Ambiguity Resolution in Legacy Sessions

The [so far unfulfilled] Promise of mbd_anchor

Axel Nothnagel[1], Hana Krásná[1], Simone Bernhart[2,3]

Abstract Multiband delays that are estimated from visibility data using the program *fourfit*, which is distributed with the Haystack Observatory Postprocessing System (HOPS), do not have a unique ambiguity resolution. At TU Wien, we are looking into options to strengthen the Vienna VLBI and Satellite Software VieVS with an automatic ambiguity resolution module. In the course of these endeavors, we stumbled across the "mbd_anchor" keyword of the HOPS fringe fitting program *fourfit*. This keyword controls how the decision is made as to which of the ambiguous multiband delays is reported. The option, which was introduced for VGOS observations, allows tying the multiband delays to the singleband delays. In order to find out whether we could use this option successfully also for legacy S/X fringe fitting, we performed an initial test. As it turned out, the precision of the S/X singleband delays is not sufficient if the singleband delays lie close to the middle between two multiband delay options.

Keywords Legacy observations, ambiguity resolution, *fourfit* mbd_anchor options

1 Introduction

Within the IVS collaboration, the estimation of multiband delays (MBD) from visibility data is done by the correlation centers using the fringe fitting program *fourfit*, which is distributed with the Haystack Observatory Postprocessing System (HOPS) software package[1]. Ambiguities of these multiband delays are a well-known effect of S/X legacy observations in a bandwidth synthesis (BWS) setup [4]. In Level-2 VLBI data analysis of legacy observations, ambiguity resolution for MBD created by this pipeline is a necessary processing step. The VIE IVS Analysis Center currently depends on the service of IVS analysis centers producing pre-processed databases with solved ambiguity resolution, which is currently done with the software package *nuSolve* [2]. Therefore, we started activities to develop an automatic ambiguity resolution tool in the Vienna VLBI and Satellite Software (VieVS) [1] to provide an alternative method and become independent of the need for preprocessing elsewhere.

In the course of our investigations, we also looked into the logic of how the HOPS fringe fitting program *fourfit* handles MBD determination. Here, we found that, almost unnoticed by the broader VLBI community, in December 2013 Roger Capallo of Haystack Observatory introduced a new option in the *fourfit* control files, named "mbd_anchor". It controls which reference value is used for the final MBD decision. The options of this keyword are "model" and "SBD". This means that the MBD is chosen which is either closest to the model delay or to the SBD (Figure 1). In fact, *fourfit* does a fringe fit on the basis of a maximum search in the singleband delay, multiband delay, and delay rate space first. Only as a secondary step, the output MBD is shifted according to the logic above.

The option "model" was and still is the implicit default for legacy S/X observations. The keyword "mbd_anchor" together with the option "SBD" was introduced because the VGOS SBDs have a nominal precision which is much better than that of legacy

1. TU Wien, Austria
2. Reichert GmbH, Germany
3. Bundesamt für Kartographie und Geodäsie, Germany

1 https://www.haystack.mit.edu/haystack-observatory-postprocessing-system-hops/

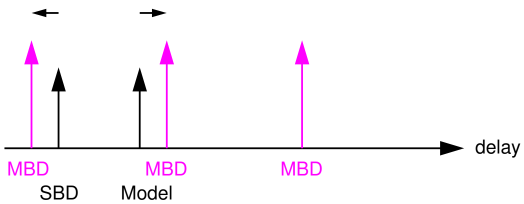

Fig. 1 Ambiguous MBD selection either as closest to SBD or model delay.

observations. The reason for this, beyond the pure number of channels, is phasecal, which is not applied in legacy SBD determinations but is applied with special phasecal sampler pool corrections for VGOS SBD. The VGOS SBD 1σ is $\sim$250 ps, while X band SBD 1σ is $\sim$2–2.5 ns. Consequently, VGOS SBDs are so good that the success rate of the MBD choice is close to 100%.

