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New Observing Strategies with Twin Telescopes for Geodetic VLBI

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Abstract

The concept of twin radio telescopes enables a lot of new observing strategies. These are investigated by creating new observation schedules, by doing careful simulations, and finally by analyzing results. Advantages are obtained by assuming the same troposphere above the two telescopes and connecting them to the same H-maser clock. Three different observing strategies are investigated. In the first one, both telescopes point simultaneously to the same radio source ("array mode") to increase the sensitivity. In the second one, one telescope is slewing while the other radio telescope is still tracking a source. Thus "continuous" observations can be realized because one antenna of the twin telescope is always on source. In the third strategy, both radio telescopes record signals of different sources at the same time; then different subnets are tied via the same site. Hence the high slewing rates of the twin telescope are fully exploited for the various new observing strategies. The scheduling package of the Vienna VLBI Software (VieVS) is used to develop different schedules allowing all the options and combinations mentioned above.

1. Introduction

Very Long Baseline Interferometry (VLBI) plays an important role in the realization of global geodetic reference frames. In particular, it is a major contributor to the definition of a stable scale, and it has a unique ability to determine the orientation of the Earth in space. From October 2003 to September 2005, the International VLBI Service for Geodesy and Astrometry (IVS) Working Group 3 (WG3) examined current and future requirements for geodetic VLBI and concluded with recommendations for a new generation VLBI system (VLBI2010). The goals of VLBI2010 are to achieve 1 mm position accuracy over a 24-hour observing session and to carry out continuous observations, i.e. observing the Earth Orientation Parameters (EOP) 24 hours per day seven days per week. Initial results shall be delivered within 24 hours after recording the data. In 2005, IVS closed the WG3 and established the VLBI2010 Committee (V2C) as a permanent body to encourage the implementation of the recommendations of WG3. The IVS WG3 final report suggests a major increase in observation density (or, equivalently, a major decrease in source-switching interval) as a strategy for increasing VLBI position accuracy. The WG3 final report also proposes the use of multiple antennas at a site to share the observing load and hence to reduce the effective source-switching interval (Niell et al., [1]). In addition, guaranteeing continuous observations is only possible with more than one radio telescope per site due to telescope maintenance cycles.

Following the recommendations made by the VLBI2010 vision report of the IVS, the project of Twin Telescope Wettzell (TTW) is the first rigorous approach to realize a radio telescope system consisting of more than one antenna per site. It consists of a pair of identical fast slewing radio telescopes with a 13.2-m main reflector. The aim is to make the first observations by the end of 2012 (Hase et al., [2]).

There are a number of advantages to using twin antennas at a geodetic VLBI site, e.g. to increase the total collecting area, to increase the total number of sources observed in a day, to remove the corrupting effect of the reference oscillators through differencing, and to increase redundancy (Petrachenko, [3]).

2. Observing Strategies

The development of the observing strategies for twin telescopes is still an outstanding issue for VLBI2010. The concept of twin radio telescopes enables a lot of new observation strategies. By having two antennas at a site, there is redundancy for many system components. This may be a significant benefit in an operational program. Two antennas are foreseen to overcome antenna failures — if one antenna needs system maintenance or repairs, the second antenna can be used to continue the observation program. Hence continuous observations without maintenance cycles can be realized.

Assuming both of the two antennas are available for observation, three different observing strategies are investigated here by creating new observation schedules, by doing careful simulations, and finally by analyzing results. Advantages are obtained by assuming the same troposphere above the two telescopes and connecting them to the same H-maser clock.

2.1. Same Source Observations

If the two telescopes point simultaneously to the same radio source and if the local tie between them is accurately known, they can be used in the "array mode" to increase the sensitivity. Sensitivity of a VLBI receiver is generally characterized by System Equivalent Flux Density (SEFD), which is calculated as follows:

$$SEFD = \frac{2 \times k \times T_{sys}}{A_{eff} \times \eta} \qquad (1)$$

where k is Boltzmann's constant, T_{sys} is system temperature, A_{eff} is the effective collecting area of the antenna, and η is the VLBI processing factor (0.5-1.0). A pair of antennas has approximately twice the collecting area of a single antenna, so it is more sensitive to the very weak signal from a quasar.

