Prospects of IVS-Intensive Sessions with Twin Telescopes

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Abstract

The Twin Telescope Wettzell (TTW) is currently being assembled and is expected to become operational in late 2012. The TTW promises various observation scenarios that are expected to strengthen the parameters estimated from the observations. This is especially true for the one-hour Intensive sessions INT3 where observations are performed on three baselines with the radio telescopes NYALES20, TSUKUB32, and WETTZELL. For this session type, the number of observations will be significantly increased, and the local hemisphere above each telescope will be covered in a better way. In this paper, we investigate optimization scenarios for the observations of the TTW within the INT3 sessions, and we present various scheduling and simulation approaches. The schedules are done with an automatic scheduling procedure that is based on the analysis of the variance-covariance matrix of the estimated parameters. Furthermore, the handling of local TTW-specific parameters, i.e., clocks and troposphere, is investigated. The results are validated by thorough analyses of the dUT1 standard deviations.

1. Introduction

Daily VLBI Intensive sessions of the International VLBI Service for Geodesy and Astrometry (IVS, [6]) realize a continuous measurement series of the phase of the Earth's rotation, UT1. The IVS-INT3 sessions, operated once a week, is the only Intensive session type where observations are performed with three radio telescopes (NYALES20, TSUKUB32, and WETTZELL). Replacing WETTZELL with the Twin Telescope Wettzell (TTW) leads to various observing constellations. The four telescopes might observe one source simultaneously, which leads to a significantly increased number of observations. Furthermore, it is possible to build two independent baselines observing different sources. Finally, one telescope might skip a scan. In addition to different observing constellations, various choices of local TTW-specific parameters are investigated. To create observing plans with the twin telescopes, an automatic scheduling procedure, which is based on the analysis of the variance-covariance matrix of the estimated parameters, is used [4]. Since dUT1 = UT1 − TAI is the geodetic target parameter of Intensive sessions, the effect of various observing plans on dUT1 is validated by analyses of the dUT1 standard deviations.

2. Scheduling

The scheduling process is based on the method of singular value decomposition (SVD). As shown, e.g., in [7] the SVD is suitable for regression diagnostics for any geodetic adjustment problem and, therefore, for geodetic VLBI as well. The SVD can be used to derive indicators which contain information on the geometry of the design with respect to the influence of observational errors. Therefore, it can be used for planning the design of the measuring process [2].

The observations are chosen stepwise by analyzing the Jacobian matrix, which characterizes the geometry of a VLBI session. The goal is to choose each successive observation in a way that

the observing geometry is optimized. This geometric improvement can be determined via SVD of the Jacobian matrix. Thus, no subjective idea on how the schedule should look needs to be introduced for this approach, as only an objective criterion, the geometry, is used.

To build the Jacobian matrix the parametrization of the solution has to be set up. The target parameter of Intensive sessions is dUT1. Additional parameters are needed to complete the functional model. These are three clock parameters per station, except for the station with the reference clock, and one atmospheric wet zenith delay parameter per station.

2.1. Singular Value Decomposition

The SVD splits the Jacobian matrix $\mathbf{X}$ into three new matrices $\mathbf{X} = \mathbf{U} \cdot \mathbf{S} \cdot \mathbf{V}^T$ [3]. The singular values are the main diagonal elements of the matrix $\mathbf{S}$, where only the first r values are different from zero and r is the rank of the matrix $\mathbf{X}$. The matrix $\mathbf{U}$ contains the left singular vectors, where the first r columns $\mathbf{U}_r = \{\mathbf{u}_1, ..., \mathbf{u}_r\}$ span a basis of the column space of $\mathbf{X}$. In the sense of a least-squares adjustment, interpreting the Jacobian matrix $\mathbf{X}$ as a mapping from the space of the model parameters into the data space, the subspace $\mathbf{U}_r$ is related to the data space of $\mathbf{X}$ [5].

The left singular vectors are used to compute the data resolution matrix $\mathbf{H} = \mathbf{U}_r\mathbf{U}_r^T$. The elements of this matrix indicate how much weight each observation has on the adjusted observations [5]. Thus the main diagonal elements $\mathbf{h} = diag(\mathbf{H})$ are called impact factors. A close relationship between the impact factors and partial redundancies exists. Therefore, the higher the impact factor of an observation, the bigger the effect on the observing geometry. Due to this characteristic, the impact factors serve as criteria of the decision process in this scheduling method.

