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VLBI2010 Simulations at IGG Vienna

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Abstract. VLBI2010, simulations are carried out at the Institute of Geodesy and Geophysics (IGG), Vienna to support the design of a new geodetic VLBI system. The main part of these simulations is a Monte Carlo simulator which produces artificial group delays by modeling the stochastic processes caused by the station clocks, the wet zenith delays, and additional system errors. The clocks are simulated with a random walk plus integrated random walk, the wet zenith delays are derived from a turbulence model, and the system errors are represented by white noise. For the analysis of the simulated data, the Monte Carlo simulator is implemented in a modified version of the software package OCCAM. Because of limitations due to the huge number of observations in the OCCAM Gauss-Markov algorithm, the Kalman Filter approach of OCCAM was applied. Different variance rates for the stochastic parameters in the Kalman Filter solutions are tested and the best values are used for antenna slew speed tests. Various schedules with antennas of different slew speeds (from 1.5°/s to 12°/s in azimuth and 0.7°/s to 3.1°/s in elevation) are compared w.r.t. baseline length repeatabilities and rms values of station position residuals. The investigation shows that there is hardly any improvement with antennas faster than 6°/s in azimuth and 2.1°/s in elevation. Alternative scheduling strategies, such as achieving uniform sky coverage, are also tested.

1. Introduction

At the Institute of Geodesy and Geophysics (IGG), Vienna University of Technology, different simulations are performed to evaluate new observing strategies and schedules, to improve the modeling of troposphere refraction and clocks, to find the best antenna design and to optimize the network geometry. A sequence of software programs is used for the simulations. After scheduling the observations with SKED [4], they are transformed to NGS format and then used as input to the VLBI analysis software package OCCAM [3], which was adapted for our simulations. The main part of the simulation studies is a so-called Monte Carlo simulator which creates the artificial observations based on realistic properties of the wet zenith delays and clocks. The observed group delay minus computed group delay $o - c$ can be described as follows:

$$o - c = (wzd_2 \cdot mfw_2\,(e_2) + cl_2) - (wzd_1 \cdot mfw_1\,(e_1) + cl_1) + wn_{bsl}\,. \quad (1)$$

In (1), $wzd_{1,2}$ are simulated wet zenith delays based on the turbulence model [2], $cl_{1,2}$ are simulated clock values modeled as a random walk plus integrated random walk [1] at station 1 and 2, and $mfw_{1,2}(e_{1,2})$ are the wet mapping functions for the elevation angle $e_{1,2}$ which are assumed to be error-free in our studies. For each baseline observation an additional white noise wn_{bsl} is added to model the instrumental errors of station 1 and 2. The Monte Carlo simulator, implemented in OCCAM, imports wet zenith delay values from the turbulence model, creates clock values for each station and epoch, and adds white noise for each observation. Performance and evaluation of the Monte Carlo simulator are presented by Wresnik et al. [5]. The following criteria can be used to evaluate the potential of the VLBI system: baseline length repeatabilities, the root mean square (rms) of the 3D station position residuals, formal errors and standard deviations of the EOP, and the standard deviation between the simulated stochastic processes (troposphere delays, clocks) and their estimates. In this paper, we are focusing on the baseline length repeatabilities and the rms of the 3D station positions to evaluate and compare different observing strategies and scenarios.

2. Slew Speed Tests

One of the main goals of the simulations is to obtain information about antenna specifications for the new VLBI2010 system by testing different slew speeds. The test values used here range from 1.5°/s to 12°/s in azimuth and from 0.7°/s to 3.1°/s in elevation. The schedules for the analysis were produced by J. Gipson (NASA/GSFC, Greenbelt, USA). To get a sufficiently dense schedule, about 100 of 230 radio sources were taken from a recently compiled list of geodetic sources, and the on-source time was reduced to a maximum of 5 to 10 s. Statistics for the schedules are summarized in Tabl. 1. As can be seen, the schedule performance improves steadily from the 1.5/0.7°/s to the 6.0/2.1°/s case, but improvement is rather small from the 6.0/2.1°/s to the 12.0/3.5°/s case. This is because on-source time and accelerate/decelerate phases begin to dominate over the maximum slew speed phase of the observing cycle. More investigations on optimizing scheduling strategies have to be carried out.

