New VLBI2010 scheduling options and implications on terrestrial and celestial reference frames

J. Böhm, C. Tierno Ros, J. Sun, S. Böhm, H. Krásná, T. Nilsson

Abstract We apply the newly developed source-based scheduling approach in the Vienna VLBI Software (VieVS) to run a series of tests with Monte-Carlo simulations. We find that increasing the number of stations from 16 to 24 and 32 in a VLBI2010 network improves the Earth orientation parameters estimated from 24-hour sessions by roughly 10% and 20%, respectively. On the other hand, we do not find an improvement of the 3D position rms of the individual stations with larger networks. As expected due to the larger number of observations, the formal uncertainties of terrestrial and celestial reference frame coordinates are improved by about 20% with 24 compared to 16 stations in the network, but we also find non-zero mean reference frame coordinates which are probably due to the small number of 25 simulated sessions. Finally, the investigations show that baseline length repeatabilities are improved if we raise the cutoff elevation angle from 5 to 10 and 15 degrees in a 16-station network.

Keywords VieVS, VLBI2010, Scheduling, Terrestrial and Celestial Reference Frames

1 Introduction

The Vienna VLBI Software (VieVS) has been developed at the Department of Geodesy and Geoinformation (GEO) at the Vienna University of Technology since 2008. It is written in Matlab, and it has been equipped recently with scheduling and simulation tools as well as with the ability of running global solutions (Böhm et al., 2012).

In terms of scheduling, the so-called *source-based approach* has been added to the classical *station-based approach* which is also implemented in SKED, the scheduling software maintained at Goddard Space Flight Center. Source-based scheduling in VieVS has been initiated following an idea by Bill Petrachenko and Anthony Searle (both Natural Resources Canada) and it implies that always a certain number of equally distributed sources on the sky is selected for observation. In case of source-based scheduling with two sources, the sources are on opposite parts of the celestial sphere, and in case of source-based scheduling with four sources, they are at the corners of a regular tetrahedron (Sun, 2013).

Compared to the classical station-based approach, source-based scheduling has some advantages and disadvantages. It is faster because there are not so many options to be tested, and it automatically results in a good global distribution of sources on the celestial sphere. On the other hand, source-based scheduling does not optimize the sky distribution above the individual sites; however, a good coverage of the celestial sphere typically implies a good sky distribution above the stations. With more and similar (VLBI2010-) stations in the future source-based scheduling will become more important. The more telescopes participate in a session, the more sources should be observed at a time (i.e., four instead of two).

In this study, we apply the source-based scheduling approach with four sources to answer the following questions: what is the impact of increasing the network size from 16 to 24 or 32 stations on the terrestrial and celestial reference frames and on the Earth orientation parameters (Section 2)? How does the repeatability of baseline lengths and station coordinates change if we raise the cutoff elevation angle from 5 to 10, 15, or 30 degrees (Section 3)?

J. Böhm, C. Tierno Ros, S. Böhm, and H. Krásná
Technische Universität Wien, GEO, Gußhausstraße 27-29, A-1040 Wien, Austria
J. Sun
Shanghai Astronomical Observatory, China
T. Nilsson
GeoForschungsZentrum Potsdam, Germany

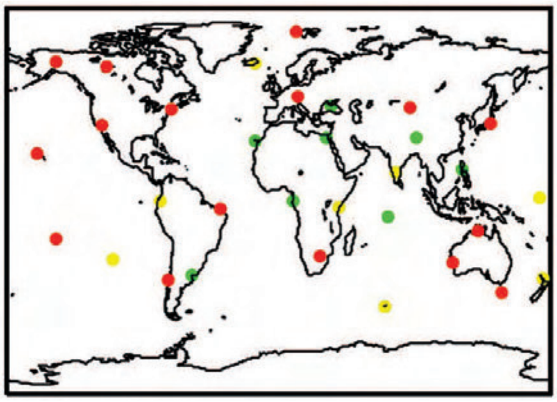

Fig. 1 Observing station network: we start with a network of 16 stations (red circles) and then add two times 8 stations to get a network with 24 (yellow circles) and 32 stations (green circles).