It should be noted that the “model” delay is able to track clock variations only as well as the correlator a priori model includes these (for example by fringe searches at multiple epochs within a session beyond just applying the gps-fmout clock models). The SBD, however, reliably tracks clock variations, though with the implicit noise level. A good SBD is, thus, needed to serve as a reliable reference, as is the case for VGOS.

The question now is whether we can make use of “mbd_anchor sbd” in legacy sessions. By the way, the availability of “mbd_anchor sbd” went unnoticed by the community, because it was not announced explicitly but just as another keyword in the VGOS *fourfit* control file of the VGOS cookbook distribution.

2 Experiment

For verifying whether the “mbd_anchor sbd” command in the fringe fitting process would help to avoid the appearance of delays at the wrong ambiguity level, we performed a test with data of IVS session R11135 looking at two cases. The first case is the standard procedure with fringe fitting, ignoring the “mbd_anchor” command. Here the model delay is the reference for the MBD. For the second case, we set “mbd_anchor sbd”, applying the SBD as reference for the MBD.

Both MBD data sets were then analyzed with VieVS in a special setup. With a “First solution” setting, VieVS estimates only simple clock polynomials and one zenith wet delay per site for the full length of the session. All model components are applied as is the common standard [3]. Another important difference from full solutions is that only independent baselines with the reference telescope WETTZELL are included. With this mechanism, we avoid having the other baselines affect the results and the residuals. The effects, which we want to see, then appear much more pronounced in the residuals than in a full network solution.

3 Results

The most important results of the two solutions are the post-fit residuals where ambiguities are normally visible by naked eye because they commonly appear as steps of 50 or 100 ns. As can be seen in the example for the standard case, where the MBD is selected to be closest to the model delay, the residuals of baseline FORTLEZA–WETTZELL in Figure 2 show two distinct populations which are separated by one ambiguity of 50 ns. The companion plot for the residuals with the “mbd_anchor sbd” setting in the *fourfit* control file (Figure 3) only shows residuals with no trace of ambiguities. So, the setting in the *fourfit* control file has served its purpose and eliminated MBD ambiguities already before the Level-2 data analysis. It should be noted that the residuals stem from two separate least squares adjustments where the first set of parameters is affected through the ambiguous observations of the second (lower) population.

Another positive example can be seen in Figures 4 and 5. The “mbd_anchor sbd” setting served its purpose and “pulled up” the small group of observations at the start of the session.

Leaving the plain and clear examples, we now look at baseline AGGO–HART15M. The observations do not contribute to the fit, but the residuals are computed nevertheless. In addition, the observations often have lower SNR down to non-detections, which manifests in the plot in some obvious outliers (Figure 6). In the case where the “mbd_anchor sbd” setting was applied, the residual plot looks cleaner, but there are still obvious outliers (Figure 7). In addition, there are data points beyond the margins by several hundreds of nanoseconds (not shown here). The reason for these is again non-detections, which affect the SBD beyond a level where they can be of help for the MBD.

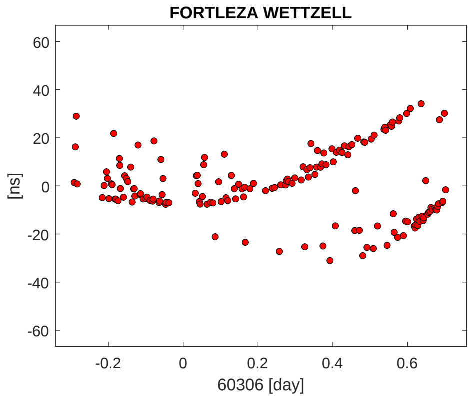

Fig. 2 Residuals using fringe fitting (FF) default setting.

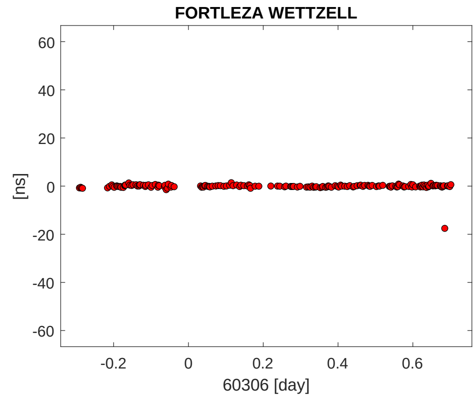

Fig. 3 FF with “mbd_anchor sbd” setting.