For the Monte Carlo simulations, the wet zenith delays are simulated using the turbulence model, the clocks are simulated with an Allan Standard Deviation (ASD) of $2 \cdot 10^{-15}$ at 15 min, and the white measurement noise is simulated using a 4 ps 1-sigma Gaussian random variable. The very small white noise corresponds to that one predicted for the new VLBI2010 antenna systems. Regarding the baseline length repeatabilities (Fig. 1) a very clear improvement from slow antennas to antennas with a slew speed of 4.5°/s in azimuth and 2.1°/s in elevation can be seen.

Table 1. Number of observations/hour/station (obs/h/st) and number of observations in total for different antenna slew speeds in azimuth and elevation for a 16 station network. The right column shows the median values of 3D station positions for the various schedules

slew speed		avg obs/h/st	min obs/h/st	max obs/h/st	N obs.	median 3D stat. pos., mm
az, °/s	el, °/s					
1.5	0.7	47	39	55	59392	2.15
3.0	0.7	61	46	76	83149	1.71
4.5	2.1	101	76	121	134134	1.14
6.0	2.1	120	89	144	159088	1.20
12.0	3.5	131	96	155	173831	1.05

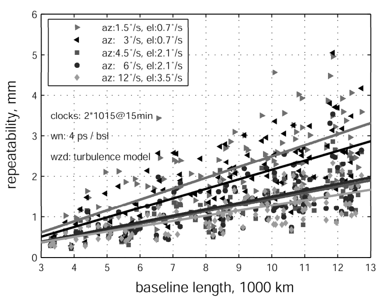

Figure 1. Baseline length repeatabilities for different slew speeds.

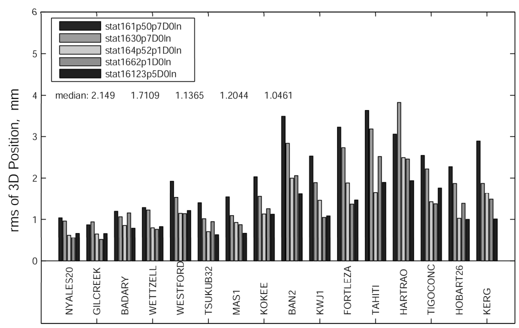

Figure 2. Simulated rms values of the 3D station positions for all 16 stations (station order: North-South)

The biggest improvement is gained when using antennas with the highest slew speed of 12°/s in azimuth and 3.5°/s in elevation, but the enhancement compared to slower antennas with a slew speed of 4.5°/s or 6°/s in azimuth and 2.1°/s in elevation is relatively small. Fig. 2 shows the simulated rms values of the 3D station positions. The median values for the different slew speeds are summarized in Tabl. 1.

3. Uniform Sky

Another scheduling strategy is to achieve uniform sky coverage at each station, which is essential to de-correlate wet zenith delays, clock parameters, and station heights. This was realized by a source-based scheduling, which means that the scheduler selects e.g. a pair of radio sources, which are located on opposite parts of the sky, from the catalogue without regarding their direct impact on individual stations. This strategy requires different sub-nets throughout the session in order to optimize geometry and number of observations. Thus, all possible baselines of the network are observed. In the following, the switching interval between the observed sources was set to a minimum of 15 and a maximum of 120 s and the uniform sky coverage was achieved for time intervals of 3 to 24 min. Tabl. 2 shows the settings for switching interval, time interval for uniform sky coverage, number of observations of the schedule and the slew speeds that are needed to realize the schedule. The uniform sky schedules were produced by Tony Searle (Natural Resources Canada). In Fig. 3, examples for the different sky coverages of the schedules used for the slew speed test and the uniform sky schedules can be seen clearly.

Table 2. Switching interval for the uniform sky coverage schedules. The right column shows the median values of 3D station positions for the various schedules

st.	switching interval, s	uniform coverage, min	slew speed az, °/s	slew speed el, °/s	N obs.	median 3D stat. pos., mm
16	120	12	2.1	0.6	34 806	3.29
16	60	12	4.8	1.1	69 708	1.52
16	45	9	7.3	1.8	93 231	1.29
16	30	6	12	3.2	139 564	1.01
16	15	3	32	8	278 830	0.88