2.2. Scheduling Concept

The basic idea of the schedule procedure is to derive information about each new scan from the SVD of the Jacobian matrix. As the geometry should be optimized, the scan with the greatest impact should be chosen. Thus, the impact factors of all possible scans have to be compared to each other. This is trivial for observations of a single baseline, but at observing sessions with more than two telescopes, sub-nets with varying numbers of baselines and, thus, varying numbers of impact factors can be built, complicating the choice of the next scan. To make unequal numbers of impact factors, which belong to different sized sub-nets, comparable, the first choice would be to compute the average impact factor of the respective scans. However, for each selection instance the average value alone does not produce sensible results, because the greater the number of observations the lower the values of the impact factors. This is the reason for introducing a scaling mechanism for the average values using the square root of the number of impact factors.

Since the formal errors of the parameters reflect the geometry of the underlying observations, the success of the scheduling method can be checked by simple covariance analysis. However, to validate the scheduling method conclusively, the information of the variance of the unit weight is also needed. For this purpose, proper simulations of observations have to be made.

2.3. Validation

The Monte-Carlo simulator as it is implemented in VieVS [1] is used to simulate the reduced observation vector $o - c$. Here, slant wet delays are simulated based on a turbulence model, and the station clocks are simulated by a combination of random-walk and integrated-random-walk.
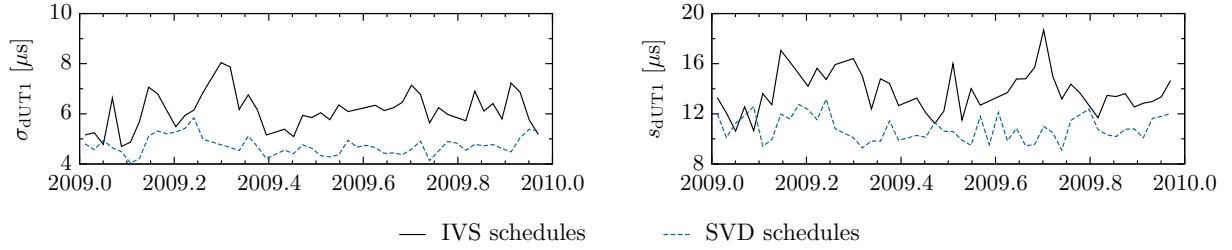
Figure 1. Formal errors (left) and standard deviations (right) of dUT1 for different scheduling methods.

Additionally white noise is added per baseline. This simulation enables the estimation of the adjusted parameters and the computation of an a posteriori variance factor via the squared sum of the residuals. With this factor the standard deviations of dUT1 can be derived from the formal errors, enabling the validation of the scheduling method. For a comparison, the SVD scheduling method is performed for INT3 in its standard configuration for each day in 2009 for which an IVS schedule exists. The standard deviations of dUT1 derived from both observing plans are shown in Figure 1. Obviously, the standard deviations of dUT1 are improved by approximately 20% owing to the SVD scheduling method.

3. Twin Telescope Scenarios

In order to evaluate possible benefits of the usage of the TTW, three different cases of scenarios for INT3 sessions with the TTW replacing WETTZELL are investigated. The first case is the standard scheduling method, choosing always the scan with the greatest impact (scaled average impact factors). Various sub-nets, different combinations of two independent baselines pointing at two sources simultaneously as well as sub-nets with three stations only, are possible. The most commonly scheduled constellation of this case consists of all four antennas pointing at one single source. In the second and the third case, the scheduling program is forced to build independent baselines. In addition, the third case is restricted to build independent baselines between each antenna of the twin telescopes and one of the single telescopes only. The different constellations are depicted in Figure 2.

The formal errors and the standard deviations of dUT1 exhibit no big difference between both cases that only used independent baselines (Figure 3). The offset between the first case and both other cases can be attributed to a much greater number of observations (150 vs. 66) for the first case. Furthermore, the north-south oriented baseline NYALES20–WETTZELL is not sensitive to
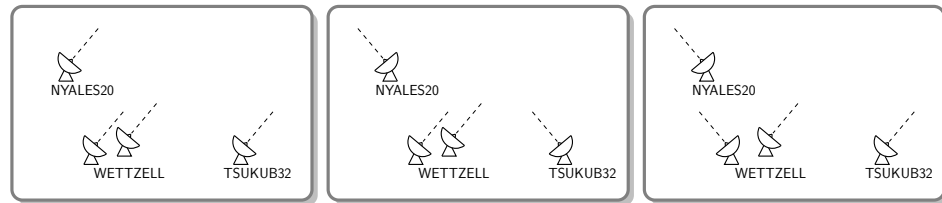