Observing the same sources, the twin telescope needs less time to achieve the minimum SNR (Signal-to-Noise Ratio), which is shown in equation (2).

$$scanlength = \left(\frac{1.75 \times SNR_{min}}{F}\right)^2 \times \frac{SEFD_1 \times SEFD_2}{2 \times B \times N_f} \qquad (2)$$

where SNR_{min} is the minimum SNR for this baseline, F is the observed flux of the source, $SEFD_{1,2}$ are sensitivities at stations 1 and 2 of this baseline, B is bandwidth, and N_f is the number of channels in this band.

Another possible application with this mode is to split high-speed data (e.g., 8 Gbps) recording capability between the antennas.

2.2. Continuous Observations

While one antenna observes, the other antenna slews to the next radio source; i.e., one of the two radio telescopes always looks at a source. Hence continuous estimation of EOP (Earth Orientation Parameters) can be realized by VLBI, similar to ring laser gyroscopes. In this mode, only one antenna observes at a time, and the entire recording system can be dedicated to that antenna.

2.3. Multidirectional Observations

The antennas simultaneously point in different directions to observe different sources; i.e., different subnets are tied at the same time. The number of observations could be increased approximately by a factor of two, which is the critical factor for the accuracy of the estimated parameters.

3. Simulations and Results

An interim network of 18 stations (see Figure 1) with fast slewing antennas was used in Monte Carlo simulations with the Vienna VLBI Software (VieVS). The azimuth and elevation angle slew rates were 12 deg/s and 6 deg/s, respectively, for all stations. The twin telescope was considered at station Wettzell, which is denoted with a red circle in Figure 1. We also did simulations with a single telescope at station Wettzell to provide comparability. Here the source-based scheduling algorithm was used in the scheduling package VIE_SCHED (Sun et al., [4]), and X/S dual bands were applied. Three schedules were generated for the three observing modes mentioned above.

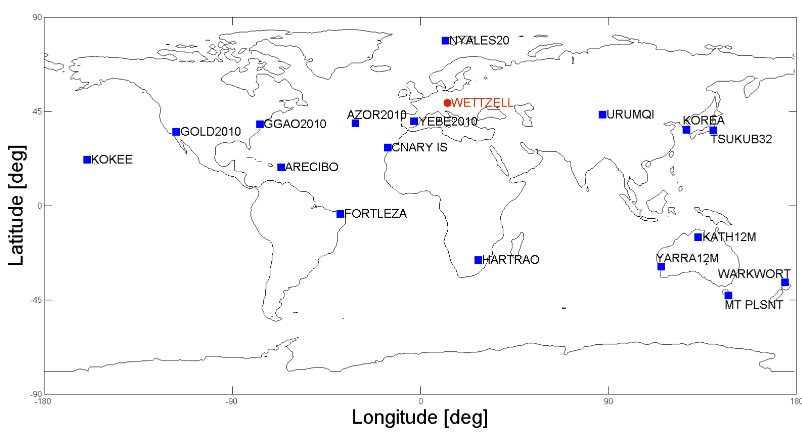

Figure 1. Network used for simulations. The red circle denotes station Wettzell with twin telescopes.

For the same source observations, with the twin telescopes the mean observing duration is decreased almost by half, which is shown in Figure 2. The numbering of the stations (station indices) is by latitude in Figures 2–5 (the Wettzell index is 17). Although we can get decreased on-source durations from same source observations and decreased slewing durations from continuous observations, the twin telescope is always waiting for other stations to start the scan because only one station has a twin telescope in the simulation network. Consequently, for these two observing modes, we get similar numbers of observations to observing with one telescope as shown in Figure 3. So the performance with one twin telescope in the network is not improved significantly with these two observing modes.

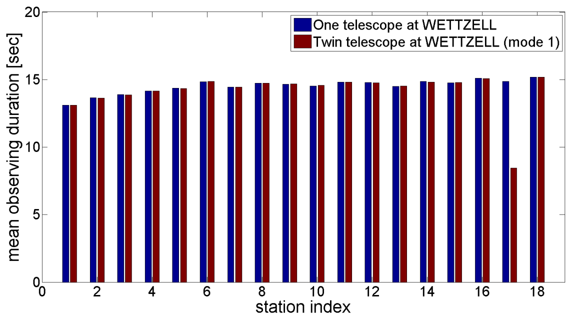

Figure 2. Mean observing duration from same source observations.

