

VLBI2010: A Vision for Future Geodetic VLBI

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Abstract. This article summarizes the results of IVS Working Group 3 ‘VLBI2010’, which was charged with creating a vision for a new geodetic VLBI instrument that will meet requirements for the coming decades. This comes at a time when problems with aging antennas, a deteriorating radio frequency environment due to interference, obsolete electronics, and high operating costs are making it difficult to achieve the required level of performance. Fortunately, recent advances in antenna manufacture, digital electronics, and data transmission technology are enabling the development of systems and modes of operation unimaginable only a few years ago, along with much reduced costs. A set of criteria to be met by a future geodetic VLBI system was established based on recommendations in reports compiled by IVS, GGOS, and NASA. These criteria are: 1 mm measurement accuracy on

global baselines, continuous measurements for time series of station positions and Earth orientation parameters, and turnaround time to initial geodetic results of less than 24 hrs.

Additionally, it is also vital to continue the measurements for the determination of UT1, nutation, and the celestial reference frame. A number of performance-enhancement strategies were studied, including reducing random and systematic components of the delay observable, increasing the number of antenna sites and improving their global distribution, reducing susceptibility to external radio frequency interference (RFI), increasing the number of observations per unit time, and developing new observing strategies. Recommendations for a new observing system include small (10-12m) antennas covering a broad frequency range (~1-14GHz), high

data rates (up to 8 or 16 Gbps/station), new correlator systems, and automated data analysis. This goes along with further improvements of the VLBI data analysis software and analysis strategies. Specific steps are recommended in order to develop, deploy, and bring the new system into operation, including system studies and simulations in parallel with development and prototyping of new antenna and data-collection systems.

Keywords. Very Long Baseline Interferometry, IVS, IAG, GGOS

1 Motivation

Geodetic VLBI stands at the brink of a new era. Such societally relevant issues as climate change and natural hazards are placing ever increasing demands on performance. This comes at a time when problems with aging antennas, a deteriorating RFI environment, obsolete electronics, and high operating costs are making current levels of accuracy, reliability, and timeliness difficult to sustain. Attaining modern requirements for significantly greater accuracy, continuous data flow, and shortened times to product delivery challenge the continuing progress made by geodetic VLBI over the past 30 years. Fortunately, recent advances in antenna manufacture, digital electronics, and data transmission technology are enabling modes of operation unimaginable only a few years ago. Furthermore, the capital investment and reduced operating costs associated with the new technology make complete renewal of present infrastructure appear cost effective. A new instrument that will meet requirements for decades to come can now be envisioned.

2 Future requirements for VLBI

IVS Working Group 3 (WG3; Niell et al., 2005) was asked to examine current and future requirements for geodetic VLBI, including all components from antennas to analysis, and to create recommendations for a new generation of VLBI systems. To constrain these recommendations, a new set of criteria by which to measure the next generation geodetic VLBI system was established based on the recommendations for future IVS products detailed in the IVS Working Group 2 Report (Schuh et al., 2001), on the requirements of the Global Geodetic Observing System (GGOS; <http://www.ggos.org>) project of the International Association of Geodesy (IAG), and on the science driven geodetic goals outlined in the NASA Solid Earth Science Working

Group Report (SESWG; <http://solidearth.jpl.nasa.gov/seswg.html>). These criteria are:

- 1 mm measurement accuracy on global baselines,
- continuous measurements for time series of station positions and Earth orientation parameters,
- turnaround time to initial geodetic results of less than 24 hrs.

While the new requirements are significant challenges, it is vital to continue the measurements for which VLBI is the unique space geodetic technique:

- UT1 and nutation,
- the celestial reference frame (CRF).

UT1 and the CRF are currently defined by VLBI, and there is no alternative for the foreseeable future. It is recognized that achieving long term accuracy at the level of 1 mm or better is a daunting task.

Of equal importance VLBI, together with satellite laser ranging (SLR), must continue to provide the scale of the Terrestrial Reference Frame.

3 Strategies and recommendations to achieve the goals

From the outset WG3 sought approaches for the design of the new system that would enable the following performance enhancing strategies:

- Reduce the random component of the delay-observable error, i.e., the per-observation measurement error, the stochastic properties of the clocks, and the unmodeled variation in the atmosphere,
- Reduce systematic errors, such as thermal effects on electronics or structure, loading errors, and radio source structure effects,
- Increase the number of antennas and improve their geographic distribution, with strong emphasis on collocation with the other techniques,
- Reduce susceptibility to external radio-frequency interference,
- Increase observation density, i.e. the number of observations per unit time,
- Develop new observing strategies.

All of the above considerations, along with the need for low cost of construction and operation, required a complete examination of all aspects of geodetic VLBI, including equipment, processes, and observational strategies. The results of this examination have led WG3 to make the following recommendations:

- Design a new observing system based on small antennas. The new system will be automated and operate unattended and will be based on small (10-12 m diameter), fast-moving, mechanically reliable antennas that can be replicated economically. The observing should be done over a broad, continuous frequency range, perhaps 1-14 GHz, which includes both the current S-band and X-band frequencies for backwards compatibility, but allows much more agility to avoid RFI and more bandwidth to significantly improve delay measurement precision. At the same time, the best of the existing large antennas will be updated for compatibility with the new small-antenna system; this will allow them to co-observe with the small-antenna systems to preserve continuity with the historical record, as well as to improve measurements contributing to the CRF, which has been defined primarily by observations with the large antennas.
- Transfer data with a combination of high-speed networks and high data-rate disk systems. Data recording rates and transmission rates are rapidly increasing courtesy of vast investments by the computer and communications industries.
- Examine the possibilities for new correlator systems to handle the anticipated higher data rates, including correlation based on commodity PC platforms, possibly widely distributed.
- Automate and streamline the complete data-analysis pipeline, enabling rapid turnaround and consistent TRF, CRF, and EOP solutions.

Because the new systems should be fully backwards compatible with the existing systems, the transition from the old to the new systems can be gradual and deliberate, maintaining important continuity of geodetic results and measurements series while dramatically upgrading the quality, precision, and timeliness of new observations. Furthermore, with more of the new VLBI systems co-located with the suite of complementary space-geodetic techniques, the space-geodetic program as a whole will be greatly strengthened.

4 Next Steps

The above recommendations describe a system that can begin to become reality very soon. The IVS WG3 report (Niell et al., 2005) identifies specific steps that need to be taken next in order to develop, deploy, and bring the system into operation. The next steps include two broad categories of efforts:

- System studies and simulations: error budget development, decisions on observing frequen-

cies, optimal distribution of new sites, including those to be co-located with the other techniques, number of antennas per site, new observing strategies, and a transition plan.

- Development projects and prototyping: small antenna system, feed and receiver, cost and schedule, higher data rate system, correlator development, backend development, and data management and analysis software.

Almost all of the recommended next steps can be done in parallel, and WG3 hopes that various IVS components will find the resources to support one or several of these studies and development projects. Results of these studies and projects should be well communicated within the community and coordinated by IVS so that common goals for the new vision are recognized and met.

It is important for IVS to make a strong recommendation that some of the resources dedicated today to routine product generation and technology development be directed to address the studies and projects recommended in this report. These studies must move forward so that a detailed plan can be generated, including defensible costs and schedules. Building on the efforts of WG3, the results of these studies and projects will provide the final element required for IVS members to move forward with requests for augmented funding to implement the new vision. We believe that this vision will renew the interest of current funding resources and inspire new interest from universities, industry, and government, based on the exciting possibilities for a more accurate and data-rich geodetic VLBI system.

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