Scheduling of VLBI Satellite Observations with VieVS

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Abstract In order to enable VLBI observations of satellite targets on a regular basis, proper scheduling procedures need to be in place. The Vienna VLBI Software VieVS has been used to schedule about 40 of these test sessions, triggering large developments in the scheduling tools. We report on the current capabilities of the available software and discuss present difficulties when preparing a new experiment. In the second part we concentrate on the scheduling of VLBI sessions observing the very low APOD satellite with the Australian AuScope array.

Keywords Space tie, Co-location in space, VLBI satellite tracking, VieVS, scheduling, APOD

1 Introduction

Scheduling depicts the process of generating suitable observation plans. This is defining the time sequence of a VLBI experiment under consideration of the telescopes specific capabilities. The result is a schedule in a standardized format, e.g. .SKD or .VEX.

The new challenge hereby is the cross-eyed observation geometry, meaning that the directions from the participating telescopes to the target cannot be considered as parallel any more, as is the case for quasar VLBI. The satellite targets are moving, requiring active tracking of the telescope. In general, accurate timing and antenna steering is more critical.

We use the Vienna VLBI Software (VieVS, Böhm et al., 2012) for scheduling.

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2 Scheduling satellite observations with VieVS

The satellite scheduling module of VieVS[1] is described in Hellerschmied et al. (2015a) and Hellerschmied et al. (2015b). All antenna specifications and steering are treated as for standard geodetic scheduling (Sun, 2013). The coordinates for the satellite targets are implemented via public two-line element (TLE) orbit data. Running in Matlab, the scheduler works interactively, where the operator can choose the best target - a visible quasar or a satellite - and add it to the schedule. An intuitive program design and interactive sky plots support this manual process. The program then internally manages antenna slewing, on source times for quasars and observation timing requiring common visibilities. In order to allow tracking tests at individual stations, the scheduler also works for a single telescope to be scheduled.

This interactive mode is very suitable for short test sessions. Over the past years, about 40 of those sessions were scheduled with this program (see Figure 1).

[1] More information including a user manual is available at `http://vievs.geo.tuwien.ac.at/`

date	duration	name	stations	targets
16.01.2014	1h	G140116a	O8, Wz	Glonass
16.01.2014	1h	G140116b	O8, Wz	Glonass
21.01.2014	1h	G140121a	O8, Wz	Glonass
21.01.2014	1h	G140121b	O8, Wz	Glonass
15.06.2015	1h	615aHo	Ho	GPS + Glonass
18.06.2015	1h	169cHo	Ho	GPS + Glonass
18.06.2015	2h	169cCd	Cd	GPS + Glonass
28.06.2015	2h	179a	Ho, Cd	GPS + Glonass + quasars
19.08.2015	28 min	ex1	Wz, Wn, Wd	GPS + Glonass
20.08.2015	25 min	ex2	Wz, Wn, Wd	GPS + Glonass
24.08.2015	11 min	ex3a	Wz, Wn, Wd	GPS
24.08.2015	4h	236a	Ho, Cd	GPS + quasars
26.08.2015	4h	238a	Ho, Cd	GPS + Glonass + quasars
12.11.2015	30 min	ex4a	Wd, Wn	GPS + Glonass
23.11.2015	33 min	23a1	Mc, Wd	GPS + Galileo + Glonass
23.11.2015	2h 15min	23b1	Mc, Wd	GPS + Galileo + Glonass + quasars
23.11.2015	2h 30 min	23c1	Mc, Wd	GPS + Galileo + Glonass + quasars
18.04.2016	9 min	ex5a	Wz, Wn, Wd	Glonass
05.05.2016	6h	126b	Ho, Cd	GPS + quasars
10.05.2016	6h	131a	Ho, Cd	GPS + quasars
11.05.2016	6h	132a	Ho, Cd	GPS + quasars
17.05.2016	12 min	ex6b	Wn, Wz	Glonass
23.05.2016	12 min	ex7a	Wn, Wz	Glonass
23.05.2016	3h	144b	Mc, O8, Sr	GPS + Galileo + Glonass + Beidou + quasars
23.05.2016	40 min	144d	Mc, O8, Sr	GPS + Galileo + Glonass + Beidou
30.05.2016	12 min	ex8a	Wn, Wz	Glonass
06.07.2016	6 min	ap01	On	APOD
06.07.2016	9 min	ap02	On	APOD
06.07.2016	8 min	ap03	On	APOD
14.07.2016	7 min	196b	On	APOD
14.07.2016	9 min	196c	On	APOD
15.07.2016	9 min	197c	On	APOD
18.07.2016	10 min	200a	Yg, Ke	APOD
20.07.2016	9 min	202	Yg, Ke	APOD
25.07.2016	6 min	207a	On	APOD
25.07.2016	5 min	207b	On, Wn, Wz	APOD
19.09.2016	6 min	263a	On	APOD
19.09.2016	6 min	263b	On, Wn, Wz	APOD
19.09.2016	5 min	263c	On, Wn, Wz	APOD
11.11.2016	33 min	316a	Ke, Yg	APOD + quasars
12.11.2016	41 min	317a	Hb, Ho, Ke	APOD + quasars
12.11.2016	35 min	317b	Hb, Ke, Yg	APOD + quasars
13.11.2016	26 min	318b	Hb, Ho, Ke, Yg	APOD + quasars
13.11.2016	26 min	318c	Hb, Ho, Ke	APOD + quasars
13.11.2016	23 min	318d	Yg, Ke	APOD + quasars
14.11.2016	40 min	319a	Hb, Ho, Ke, Yg	APOD + quasars
23.11.2016	1 h	328a	Wa	GPS
27.11.2016	24 h	a333	Hb, Ke, Yg	APOD + quasars
01.12.2016	3h 10 min	g336	Ho, Cd, Wa	GPS + quasar (pol. calibrator)