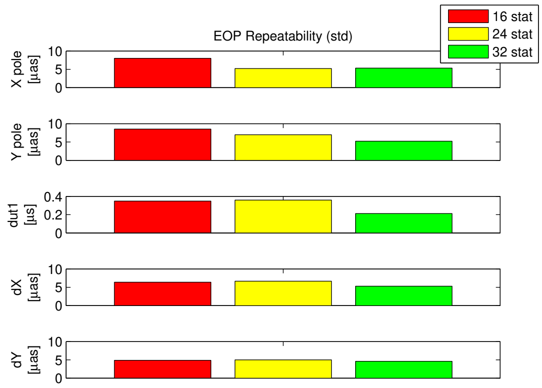

Fig. 2 Standard deviation of Earth orientation parameters estimated with networks of 16, 24, and 32 stations. From top to bottom we show polar motion, UT1-UTC, and nutation.

2 Increasing the network size

We start with a network of 16 fast VLBI2010 antennas (slew rates of $12^o/s$ and $6^o/s$ in azimuth and elevation, respectively, slew acceleration of $12^o/s^2$ in both axes) and then add more stations of the same type to realize a 24- and a 32-station network (see Figure 4 for the distribution of the sites). The global distribution of stations is quite uniform in all three cases.

For scheduling, we use a list of 211 radio sources with a positional accuracy of better than $200\mu as$, with an X-band structure index lower than 3, and which are stronger than $0.25Jy$ at both X- and S-band. The same System Equivalent Flux Density (SEFD) of 2500 is used for all antennas, and the data rate is 8 Gbps (assuming a bandwidth of 128 MHz, a sample rate of 256 MHz, 16 channels, and 2 bits quantification). A minimum SNR of 20 and 15 is required in the schedules for X- and S-band, respectively, and 5/20 seconds are set as minimum/maximum for the scan lengths.

We apply source-based scheduling with four sources observed at a time and a cutoff elevation angle of 5 degrees to create schedules for all three networks. Then we run the VieVS simulator (Pany et al., 2011) to create 25 24-hour simulated observation files for each network. We simulate the reduced observation vectors ($observed - computed$) as sum of slant tropospheric delays, clock random walk series, and white noise per baseline observation. For the description of the tropospheric delay, we apply the turbulence model as proposed by Nilsson et al. (2007) with station-dependent Cn values (Nilsson and Haas, 2010) and constant scale heights of 2 km at all stations. For the simulation of the clocks, we assumed a random walk process with an Allan Standard Deviation (ASD) of $1 \cdot 10^{-14}$@ 50 minutes, and the values of white noise added per baseline observation have a standard deviation of 8 ps.

In the least-squares estimation, we estimate zenith wet delays every 15 minutes, and gradients and clocks every 60 minutes as piecewise linear offsets. A full set of Earth orientation parameters (EOP) is estimated once per 24-hour session. In a first solution, station coordinates are estimated once per 24-hour session with no-net-rotation and no-net-translation (NNR/NNT) conditions on all stations in the network and with the source coordinates fixed. In a second solution we estimated terrestrial and celestial reference frames globally from all 25 sessions of the 16- and 24-station network with NNR/NNT on the same 16 stations and NNR on all sources with more than 100 observations.

As expected, the repeatability (standard deviation) of the Earth orientation parameters (polar motion, UT1-UTC, and nutation) estimated per 24-hour session improves considerably when using larger networks (see Figure 2). Compared to the 16 station network, we find a mean improvement of 8 % for the 24-station network, and a 26 % improvement for the 32-station network.

Next, we use the session-wise estimates of station coordinates to calculate their 3D position root-mean-square (rms) values. Figure 3 shows these values for those 16 stations which are participating in all three networks together with the corresponding numbers of observations. It is interesting to note that - although there are more observations with more stations in the larger networks - the median 3D position rms value over the same 16 stations does not significantly change. It is 1.2 mm, 1.3 mm, and 1.2 mm for the networks with 16, 24, and 32 stations, respectively.