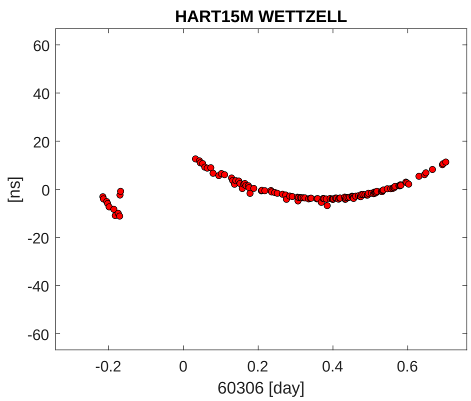

Fig. 4 Residuals using fringe fitting (FF) default setting.

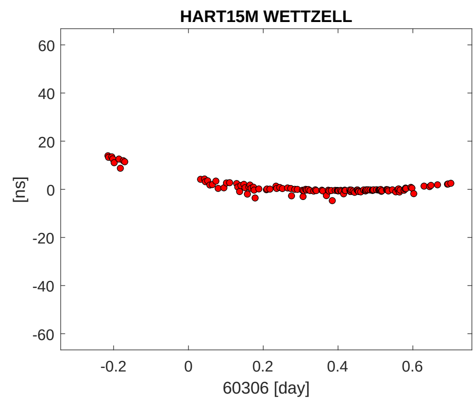

Fig. 5 FF with “mbd_anchor sbd” setting.

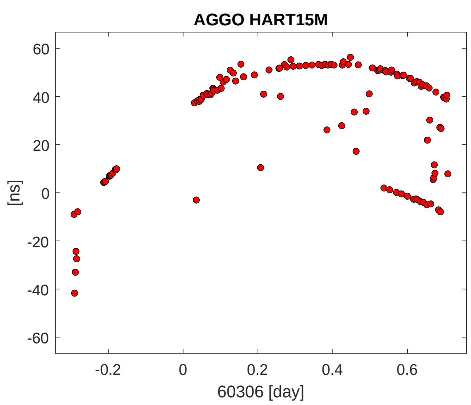

Fig. 6 Residuals using fringe fitting (FF) default setting.

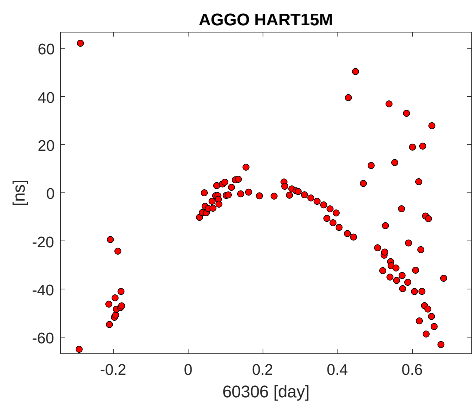

Fig. 7 FF with “mbd_anchor sbd” setting.

The last example shown here is baseline HART15M–MATERA (Figure 8), where the residuals of the standard fringe fitting produce a clear two-population distribution at the beginning of the session, which should be a good candidate for a successful elimination by the “mbd_anchor sbd” setting. Unfortunately, reliable ambiguity avoidance is contradicted by this example because the residual plot with “mbd_anchor sbd” setting shows a clear random two level ambiguity toggling (Figure 9).

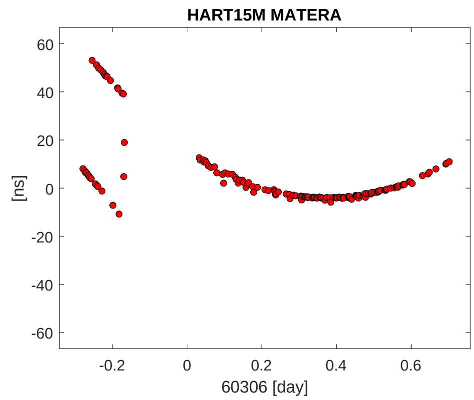

Fig. 8 Residuals using fringe fitting (FF) default setting.