Fig. 1 List of scheduled satellite VLBI sessions with VieVS.

2.1 Automatic scheduling mode

Prompted by the aim to observe longer sessions of a few hours duration, VieVS now also allows for automated scheduling of combined observations of satellites and quasars. It uses the station-based scheduling approach (Sun et al., 2014), optimising for sky coverage and slew times at each site equally for quasar and satellite scans. One can define alternating blocks in a defined time duration for a preselected list of satellite and quasar targets. Following simulations by Plank et al. (2016), we chose a mix of 10 minutes of quasar observations every 50 minutes in experiments 126b, 131a, and 132a. We also found it useful to restrict the observed GNSS satellites to only a handful, since re-observing the same targets allows for better interpretation of the results (see Plank et al. , this volume).

This newly developed automatic scheduling mode is suitable for longer sessions of satellite observations as well as it supports the integration of satellite scans into a geodetic schedule.

2.2 Challenges

Having scheduled numerous sessions, we express our thanks to all our collaborators and stations contributing to the experiments. It really was the request for actual sessions' schedules that triggered the rapid development.

Looking back we can say that the only real challenge in creating a new schedule (for a new station) is the definition of the correct observing mode in the .VEX files. While the schedule itself could be made within a few hours, collecting the necessary information about the station's equipment and capabilities was the hardest part. One reason for this is the fact that the observations of GNSS satellites are performed in L-band, often using different equipment (and telescopes) than typically used in geodetic VLBI. In addition, with VLBI being such a complex technique, the local knowledge of the scheduler is often not sufficient to thoroughly control the selected mode whether it is suitable for the individual stations.

As a consequence, we have identified the communication and feedback loop between station personnel, correlator staff and the scheduler as an item for future improvement. This will allow an easy integration of new telescopes into future observing efforts in VLBI satellite tracking.

2.3 Observing APOD

The APOD satellite mission (Tang et al, 2016) is a Chinese CubSat carrying a dedicated VLBI transmitter sending tones in S- and X-band. The orbit is extremely low, at about 470 km orbital height. This makes common visibility between two or more VLBI telescopes challenging. VieVS was used for tracking tests using the telescopes in Australia, Onsala and Wettzell. In November 2016 intensive observing was done using the Australian AuScope telescopes in Hobart, Katherine and Yarragadee. The novelty hereby was the successful application of continuous tracking as well as the integration into a full 24 hour geodetic schedule observing quasars.

