

VieSched++

Recent Developments and Lessons Learned from Two Years of Fully Automated Scheduling

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Abstract VieSched++ is an open source VLBI scheduling and simulation software that is already operationally used worldwide. Within the IVS, over ten active observing programs are currently scheduled using VieSched++. This accumulates to over 400 sessions for the year 2022 alone. Within this work, the most recent developments of VieSched++ are summarized. Additionally, the quality of the derived schedules is investigated based on the INT2 and INT3 observing programs. Within these programs, the reported UT1-UTC formal errors could be reduced by up to 50%. Finally, improvements in the robustness of the automated scheduling pipelines are discussed, as well as an outlook of future development plans of VieSched++ is provided.

Keywords Scheduling, VieSched++

1 Introduction

Scheduling is an integral part of every VLBI experiment. It directly determines the quality of the results by defining the observations that will be available for the analysis. Over the last decades almost all geodetic VLBI schedules were generated using the scheduling software *sked* [1], developed and maintained by the NASA Goddard Space Flight Center VLBI group. However, in the most recent years, the new scheduling software *VieSched++*¹ [3], developed at TU Wien

and now maintained at ETH Zurich, has become more and more popular. As of today, VieSched++ is used to schedule the IVS observing programs AUA, AUM, CRD, CRF, INT2, INT3, OHG, T2, T2P, VGOS-B, VGOS-C, VGOS-R&D, VGOS-S, as well as other test sessions. This accumulates to a total of approximately 400 schedules that will be scheduled in the year 2022 alone. In order to enable the processing of this huge amount of sessions a fully automated VLBI scheduling pipeline was developed². This pipeline is in operational use since 2020. As of June 2022, over 70 24-hour sessions and over 450 one-hour Intensives have been automatically, and successfully, scheduled and submitted to the IVS Data Centers.

Furthermore, VieSched++ is used for research and development purposes. In addition to classical R&D sessions, such as VGOS-R&D, VieSched++ is also used to test new algorithms, approaches, and capabilities. For example, a VLBI satellite scheduling module is currently being developed and studied at TU Wien.

Within this work, we give an overview of the most recent developments (Section 2), discuss the scheduling quality based on two selected observing programs, namely INT2 and INT3 (Section 3), and report on the status and lessons learned from the fully automated scheduling pipeline (Section 4). Finally, a short outlook regarding the future of VieSched++ is provided (Section 5).

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¹ <https://github.com/TUW-VieVS/VieSchedpp>

² https://github.com/TUW-VieVS/VieSchedpp_AUTO

2 Recent Developments

VieSched++ is still in active development, although the development speed of major new features has decreased over the last year to provide some form of stability, required to ensure a reliable operational use.

However, some major updates have still been released within the last year. For the VGOS-R&D session VR2202, the treatment of the sky-coverage objects has been extended. One major goal of VGOS is to greatly improve the sky coverage within short periods [2] for a more rapid determination of tropospheric turbulences. To properly account for different slew rates and visibility areas of VGOS stations, it is now possible to assign custom sky-coverage optimization parameters per sky-coverage object. The sky-coverage optimization parameters describe the saturation of the local sky as a function of the previously scheduled observations, azimuth, elevation, and time. Thereby, multiple stations, such as twin radio telescopes, can share the same sky-coverage object. During VLBI scheduling, one task is to find a good balance between the station sky coverage and the number of scans. The former requires having long slew distances between two consecutive scans, while the latter requires having short slew distances. In practice, this means that stations with a poor common visibility with the remaining network, or stations with slower slew rates, can use smaller saturation areas, leading to a worse distribution of scans over the local sky. In contrast, stations with high slew rates can be parameterized by using larger saturation areas, forcing longer slew angles and therefore a better distribution of scans.

Furthermore, several algorithms, such as the fillin-mode a posteriori, were improved. The motivation for these changes were, again, the VGOS-R&D sessions, in particular the better inclusion of the southern-hemisphere station HOBART12 (Tasmania) with the remaining VGOS network that only consists of northern-hemisphere stations. The imbalanced network geometry leads to a challenging situation to properly include HOBART12 with the remaining network, especially since HOBART12 is scheduled in tagalong mode, meaning that the schedule is first generated without considering HOBART12, while HOBART12 is later added to as many scans as possible. Normally, this leads to a poor inclusion and large idle times for HOBART12, because the remaining

stations tend to observe mostly northern-hemisphere sources, which are not visible for HOBART12, especially since only three-station scans are scheduled in VGOS experiments. Figure 1 depicts the observable sky coverage of HOBART12 with the remaining VGOS stations. Only the blue areas would be observable based on the default algorithms.