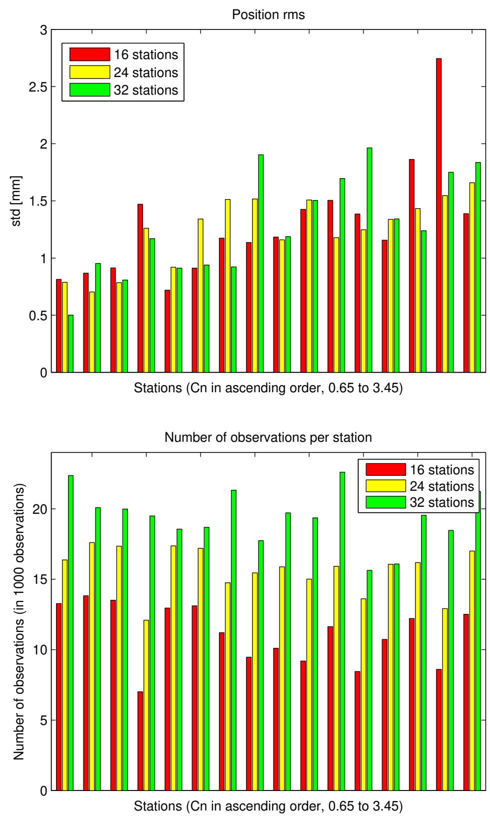

Fig. 3 3D position rms values of station coordinates (upper plot) and the corresponding numbers of observations (lower plot). The stations are sorted by their Cn values which describe the tropospheric turbulence. Only those stations are plotted which are part of all three networks.

As already mentioned above, we ran a global solution to estimate terrestrial and celestial reference frames for the 16- and 24-station networks. Due to the significantly larger number of observations with the 24-station networks, the formal uncertainties for the coordinates in the terrestrial and celestial reference frames are reduced by about 20% in the 24-station network. We also determined the mean coordinate differences with respect to the a priori coordinates for the stations and sources. Surprisingly, we find a systematic behavior in the north components of the stations (Figure 4) which is also reflected in the declinations of the sources (Figure 5). This is not expected because we did not simulate any systematic effects like gradients. We assume that the Monte-Carlo simulations should be based on more realizations of the same session, i.e., we should use at least 100 instead of 25 realizations.

3 Raising the cutoff elevation angle

The source-based scheduling approach is well suited to raise the cutoff elevation angle, because with four sources equally distributed on the celestial sphere, at least one source should be observable at a relatively high elevation angle. We take the 16-station network and create schedules for 10, 15, and 30 degrees elevation cutoff angles in addition to 5 degrees. Running Monte-Carlo simulations with 25 realizations, we find the best 3D position rms values for cutoff angles of 10 and 15 degrees. The median 3D rms values are 1.0, 0.9, 0.9, and 2.0 for cutoff angles of 5, 10, 15, and 30 degrees, respectively. Figure 6 shows a significant improvement in baseline length repeatabilities with a cutoff angle of 10 degrees compared to a cutoff angle of 5 degrees. This underlines, that very low observations (below 10 degrees) are difficult to model due to effects of turbulence. And with more stations available, it is possible to do better without those observations because there are enough common visibilities.

4 Conclusions

Applying the Vienna VLBI Software (VieVS), we created schedules following the newly developed source-based scheduling approach with four sources observed at a time and ran Monte-Carlo simulations. We find that increasing the number of stations in the network (from 16 to 24 and 32 stations) improves the Earth orientation parameters estimated in 24-hour sessions, but it does not improve the 3D position rms of the individual stations. Moreover, we showed that increasing the cutoff elevation angle from 5 to 10 and 15 degrees elevation improves baseline length repeatabilities in a 16-station VLBI2010 network.