For the scheduling of APOD, again orbit information provided by the public TLE was used. Before the actual tracking, the antenna steering information in terms of azimuth (Az) and elevation (El) at one second intervals was calculated using the latest orbit prediction provided by the APOD mission control centre BACC, the Beijing Aerospace Control Center.

Initial test sessions in July 2016 showed that the TLE tracking features implemented in recent Field System (FS) versions are not suitable to track this fast satellite with the AuScope antennas. The shortest available position update interval of 1 second could not be maintained (blocked all other FS commands) and larger intervals were not suitable for keeping the target within the antenna beam. Alternatively, the continuous tracking mode provided by the antenna control units (ACU) of the AuScope antennas was used for satellite tracking. Using this option, the ACU interpolates positions and adjusts slew speeds between AzEl tracking points directly loaded from an ASCII table. At the moment, this mode can only be controlled manually by changing the tracking mode and loading the AzEl files via the ACU interface.

Practically the APOD scheduling was done as follows:

- Define a session time window and search for satellite passes and common visibilities using the latest TLE (several days in advance). VieVS provides convenient features to check for mutual visibility and to determine possible observation times while taking into account various observation restrictions. The visibility graphs in VieVS (as shown in Figure 2) ease this process.
- Select suitable passes and request the VLBI signal switched on at the APOD BACC (minimum two days in advance). BACC may also provide predicted APOD ephemeris shortly before the actual observations. These ephemeris are preferred for tracking as they are assumed to be more accurate than TLE data.
- Build the schedule. Be aware that final scan times may change up to a few seconds with updated satellite ephemeris. The APOD scans were either fully embedded into a geodetic schedule (e.g. session a333) or at least a block of sveral minutes of quasar observations was added before and after the APOD block. While the quasar scans were scheduled automatically, the observations of APOD needed manual interaction. In order to allow for the switch between the automatic observations controlled by the FS for the quasar scans and the direct AzEl tracking mode for APOD, gap times of five minutes were included in the schedule. Result of the schedule is a VEX file defining the observing mode (see Figure 3), which in our case was identical for the satellite and quasar scans. Furthermore, it triggers the recording for both types of scans and provides the source coordinates of quasars.
- Once the latest orbit information was received by the APOD BACC, the AzEL tracking files were prepared. These are essentially simple ASCII tables containing AzEl tracking points at one second intervals. Additional care had to be taken to provide Az values within the cable wrap limits of the antenna.

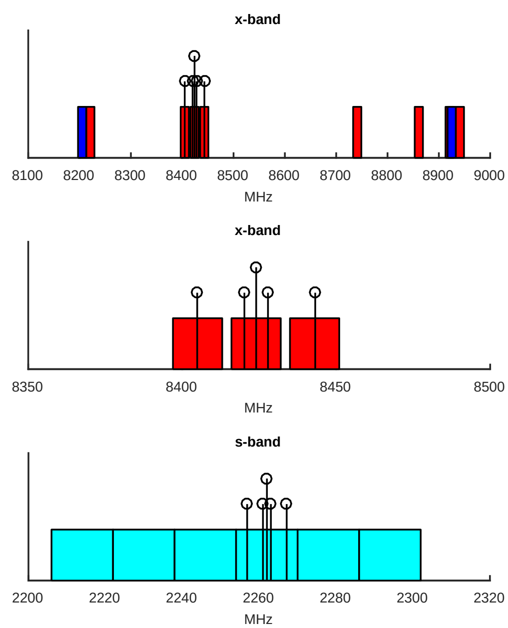

Fig. 3 Observing mode in APOD experiments 316 to 333. We observed 16 channels with 16 MHz bandwidth at two-bit sampling. In X-band, the DOR tones are covered by channels 2 to 4 with the carrier at 8424.04 MHz. In S-band, all satellite tones lie within one channel. Due to RFI, all S-band channels were allocated contiguous to cover a continuous band.