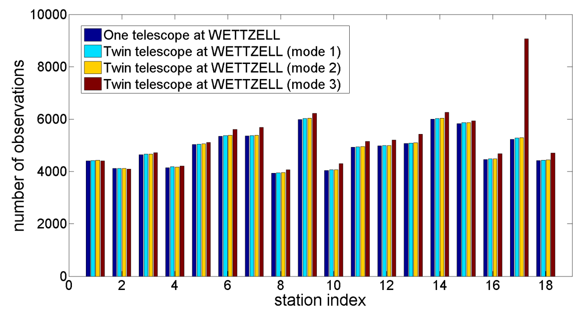

Figure 3. Number of observations from the three observing modes.

On the other hand with multidirectional observations, the number of obervations is increased by a factor of two, and a better sky coverage is obtained, as shown in Figures 3 and 4. To support the evaluation of multidirectional observations, Monte Carlo simulations were carried out with VieVS. After scheduling the observations with VIE_SCHED, they were transformed to NGS format and used as input to the VieVS simulator (VIE_SIM) (Pany et al., [5]). VIE_SIM set up the o-c vector (observed minus computed) of the least-squares adjustment with simulated values of zenith wet delays, clocks, and observation noise at each epoch. The simulation parameters included the refractive index structure constant C_n ($1.0 * 10^{-7} m^{-1/3}$, used for all stations), the effective height of the wet troposphere H (2000 m), and the wind velocity vector v (8.0 m/s) towards east (Nilsson and Haas, [6]). The stochastic variations of station clocks were computed as the sum of a random walk and an integrated random walk, with a power spectral density corresponding to an Allan Standard Deviation (ASD) of 10^{-14} @ 50 min. A white noise of 4 ps per baseline observation was added. Additionally, certain modifications were made with VIE_SIM, e.g., the introduction of condition equations to account for two co-located VLBI antennas using the same clock. Careful simulations were carried out to assess the real benefit of this approach. The simulated NGS data files were entered into the software package VieVS, which computed a classical least-squares solution. The parameters to be estimated were troposphere parameters, clock parameters, and station position residuals (with No-Net-Rotation (NNR) and No-Net-Translation (NNT) on all stations), as well as daily EOP. The simulation process was repeated 50 times to obtain a sample of output parameters that could be analyzed statistically. The station position repeatabilities are compared in Figure 5. We find that the performance generally improves because of more observations per day at Wettzell. 12 out of 18 stations are improved, while 6 stations get worse. We cannot count on one twin telescope for the global improvement.

4. Conclusions and Prospects

The mode with multidirectional observations improves the sky coverage greatly (53.4%), and the station position repeatability is improved correspondingly (22.2%). For the “same source

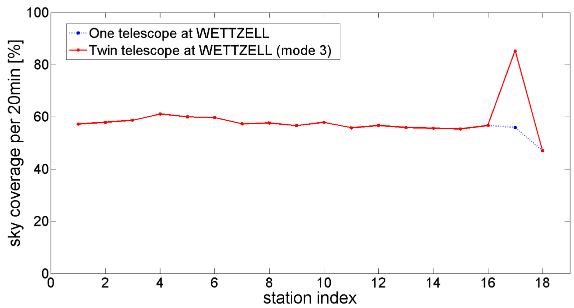

Figure 4. Sky coverage from multidirectional observations.

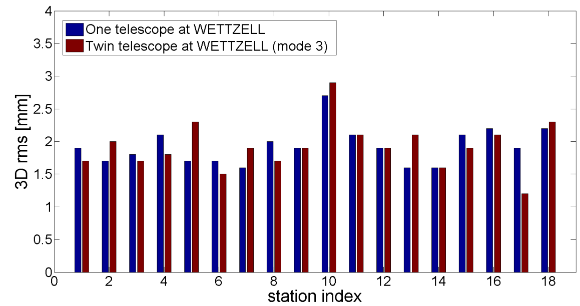

Figure 5. Station position repeatabilities from multidirectional observations.

observations" mode and "continuous observations" mode, there is hardly any improvement. In a case with more than one twin telescope in a network, these two strategies will be more beneficial.

All the modes may even include the existing 20-m radio telescope in Wettzell as a third contributor to a VLBI2010 observing session. More twin telescopes in the network will also be included in scheduling. Considering there is a strong correlation between the vertical component of the baseline and the constant terms of the clock and atmosphere during parameter estimation, we will implement the differencing of simultaneous observations to remove the effect of the clock entirely.

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