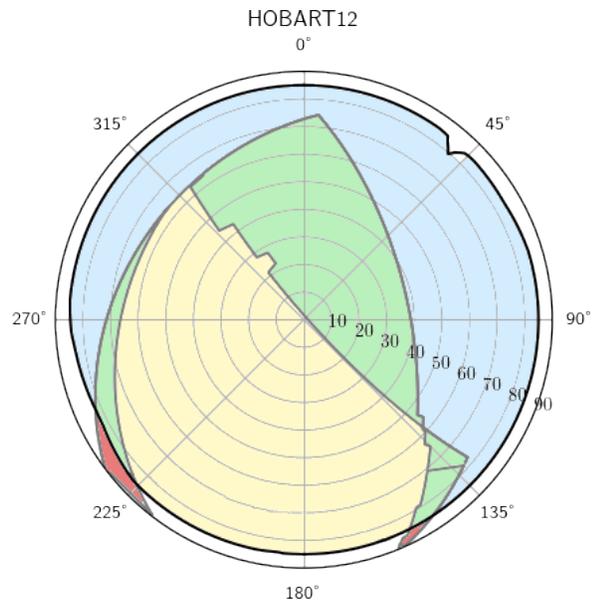


Fig. 1 Sky coverage of HOBART12. Blue: visible by 3+ stations. Green: visible by two stations. Yellow: only visible by HOBART12.

To overcome this issue, the fillin-mode a posteriori is used. After station HOBART12 is added to as many scans as possible using the tagalong mode, a new iteration of fillin-mode is started. Since it happens at the very end of the scheduling process, it is called fillin-mode a posteriori. This mode investigates the station idle times between all consecutive scans and schedules some additional scans in between, in case of available idle time. Within this mode, station HOBART12 is treated as a normal station. Furthermore, also two-station scans are allowed during this special fillin-mode and the restriction of minimum time between two scans to the same source is lowered as well. This leads to a significantly better inclusion of HOBART12 within the remaining network.

Among the improved features is also the previously mentioned satellite scheduling module. Within VieSched++, satellites are now treated similarly as any

other available source. Therefore, the full capability of the source-based parameterization can be utilized. This means that every satellite, or custom-defined group of satellites, can utilize its own set of scheduling parameters. This ensures the highest flexibility when scheduling satellite observations. Furthermore, a manual satellite scheduling graphical user interface (GUI) is available as well. Within this GUI, possible satellite scans can be hand-picked and adjusted freely. After the satellite scans are fixed, the remaining time is filled using classical observations of active galactic nuclei. However, it is to note that the satellite scheduling module is still in development and has been, so far, only used for simulation studies [7].

3 INT2 and INT3 Session Performance

To assess the quality of schedules generated with VieSched++, the INT2 and INT3 observing programs are studied. INT2 sessions are typically observed with a single baseline using a recording rate of 256Mbps while INT3 sessions are multi-baseline Intensives involving up to five stations and using a recording rate of 1Gbps [6]. Starting in 2019, INT3 sessions were scheduled using VieSched++ instead of sked and INT2 followed mid-2020. Figure 2 compares the performance of sessions generated with the two scheduling software packages between August 2016 and August 2021. The performance is expressed via the formal error of UT1-UTC. The top plot depicts the most observed INT2 baselines, while the bottom depicts the most frequently used INT3 networks. The bars in the background represent the number of corresponding sessions.

It can be seen that the INT2 performance of baseline IsWz was improved by 11 %, while the improvement is 32 % for baseline KkWz and 44 % for baseline MkWz.

For INT3, the five-station network was improved by 45 %, while the four-station network is improved by 25 %. Only the three-station network shows a degradation of the UT1-UTC precision of 12 %. However, on further inspection, it is revealed that the majority of three-station INT3 sessions were originally scheduled using a bigger network where some stations dropped out. This is indicated by the hatched areas in Figure 2.