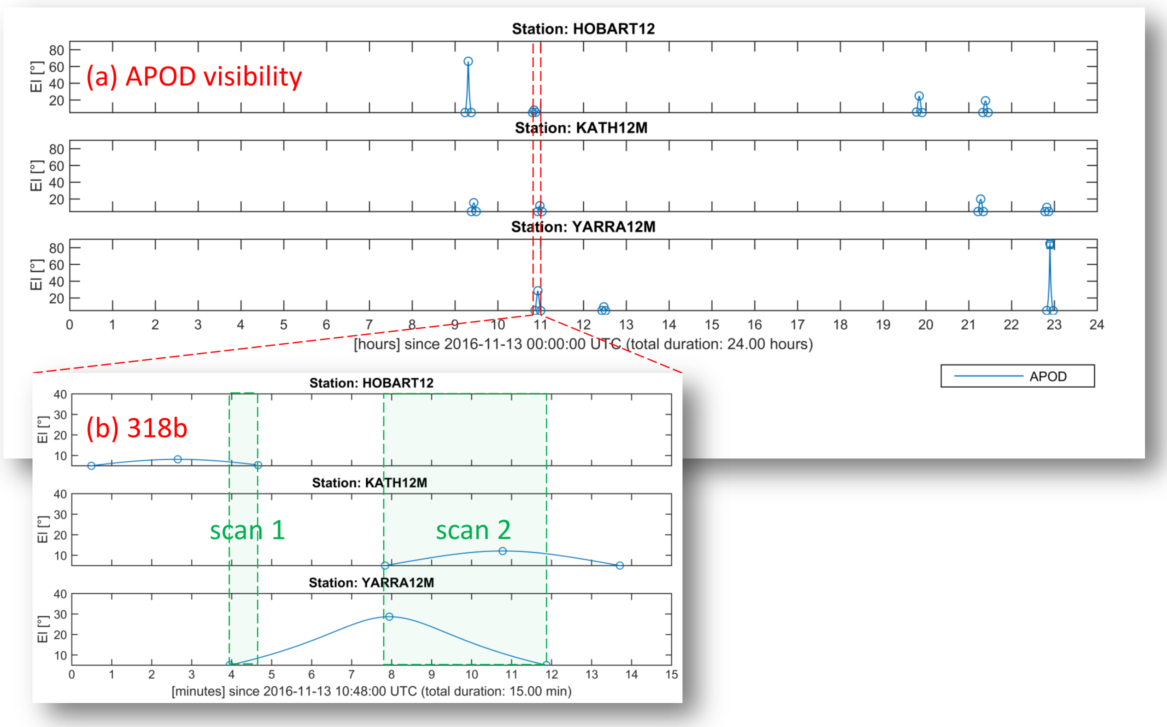

Fig. 2 Graphical illustration of the APOD visibilities in VieVS (satellite elevation at stations versus time). After checking (a) APOD visibility roughly for the whole day (Nov. 12, 2016) and selecting suitable passes, (b) definite scan times were accurately determined. Scan durations for common visibilities are a few minutes at most.

3 Conclusions

The VieVS satellite scheduling module has been repeatedly applied for generating observing files for VLBI satellite observations. The newly developed mode now allows for automatic scheduling of combined sessions including satellite targets and quasars, suitable for scheduling sessions of longer duration. While the scheduling process is easy to run, the most difficult part of generating a schedule was identified to be the correct implementation of a selected observing mode, considering station specific back-ends and equipment.

Latest developments in VieVS were dedicated to observing the very low APOD satellite. Hereby the connection between antenna steering using the field system and satellite tracking directly via the ACU revealed new challenges for our scheduling module.

Keep up to date with the latest developments at the IVS Working Group 7 "Observation of satellites using VLBI" Wiki: `http://auscope.phys.utas.edu.au/opswiki/doku.php?id=wg7:home`.

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