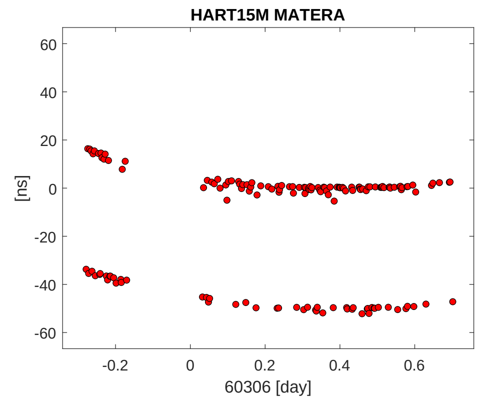

Fig. 9 FF with "mbd_anchor sbd" setting.

4 Discussion and Conclusions

At first glance, the "mbd_anchor sbd" setting in the *fourfit* fringe fitting control file for ambiguity clearing showed promising results. However, there are examples where the logic implemented in *fourfit* is unable to avoid ambiguity effects. We attribute this to the fact that SBDs might lie close to the middle between two ambiguity levels. Then the formal errors of SBDs of about 2–2.5 ns produce a 2σ corridor (95% confidence) of about 4–5 ns as depicted in Figure 10. The probability of selecting the "wrong" MBD is rather high, and the decision of which MBD to report becomes random.

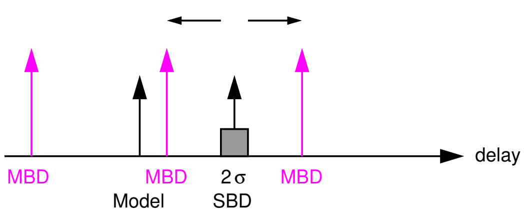

Fig. 10 Ambiguous MBD selection either as closest to SBD or model delay.

The conclusion of our investigation is that the "mbd_anchor sbd" setting in the *fourfit* fringe fitting control file does not provide sufficient reliability for ambiguity avoidance in legacy S/X band sessions. Owing to its adverse effects for SNRs close to the detection limit, the default setting "mbd_anchor model" should be used, which is equivalent to not listing this command in the control file at all. At the end, it should be mentioned that the VGOS MBDs have 1σ formal errors of $\sim$250 ps. For this reason, the probability of erroneous decisions is reduced dramatically, and the "mbd_anchor sbd" setting in the *fourfit* fringe fitting control file serves its purpose well.

References

1. Böhm J., Böhm S., Boisits J., Girdiuk A., Gruber J., Hellerschmied A., Krásná H., Landskron D., Madzak M., Mayer D., McCallum J., McCallum L., Schartner M., Teke K., Vienna VLBI and Satellite Software (VieVS) for Geodesy and Astrometry. Publications of the Astronomical Society of the Pacific, 130(986), 044503. https://doi.org/10.1088/1538-3873/aaa22b, 2018.
2. Bolotin S., Baver K. D., Gipson J. M., Gordon D., MacMillan D. S., The First Release of νSolve. International VLBI Service for Geodesy and Astrometry, 2012 General Meeting Proceedings, NASA CP/2012-217504 222-226, 2012.
3. Krásná H., Baldreich L., Böhm J., Böhm S., Gruber J., Hellerschmied A., Jaron F., Kern L., Mayer D., Nothnagel A., Panzenböck O., Wolf H., VLBI celestial and terrestrial reference frames VIE2022b. A&A 679 A53, https://doi.org/10.1051/0004-6361/202245434, 2023.
4. Rogers A. E. E., Very long baseline interferometry with large effective bandwidth for phase-delay measurements. Radio Science, 5(10), 1239–1247. https://doi.org/10.1029/RS005i010p01239, 1970.