Presentation of a new VLBI scheduling software VieSched++

Matthias Schartner[1] and Johannes Böhm[1]

[1]*Department of Geodesy and Geoinformation, TU Wien, Vienna, Austria;*
`matthias.schartner@geo.tuwien.ac.at`

Abstract. VieSched++ is a newly developed VLBI scheduling software written in C++. The main purpose of this software is to improve results gained by geodetic and astrometric VLBI experiments due to providing optimized schedules. Therefore, VieSched++ features an elaborate backward fill-in mode for optimizing the number of observations and runs multiple versions of the same schedule in a fast batch mode using different optimization criteria and parameters. Large scale Monte-Carlo simulations with VieVS are used for selecting the best schedule based on the scientific purpose of this session.

VieSched++ is already successfully used for scheduling official geodetic and astrometric IVS sessions like T2, INT3, EUR&D, EUR, OHG, CRDS, CRF and more. In this work, we want to highlight some of the new algorithms used to optimize schedules as well as show some comparisons with previously submitted schedules.

1. Introduction

The VieSched++ software (Schartner & Böhm 2019) is developed at the Department of Geodesy and Geoinformation at TU Wien under the umbrella of the Vienna VLBI and Satellite Software (VieVS) (Böhm et al. 2018). Its main purpose is the generation of high-quality geodetic VLBI schedules. VieSched++ is written in C++ and is already used to schedule multiple official observing programs of the International VLBI Service for Geodesy and Astrometry (IVS) (Nothnagel et al. 2017), such as T2, EURR&D, EUR, OHG, INT3. However, the software is already extended to be able to generate astrometric schedules and is used to generate schedules for the CRDS and CRF observing programs. It is currently considered to extend the software even further for astronomy needs.

Geodetic VLBI scheduling is different from scheduling astrometric or astronomic VLBI sessions in terms that it is usually not important which sources are observed as long as they are strong and point-like. A typical 24-hour long geodetic experiment observes around 100 sources and uses around 10 globally distributed telescopes. The main criteria for the source selection are to provide a high number of observations as well as an evenly distributed sky-coverage for all stations. An evenly distributed sky-coverage helps to estimate tropospheric delays which are one of the main error sources in geodetic VLBI (Böhm et al. 2006). Since a globally distributed station network is used not all stations may observe the same source simultaneously. Therefore, a technique called *subnetting* is applied, where the network is divided into two sub-networks which observe different sources simultaneously (Gipson 2016). The integration time varies from station to station to reach a required signal to noise ratio (SNR) (Petrov et al. 2009). It is calculated per baseline based on the station sensitivities, source flux density, and recording mode.

2. Algorithmns

In this section, some of the key algorithms of VieSched++ are discussed. More information can be found in Schartner & Böhm (2019).

2.1. Scan selection

VieSched++ uses a brute force algorithm to generate the schedule similar to other geodetic scheduling software such as sked (Gipson 2016). Simplified speaking, the software is generating the schedules scan after scan. At each point, the software is generating all possible next scans based on a list of available targets. All scans are evaluated based on multiple optimization criteria, such as the number of observations, the improvement in sky-coverage, the total duration of the scan, and more. Based on these criteria, a score is calculated per scan and optimization criterion.

The individual scores per scan are further combined to calculate the total score per scan. The combination is calculated as a weighted sum using so-called weight-factors (Schartner & Böhm 2019). Finally, the scan with the highest total score is selected and scheduled and the whole process starts over again until the schedule is finished.

2.2. Recursive scan selection

In contrast to already existing scheduling software such as sked, VieSched++ is not generating a schedule in a strong sequential time order. Instead, it is using a recursive scan selection which helps to significantly reduce station idle time. Figure 1 depicts a visual representation of how the scan selection works. After a scan is scheduled, the software checks the time between the scheduled scan and possible previous and following scans and investigates if it is possible to squeeze in another scan in between.

2.3. Multi-scheduling

The VieSched++ multi-scheduling tool is a new feature that can be used to optimize a schedule. The main idea is that instead of generating only one schedule for a session, hundreds of schedules are generated. These schedules are simulated and based on the expected accuracies, the best schedule is selected.

The different schedules are typically generated by changing the relative ratio between the weight-factors since the weight factors directly determine the scan selection, see section 2.1. The difficulty arises since multiple optimization criteria are needed for the generation of geodetic schedules and some of the criteria are competing against each other. One example is the need for having a high number of observations versus the need for having an evenly distributed sky-coverage. While the former implies that the telescopes are observing as much as possible, thus minimizing the slewing time, the later implies that the telescopes are slewing long distances between two consecutive scans. The challenge is to find a good sweet spot between all factors. Since this sweet spot changes based on the participating stations, available sources and scientific goal, the best approach is to individually optimize each schedule by generating multiple schedules trying different combinations of weight factors.