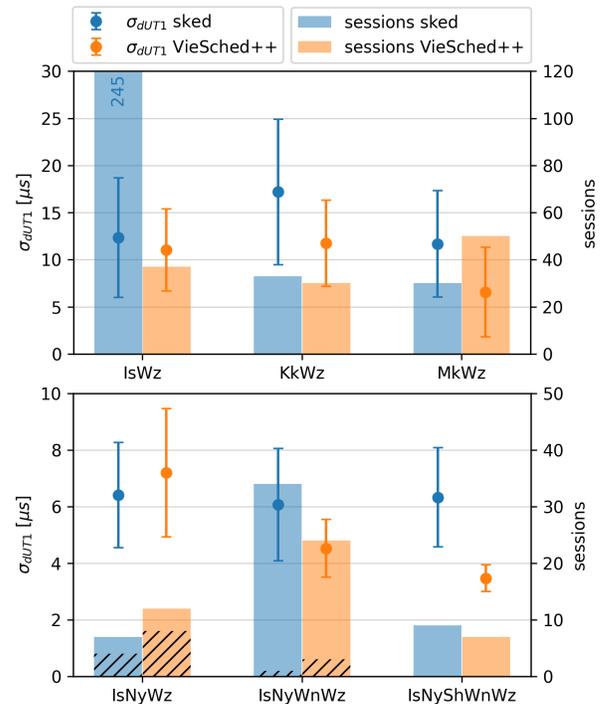


Fig. 2 Top: performance of INT2 sessions grouped by observed baseline. Bottom: performance of INT3 sessions grouped by the observing network. The dashed areas mark sessions that were originally scheduled with a larger network, but only analyzed using the listed stations.

Therefore, these sessions are not suitable for a scheduling comparison.

A more detailed investigation of the INT2 and INT3 session performance including a comparison of the scheduling approaches can be found in [6]. A discussion regarding the utilized VieSched++ Intensive scheduling approach is available in [5], Appendix A.

4 Automated Scheduling

The majority of the schedules created with VieSched++ are generated and distributed using a fully automated scheduling approach. The automated scheduling pipeline is based on a Python framework, which is executed daily. It downloads the most recent schedule master, as well as the scheduling catalogs, and generates the upcoming schedules using templates describing the scheduling approaches that should be taken. In general, several hundred different schedules

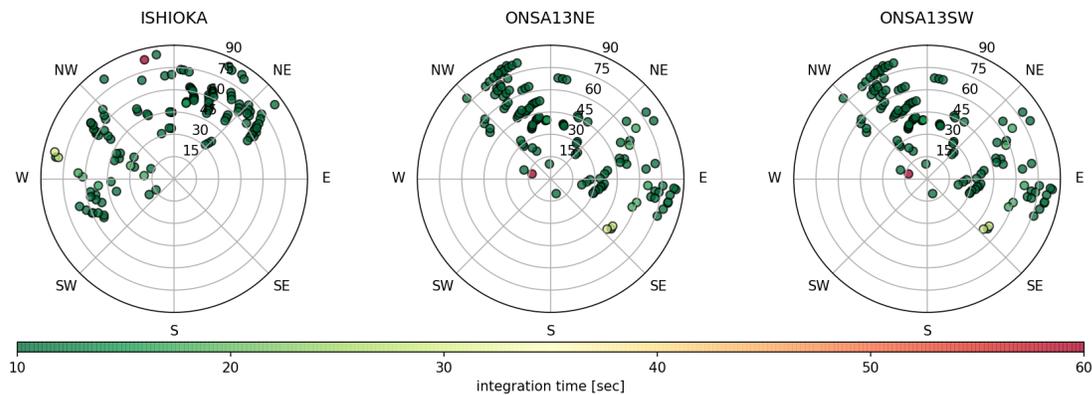


Fig. 3 Sky coverage as reported by the automated VLBI scheduling software for VGOS-B session B22176 (2022-06-25).

are generated per session. Every schedule is further simulated and analyzed one thousand times to assess the expected precision of the estimated geodetic and astrometric parameters. Based on the simulated results, the best performing schedule is selected and distributed. More information regarding the automated scheduling approach can be found in [4].

