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VLBI2010: Networks and Observing Strategies

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Abstract

The Observing Strategies Sub-group of IVS's Working Group 3 has been tasked with producing a vision for the following aspects of geodetic VLBI: antenna-network structure and observing strategies; source strength/structure/distribution; frequency bands, RFI; and field system and scheduling. These are high level considerations that have far reaching impact since they significantly influence performance potential and also constrain requirements for a number of other WG3 sub-groups. The paper will present the status of the sub-group's work on these topics.

1. Introduction

The formation of Working Group 3: VLBI2010 was motivated by: 1) deficiencies of the current system, e.g. aging electronics and antennas, growing S-band interference, sub-optimal networks, etc; 2) advancing requirements in terms of accuracy, duty cycle and timeliness; and 3) recognition that the cost of currently planned operational modes is not sustainable indefinitely. Early indications are that WG3 is considering a bold vision for the future. For the first time in history, the geodetic VLBI community is contemplating the specification of an internationally funded global "instrument" for the establishment and maintenance of geodetic reference frames.

In order to constrain the scope of this discussion, it will be helpful to begin by looking at future accuracy requirements of geodetic VLBI. The most strict requirements typically come from scientific applications where it is generally agreed that long term accuracy of geodetic reference frames will be needed at the level of 1mm or below. Since WG3 is looking a decade or more into the future, it would be prudent to aim for accuracies significantly below the 1mm level so that its recommendations don't become prematurely obsolete. In addition, it is generally agreed that observations of EOP are required continuously.

What does 1mm accuracy mean in terms of the primary geodetic VLBI observable, the delay? In terms of systematic error, the answer is clear. If you want to guarantee unbiased long term accuracy below the 1mm level, then the sum total of all systematic contributions to delay must be below 3ps (1mm equivalent light travel). It goes without saying that this is a daunting task. With respect to random measurement error, the answer is less clear-cut since the connection between delay precision and baseline precision involves complex interactions that include elements such as network size and geometry, the observing schedule, etc. However, a rough idea of the requirement was obtained by scaling the post-fit residuals of a typical R1 experiment by the ratio of the achieved R1 baseline precision relative to a target precision of 1mm. After applying some reasonable assumptions regarding added contributions due to maser and atmospheric instability, precision for delay of about 4 ps per observation was estimated.

WG3 has been divided into 7 sub-groups. This is the progress report of the Observing Strategies Sub-group. The topics assigned to this sub-group for consideration are:

- antenna-network structure and observing strategies
- source strength/distribution/structure
- frequency bands, RFI
- field system and scheduling

2. Antenna-Network Structure

Currently, there are 27 IVS network stations. Of these, 9 are in Europe, 6 in Japan and 5 in North America, leaving 7 for the rest of the globe. Many of the antennas currently in use were acquired on an “as-is where-is” basis and hence their location and performance were not optimized for geodesy.

2.1. Network Geometry

How can network geometry be improved?

First, since scale and orientation of geodetic reference frames are aggregate parameters, i.e. they are determined by making measurements at a number of stations, having more stations will in general improve the result.

Second, a more uniform distribution of stations will help, e.g.: 1) It will add to the geometric strength of adjustments. 2) If at least three stations are located on each major plate, an independent VLBI TRF can be defined. Since VLBI baseline solutions begin to deteriorate for lengths greater than about 6000km (due to lack of common sky visibility), a final constraint should be added that neighboring stations never be separated by more than 6000km.

Finally, it is worth remembering that an important asset of geodetic VLBI is the twenty years of uninterrupted data. In order to maintain and enhance this asset, these data sets should be carefully continued into the future. Consequently, as many of the new stations as is practical should be co-located at existing sites.

Reducing station capital and operating costs will make it easier to significantly increase the number of geodetic VLBI sites. In this regard, recent advances have been made in reducing the cost of small to moderate size antenna systems, e.g. the Allen Telescope Array. When this is coupled with new low cost disk recording systems and digital data acquisition systems (DAS), the potential exists for a breakthrough in the cost of geodetic VLBI stations.

2.2. Site Selection and Station Design Criteria

Achieving millimeter and submillimeter accuracy will require attention to detail. An exhaustive list of site selection and station design criteria will help minimize site related systematic errors.

With respect to **site selection** criteria, important examples might include: benign tropospheric conditions, good horizon mask; geological stability; accessibility of bedrock; lack of local interference; proximity to other fundamental geodetic measurements; etc.

With respect to **station design** criteria, important examples might include: ease and accuracy of site ties; fast slew rates; low elevation capability; well understood thermal and gravity deformations; interference tolerance; adequate sensitivity; stable and accurately calibrated electronics; etc.

It is likely that significant performance and operating benefits will result from using an identical station design at each site.

2.3. Multi-Beam VLBI

The ability to observe more than one source at a time may have advantages, e.g.: 1) The clock contribution to the delay observable will disappear in the differenced data. 2) It may allow more scans per day. 3) It may allow more than one type of observation to be made at a time, e.g. CRF simultaneous with EOP. In the past, although the benefits of multi-beam VLBI have been appreciated, it has never been implemented due to the high cost of antennas. The recent reduction in cost of high performance small to moderate size antennas, e.g. those of the Allen Telescope Array, may make this option worth reconsidering.

2.4. Site Ties

The integration of all space geodetic techniques is becoming increasingly important. Efficient determination and maintenance of accurate site ties is necessary for effective inter-technique integration. It also allows local movements of the antenna structure and pier to be separated from large scale geologic movements.

Recently, a novel approach has been proposed to improve local ties [Y. Koyama, unpublished]. The position of a small nearby antenna relative to the larger VLBI antenna can be accurately established using connected element interferometry. Since the antenna is small, if designed properly, very accurate ties could be established between it and the local monumentation. Perhaps the process can even be automated. The small antenna could also be used to verify thermal and gravitational deflection models of the large antenna.