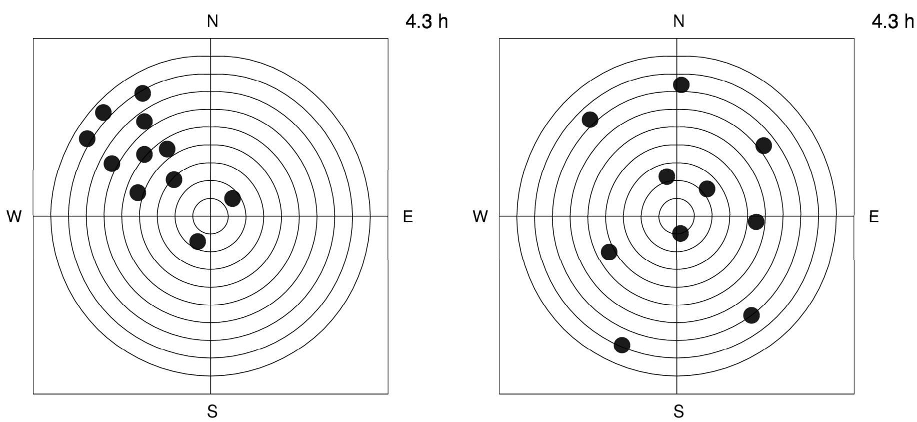

Figure 3. Sky coverage of 6 min at station FORTALEZA for different scheduling strategies. Left plot: a D0ln schedule created with the automatic scheduling software SKED, where the observation is often clustered. Right plot: a uniform sky schedule created with a source dependent scheduling strategy, where the observations are well destributed

Using the same approach for the simulations as for the slew speed tests, but a worse ASD for the clocks (10^{-14} at 50 min), the baseline length repeatabilities and the rms of the 3D station positions have been estimated. Fig. 4 shows that the schedule with the shortest switching interval and most observations yields the best results, but that there is hardly any difference between the schedules with the 15 and 30 s switching interval.

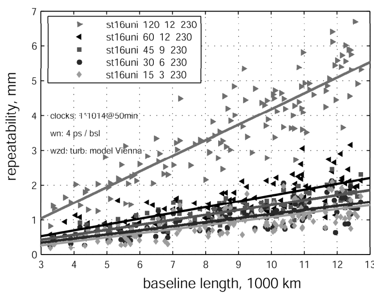

Figure 4. Baseline length repeatabilities for different uniform sky schedules with different switching times

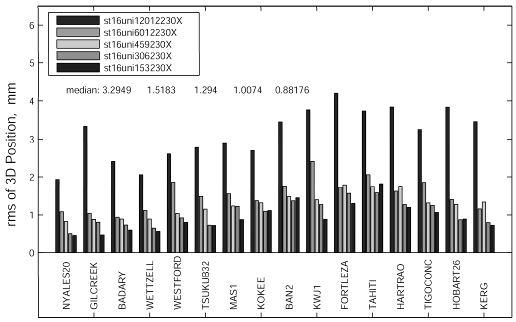

Figure 5. Simulated rms values of the 3D station positions for all 16 stations (station order: North-South)

The simulated rms of the 3D station positions can be seen in Fig. 5. It shows the improvement for the schedule with the shortest switching interval. Tabl. 2 summarizes the median values for the different schedules, e.g., the scheduling with the minimum of 15 s switching interval achieves a median value for the 3D station positions of 0.88 mm.

4. Conclusions

For the VLBI2010 Committee, simulation studies are of very high interest because decisions about the next generation VLBI system will be mainly based on these results. Therefore, the Monte Carlo simulator has to be able to reproduce real observations [5]. Since wet zenith delays have the largest influence on the simulation results, they have to be simulated as realistically as possible. Thus, applying a turbulence model, which is assumed to yield the most realistic description of the stochastic properties of troposphere up to date, is an important part of these Monte Carlo simulations. The determination of optimal slew speeds for the VLBI2010 antennas was a very critical issue for the VLBI2010 committee. The estimated baseline length repeatabilities are improved considerably for antennas with slew speeds up to 4.5°/s in azimuth and 2.1°/s in elevation, but for faster antennas the enhancement is hardly significant. To profit from very fast moving antennas, more investigations on scheduling (e.g. reducing the idle time of the antennas) have to be carried out.

The baseline length repeatabilities of the schedules with uniform sky coverage yield a significant improvement for the schedules with 15 s and 30 s switching intervals and 3 and 6 min intervals of uniform sky coverage. The median value of the rms of 3D station position for these schedules is at the 1 mm level, which is the defined goal of the VLBI2010 Committee. Considerable improvements can be expected with the use of twin telescopes, i.e. two identical antennas at each site. Tests for the use of twin antennas will be carried out with the Monte Carlo simulator in the near future.

Acknowledgements

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