Figure 2. Possible twin telescope scenarios within the INT3 setup. Case 1: left, middle and right; case 2: middle and right; case 3: right only.
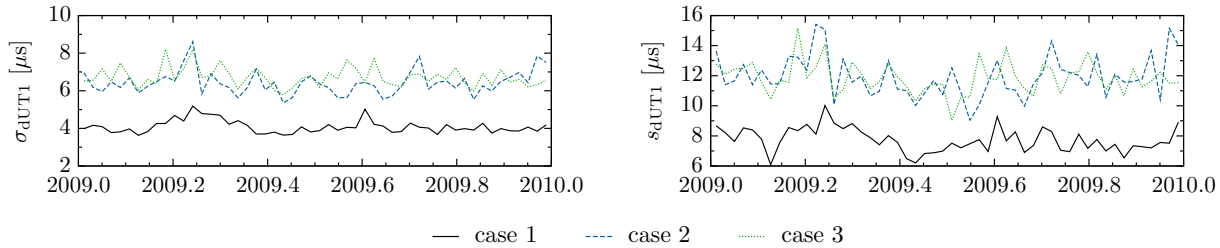
Figure 3. Formal errors (left) and standard deviations (right) of dUT1 for three different scheduling scenarios. Solid line: all possible sub-nets allowed; dashed line: forced independent baselines; dotted line: restricted forced independent baselines. The scenarios of the different cases are shown in Figure 2.

dUT1 and, thus, it does not help to improve the precision. With respect to the standard INT3 schedules with three telescopes only (Figure 1), there is an improvement for the first case and a worsening for the other two cases. But, this can also be referred to the different number of observations - more observations in the first case and fewer observations in the schedules with independent baselines. Ignored correlations between twin telescope observations could also be conceivable.

4. Twin Telescope Parametrization

In the least-squares estimation process, various parameterizations of the TTW are possible. For the results shown above, an independent setup for each of the twin telescopes was used, i.e., individual clock and atmospheric parameters per station. In this section, several modifications of this standard approach are considered:

 (a) one common atmospheric parameter for the twin telescopes, but individual clock parameters

 (b) common clock parameters for the twin telescopes, but individual atmospheric parameters

 (c) common clock parameters and one common atmospheric parameter for the twin telescopes.

To make the results of different parametrizations comparable it is ensured that identical clock and atmospheric variations are simulated for the twin telescopes while the schedule remains unchanged. Once more the results are characterized by the formal errors and the standard deviations of dUT1 (Figure 4). The respective results of the three different scenarios of Section 3 are similar to each other, so only case 1 is shown. The formal errors of dUT1 are unaffected by the parametrization of the twin telescopes (Figure 4 left), because the parameter dUT1 is hardly correlated with any other parameter. Also, these have no big influence on the standard deviations of dUT1 (Figure 4 right). The standard deviations of all common setups (cases (a)–(c)) are always slightly below the standard deviations of the individual setup, but they exhibit no significant improvement.

5. Conclusions

The effect on the parameter dUT1 of the scheduling method based on SVD, which was used to create the various observing plans, was validated by the simulation of observations with a Monte-Carlo-Simulator. For standard INT3 sessions with three radio telescopes this scheduling method improves the standard deviations of dUT1 by approximately 20%.
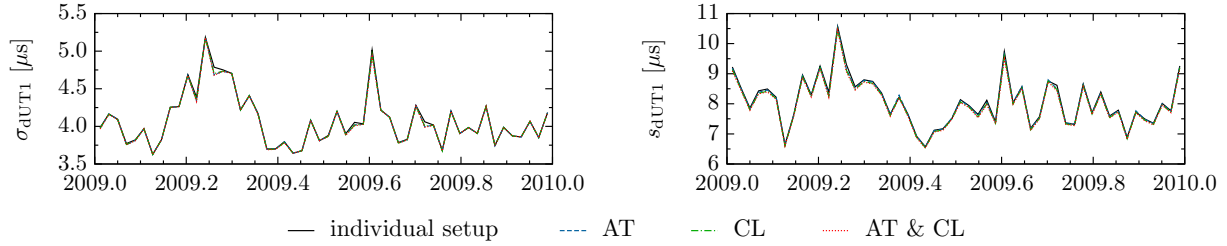
Figure 4. Formal errors (left) and standard deviations (right) of dUT1 for four different twin telescope parametrizations. Solid line: individual atmospheric and clock parameters per twin telescope; dashed line: common atmospheric parameter for the TTW; dash-dotted line: common clock parameters for the TTW; dotted line: common atmospheric and clock parameters for the TTW.

The implementation of the TTW in INT3 sessions was investigated for three different observing constellations. The schedules with forced independent baselines showed worse results than the schedules with all possible sub-nets, and with respect to the standard INT3 sessions there is only a precision improvement for the schedules with all possible sub-nets. These results are due to different numbers of observations in the various schedules. Furthermore, correlations between twin telescope observations have been neglected.

For the INT3 as they are designed today, the examined twin telescope parametrizations hardly affect the formal errors and the standard deviations of dUT1 and do not significantly improve the results.

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