2.5. Sensitivity

Increased sensitivity has a number of benefits: 1) The precision of the delay observable increases proportionately. 2) Shorter scans can be used (which is an important element in acquiring more scans per day). 3) System performance can be evaluated more readily. 4) Weaker sources can be observed.

In general, sensitivity is defined based on the weakest source that needs to be observed and the minimum SNR required per observation. Unfortunately, it also comes at a price. Sensitivity is a function of antenna diameter, antenna efficiency, system temperature, bandwidth and integration time. The impact on antenna diameter is of particular interest since antenna cost increases approximately as the cube of the diameter. Making an informed trade-off between sensitivity and antenna diameter will have significant impact both on system cost and future performance potential.

3. Observing Strategies

The IVS delivers global geodetic scale and orientation by contributing to the ITRF, ICRF and EOP through a series of observation types, each optimized for its own specific purposes. This somewhat complex strategy does a good job of making the best use of available resources. However, it requires compromises which limit performance.

For example, the VLBI contribution to the ITRF is established primarily through a series of 8-station observations in which certain core stations are observed repeatedly while the rest are added cyclically. Clearly, observing all stations simultaneously would provide a more robust result. This is currently not possible because of the limited number of inputs to existing correlators. Although the goal of using all available stations simultaneously will not happen immediately, the situation may improve in the not too distant future. All Mark IV correlators were built as 16-station correlators, but they have been equipped with only seven to nine station inputs. With the introduction of the much lower cost Mark 5B to replace both the Mark IV playback system and station unit, the input from all sixteen stations should be affordable.

There are also compromises with respect to the measurement of EOP. For example, the full set of EOP is only quaranteed to be determined twice per week. Although UT1-UTC is determined an additional 5 times per week using short 2-station observations referred to as the Intensives, it would be better to determine the full set of EOP daily and continuously. This is currently not possible due to a lack of station availability. In addition, larger and better distributed networks would make EOP more robust and improve the connection to the ITRF. Unfortunately, increasing network size puts further stress on station availability. This situation is not likely to improve without adding a number of VLBI stations dedicated to geodesy and designed specifically to be operationally efficient, e.g. robust and capable of unattended operation.

Because ITRF and EOP on the one hand, and ICRF on the other, have quite different observational requirements, the challenge for the future will be to find a way to optimally determine all three. A number of interesting scenarios have been considered, but more work will be required before the full range of possibilities can be explored and final contenders proposed.

4. Source Strength/Distribution

As source strength decreases, the number of visible sources increases rapidly. Having more sources available makes it possible to be more selective with respect to the source's positional stability and lack of structure. It also allows better optimization of schedules since it is more likely that a source can be found in a specified target region.

5. Source Structure

As the precision of geodetic VLBI moves into the submillimeter range, it will be necessary to review the contribution that source structure makes to the error budget. Two approaches can be taken with regard to minimizing the effect of source structure. First, an attempt can be made to select only sources with minimal structure. This is the approach taken today. In this regard, it is worth noting that weaker sources tend to have less structure and that sources tend to have less structure at higher frequencies. If required, a second, more labour intensive approach involves actively monitoring source structure and correcting for it.

6. Frequency Bands

Troublesome S-band interference and the move by the NASA Deep Space Network (DSN) from S/X band to X/Ka band are motivating a review of the frequency allocations used for geodetic VLBI. Regardless of which bands are selected, it is clear that a large separation (greater than a factor of 2) is required between the highest and lowest frequencies to effectively calibrate the ionosphere. Reasons have been proposed for frequency coverage all the way from L-band to Ka-band.

There is interest in L-band because it will allow observation of GNSS satellites (GPS, Glonass, Galileo). Direct comparisons can then be made with the GNSS, and observational access to the geocenter by VLBI may be possible.

Observations at S/X band will allow the continuation of the 30-year history of CRF in those bands.

Observations at X/Ka band is attractive because sources tend to have less structure at higher frequency, there is less interference at those frequencies, and the wider bandwidths will allow more precise group delay determinations. Ka-band observations will also support the CRF requirements for planetary navigation of spacecraft by NASA. On the negative side, sources tend to be weaker at Ka-band and everything technological is more difficult, e.g. antenna surface accuracy, support structure and pointing, coherence, etc.

Frequencies near the 22 GHz water vapour line are interesting because they may enable line-of-sight calibration of water vapour content.

More dense frequency coverage may be desirable to allow phase delay determination at moderate SNR. Phase delay is typically about an order of magnitude more precise than group delay.

7. RFI

In this communications intensive world, it is almost certain that problems with RFI will intensify. As a result, it is important for geodetic VLBI to develop a strategy to minimize the impact of RFI.

To begin, it makes sense to avoid spectral regions which are a problem everywhere on Earth, e.g. commercial satellite downlink and broadcast allocations. Fortunately, with these removed, there are still significant spectral regions available, e.g. 2.69 to 3.4 GHz, 4.8 to 6.7 GHz, 7.75 to 10.7 GHz, 12.75 to 17.3 GHz, and 22.0 to 37.5 GHz.

Next, when VLBI sites are being selected, low local interference can be set as a criterion. Sites should typically be located away from large urban areas, airports, military installations, communications repeaters, satellite ground stations, etc. Once a good site has been found, working with local regulatory agencies can ensure that within reasonable limits the low RFI situation will continue into the future.

Finally, the frequency structure used and the DAS design should be robust against RFI. For example, 1) Frequency structures that depend on critically spaced narrow channels should be avoided since RFI can cause serious degradation if even one of the channels is compromised. 2) The DAS should be designed such that only the frequencies affected by RFI will be degraded and not entire broad-band channels.