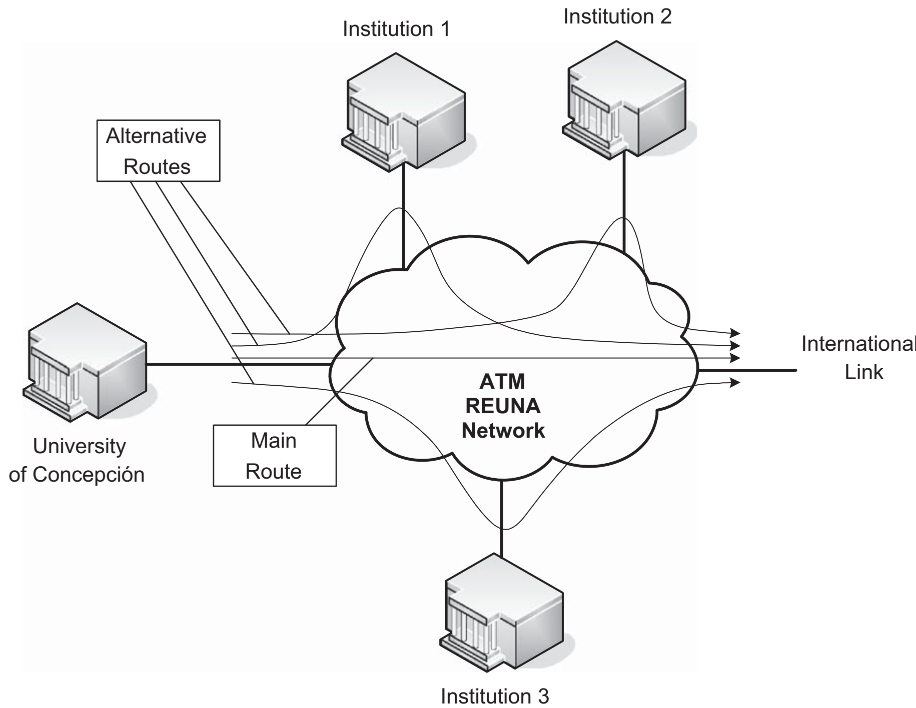

Fig. 1. Chilean NREN REUNA (Red Universitaria Nacional) configuration with some possible alternative routes.

is oriented towards this direction, but its design objective is not necessary to increase the bandwidth.

Usually, some VLBI stations are located near university facilities with very wide network links, and the universities in turn are connected to a high speed National Research and Education Network (NREN). The international outgoing links are usually managed for every institution according to their own contracts, and that is where eVLBI traffic bottlenecks are commonly located. An example is shown in Fig. 1 which depicts the University of Concepción connection to the Chilean NREN REUNA. The international link of the University of Concepción is managed by the NREN, which also manages the restrictions of the other institutions connected to it. This configuration allows the use of different parallel routes overcoming the limitations imposed by the main route (Lougheed and Rekhter, 1991; Malkin, 1998; Moy, 1998). Different configurations also have alternative routes allowing significant increases of the available bandwidth compared to the default single route scheme.

Following the example, a good candidate to benefit from multipath routing for eVLBI is the Chilean fundamental geodetic station TIGO, which is connected to the backbone of the University of Concepción. Similar cases can be found in other southern hemisphere stations, where presence in the IVS network is essential for its performance (Nothnagel, 1991).

This paper is organized as follows: the mathematical framework underlying the developed protocol for eVLBI is covered in Section 2. The algorithm proposed to organize and control the data flow is summarized in Section 3. The comparison between the novel algorithm and an ad-hoc challenging scheme is shown in Section 4. Finally, the main contributions of this paper are discussed in Section 5.

2. eVLBI multirouting mathematical background

Since the development of the eVLBI protocol mainly covers two areas of interest, we divide this section into multipath routing and load control. The main issues to address in the development of the multipath routing algorithm are related to the splitting and the rejoining of data across a number of paths with different properties. Moreover, the challenges to overcome in proposing a load control technique for eVLBI deals mainly with the design aspects aiming to a correct load management exerted over the network.

2.1. Multipath routing mathematical background

After a close inspection to some NREN networking maps, it is possible to find a number of alternative outgoing paths to any of the default ones. If it is possible to send the data across several alternative routes, the bandwidth of each one has to be added resulting in a significant increase of the available bandwidth with respect to the default route.

As the main objective of this work is to increase the available bandwidth, a cooperative solution is researched where partners donate part of their bandwidths resulting in a number of parallel streams from the station to the correlation centers.

As long as the VLBI data travels through alternative routes, the various data streams suffer different delays along the path (see Fig. 2). Since there is a need of delivery in sequential order, the receiver must wait some time for the packets traveling through the slowest route and rearrange them before the final writing. This delay time can be calculated using the following equation:

$$\tau = \beta\overline{D}_{\max} - \overline{D}_{\min} \quad (1)$$

where τ is the waiting time, $\overline{D}_{\max}$ and $\overline{D}_{\min}$ are the maximum and minimum average delay within the set of routes respectively and β is the delay variance factor which compensates the effect of load increases with a suggested value of $\beta = 2$ (Postel, 1981).

This waiting time can be accomplished at the receiver by using a buffer. The associated buffer size B is determined by

$$B = \tau \sum_{n=1}^{N} W_n \quad (2)$$