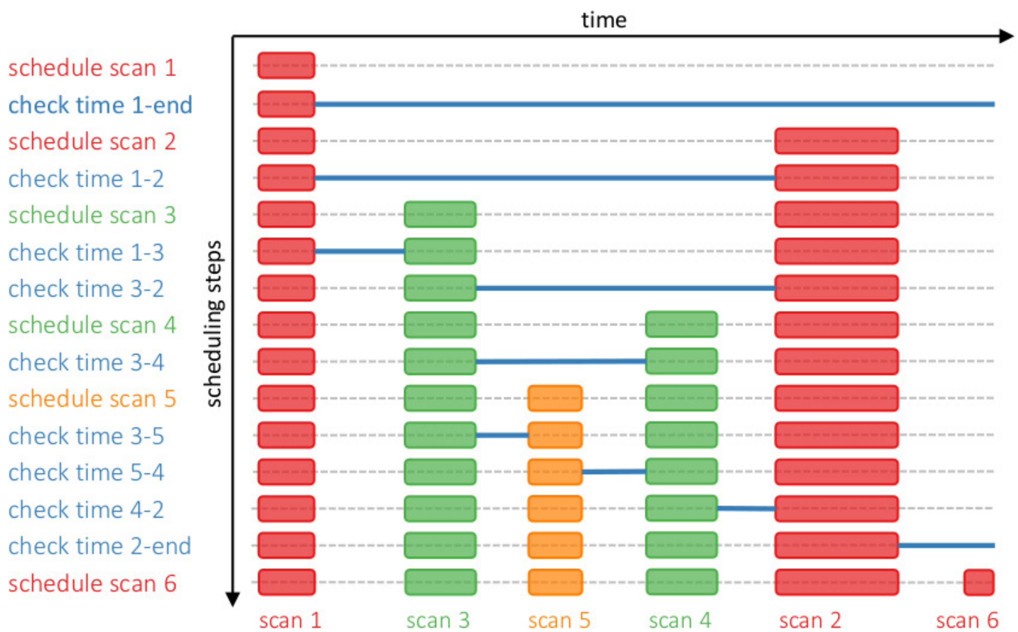

Figure 1. Step-by-step visualization of recursive scan selection.

3. Results

The first results from sessions scheduled with VieSched++ reveal a significant improvement in the accuracy of the estimated results. Here, the results of the IVS observing programs T2 and EURR&D are highlighted. They are geodetic programs with the main purpose to provide high-quality station coordinates for the next generation terrestrial reference frame (TRF).

Table 1 lists scheduling statistics for the T2 observing program. The T2 program is using a high number of globally distributed stations. In terms of the number of participating stations, it is the biggest observing program within the IVS. Starting with T2129, VieSched++ is used to schedule the T2 sessions. By changing the scheduling, it was possible to increase the number of observations by a factor of two to three. Furthermore, the station idle time is decreased from $\approx 27\%$ to $\approx 8\%$. In contrast the observing time is increased from $\approx 50\%$ to $\approx 70\%$. Together, this leads to a significant improvement in the quality of the schedule and thus in the accuracy of the estimated parameters. One additional goal of the T2 schedules is to properly include the station O'Higgins (Oh) in Antarctica into the schedule. The schedules generated with VieSched++ contain significantly more observations to this station as before.

The EURR&D observing program is using a regional network of ≈ 8 stations mostly located in Europe. Starting with EURD09, VieSched++ is used to schedule this program. For these schedules, a 50% increase in terms of the number of observations was achieved and the idle time is reduced significantly by a factor of five. However, the biggest change is achieved in terms of sky-coverage where the VieSched++ schedules show big benefits.

When looking at the accuracy of derived geodetic parameters from the analysis of the T2 and EURR&D sessions, an improvement in terms of station coordinates by

Table 1. Key scheduling statistics for T2 schedules. Starting with T2129 VieSched++ is used for scheduling. The last column lists the number of observations to O'Higgins.

	#sta	#scans	#obs	%idle	%obs	#obs Oh
T2124	17	733	7175	28.10	44.54	22
T2125	17	1064	5528	22.94	53.70	48
T2126	17	1075	6081	24.55	49.66	98
T2127	19	627	6304	34.30	45.22	73
T2128	18	803	5983	26.24	44.90	97
T2129	15	526	12713	8.20	66.90	400
T2130	22	626	16730	10.45	69.24	451
T2131	19	771	15714	4.33	73.68	267
T2132	18	631	10219	6.04	73.37	406
T2133	19	732	12978	10.07	65.90	285

a factor of two to three can be seen. Since highly accurate station coordinates are the primary goal of these programs, the use of VieSched++ for scheduling is a great success. Additionally, an improvement in the accuracy of secondary parameters such as the estimated earth orientation parameters (EOP) can be seen as well.

4. Conclusion and Outlook

VieSched++ is capable of generating high-quality VLBI schedules. It uses a brute force approach to generate schedules by evaluating all possibilities and many innovative newly designed algorithms such as the recursive scan selection. The schedules are optimized via the so-called multi-scheduling feature, which is generating hundreds of schedules for one session which can be further compared based on simulations. This leads to a significant improvement in the accuracy of geodetic parameters.

In the future, it is planned to extend the VieSched++ software to be able to generate optimized schedules for imaging as well.

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