Within the last years, some major improvements regarding the robustness and quality control of the automated scheduling software were achieved.

First of all, the software does now perform daily checks if a station network has been changed since the submission of the schedule. In case of a network change, the corresponding personnel is notified via mail.

Furthermore, daily checks are conducted if the scheduled sessions are properly available at the IVS Data Centers. Therefore, it is more rigorously checked if the upload has been successful. In case of missing schedules, notifications are distributed via mail as well.

Finally, the quality control has been improved. This is done by a complete overhaul of the reports that are distributed via mail for every scheduled session. The reports do not only include the schedule files but also various statistics and comparisons of the scheduled session with previously scheduled sessions of the same observing program. The statistics are provided graphically. Furthermore, sky-coverage images are distributed, once by color-coding the observation duration per scan and once by color-coding the scan start time. Figure 3 depicts the sky coverage of session B22176 (VGOS-B) with color-coded observation duration. Together this provides a comprehensive but also very con-

cise overview of the scheduling quality. Examples can be seen at the IVS Operation Center DACH webpage.

However, it is to note that some observing programs, such as CRDS and CRF were removed from the automated scheduling pipeline. This was mainly done since these sessions require a more detailed assessment of the observed sources. For every session, the source list is adapted based on previous sessions. Furthermore, special care has to be taken to include enough calibration scans and to also include some special sources. Since not all of these sources are properly defined within the sked catalogs, some further adjustments are needed. For example, the integration time is fixed for some sources with insufficient or missing flux density information. More research and development work is required to be able to automatically schedule CRDS and CRF sessions again.

It is to note that some R&D sessions are not scheduled using the automated approach.

5 Future Plans

In future, it is planned to further extend VieSched++.

First of all, it will be required to work towards defining a new set of scheduling catalogs. Currently, VieSched++ utilizes the sked catalogs. However, several key parameters, especially for VGOS, are not included in the current catalog files. This does not only include the VGOS observing mode definition but also (elevation-dependent) SEFD values for the VGOS frequencies, as well as new methods of defining source flux densities.

Next, it is planned to improve the simulation capabilities. Scheduling is only as good as the underlying simulations. Deficiencies in simulations will prevent the selection of the most optimal schedule. Therefore, improving simulations will be a key requirement to improve scheduling in the future. In particular, it is planned to provide custom tropospheric turbulence parameters per station, which should lead to more realistic simulations.

Another project includes the mitigation of space-born radio frequency interference (RFI) via dynamic masks. With the drastic increase of satellites emitting radio signals, it will be required to properly mask areas where satellites are present in order to not schedule observations in these directions.

6 Conclusion

Within the IVS, VieSched++ is operationally used for over ten active observing programs. In the year 2022, it is expected that the schedules of around 400 VLBI experiments of the IVS will be generated using VieSched++.

In this work, some of the more recent major developments are briefly introduced. This includes a more flexible definition of the sky-coverage objects, potentially leading to an improved sky coverage at the stations, an improvement of existing algorithms, as well as an improvement of the satellite scheduling module. While the improved sky-coverage definition has already been utilized in VGOS-R&D sessions, the satellite scheduling module has been, so far, only used for simulation studies.

Moreover, the quality of the operationally generated schedules was assessed by investigating the INT2 and INT3 session performance. Thereby, it was revealed that the formal errors of UT1-UTC were reduced by up to 50 %. More detailed investigations regarding the INT2 and INT3 session performance is available in [6].

Furthermore, a report regarding the automated scheduling pipeline [4] is presented. It is in operational use since 2020 and in total over 500 IVS sessions have already been scheduled fully automatically. Improvements in the automated scheduling pipeline aim to provide a more robust system. Therefore, additional checks are executed every day looking for changes

in the scheduled station network after schedule submission and checking the availability of uploaded schedules. Furthermore, the reports that are distributed for every scheduled session were overhauled. The reports include valuable statistics and comparisons of the current schedule with past schedules of the same observing program, allowing for a quick evaluation of the scheduling quality.

Overall, it can be seen that VieSched++ is in a healthy state. It is still actively developed and maintained and the resulting schedules are of excellent quality, while mostly being generated fully automatically.

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