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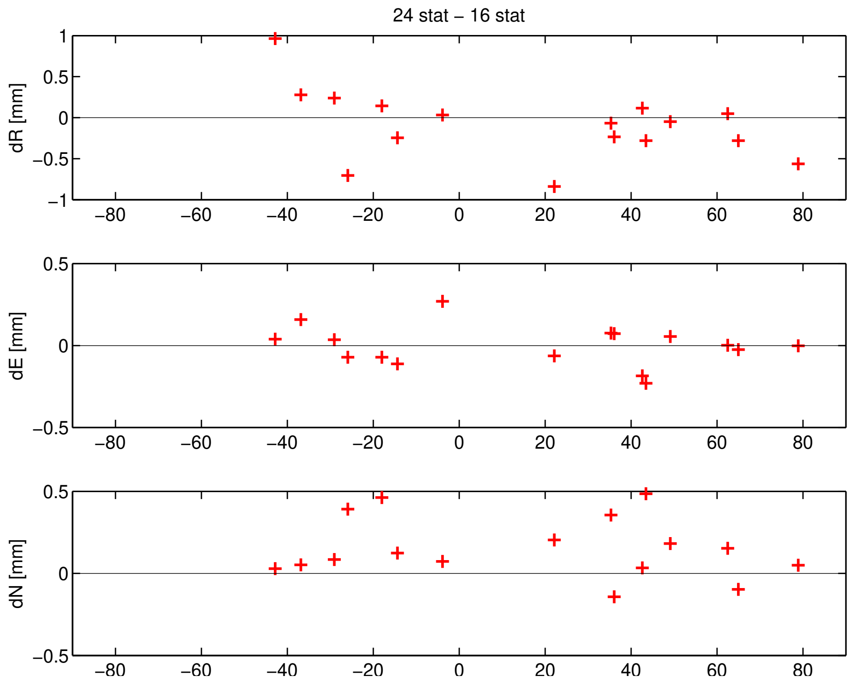

Fig. 4 Difference in the terrestrial reference frame coordinates with the 24-station network compared to the 16-station network. Radial, east, and north components are shown with respect to latitude. It is interesting to note that all north components are positive in the southern hemisphere.

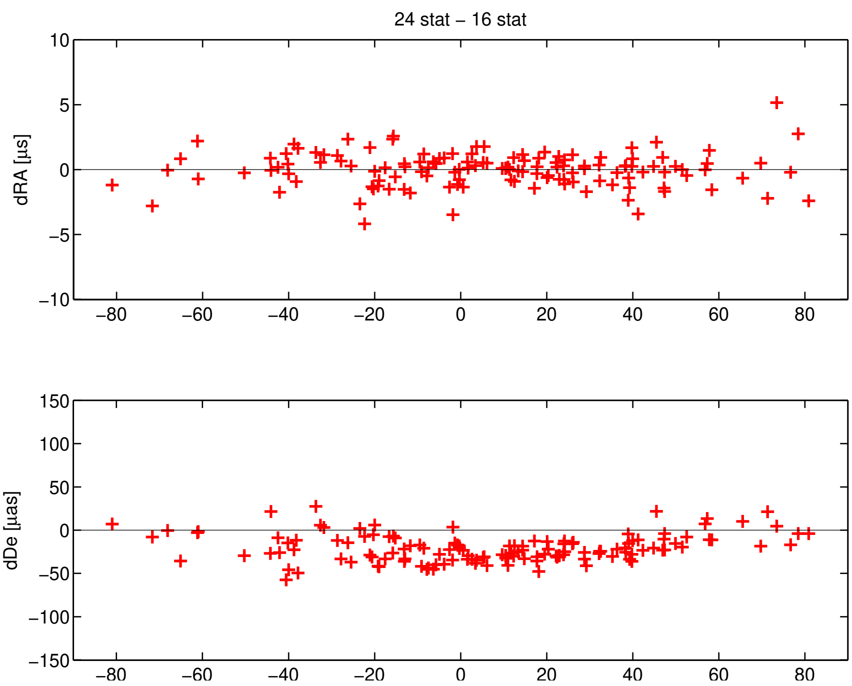

Fig. 5 Difference in the celestial reference frame coordinates with the 24-station network compared to the 16-station network. Right ascension and declination are shown with respect to declination of the source.

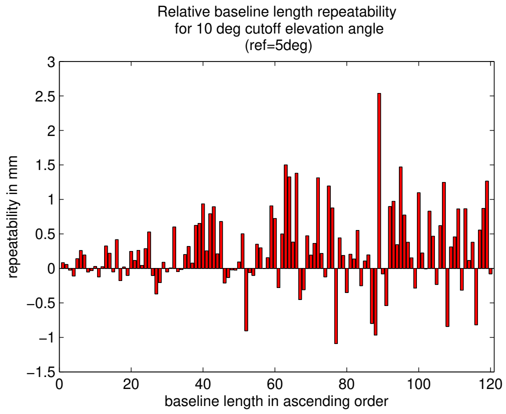

Fig. 6 Improvement in baseline length repeatability with a cutoff angle of 10 degrees compared to 5 degrees. The baselines are ordered by length.

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