Automated multi-baseline VLBI analysis with c5++

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Introduction

Automated processing of UT1 single baseline session has been demonstrated by Hobiger et al. (2010) and is currently applied to regular INT2 sessions as well as ultra-rapid test sessions. We have extended the concept of fully unattended session analysis to multi-baseline sessions and applied it successfully to three station EOPs experiments. Thereby the ambiguity resolution is the crucial part which needs to be handled by a robust and straightforward algorithm before the estimation of the geodetic target parameters can start.

The ambiguity resolution problem

Due to the fact that current geodetic VLBI systems do not observe broadband delays, but rather sample the covered observing band by several narrow channels, the obtained delays contain an unknown number of integer ambiguities. Thereby, the ambiguity spacing is equal to the reciprocal of the unit spacing of all channels belonging to one observing band. Ambiguity estimation in VLBI is an iterative process that involves the computation of a simplified geodetic solution and shifting of the ambiguities according to the residuals obtained. Thereby one needs to consider closure conditions (see figure 1) in order to make sure that ambiguities are distributed over all existing baselines without evoking inconsistencies in the station clocks.

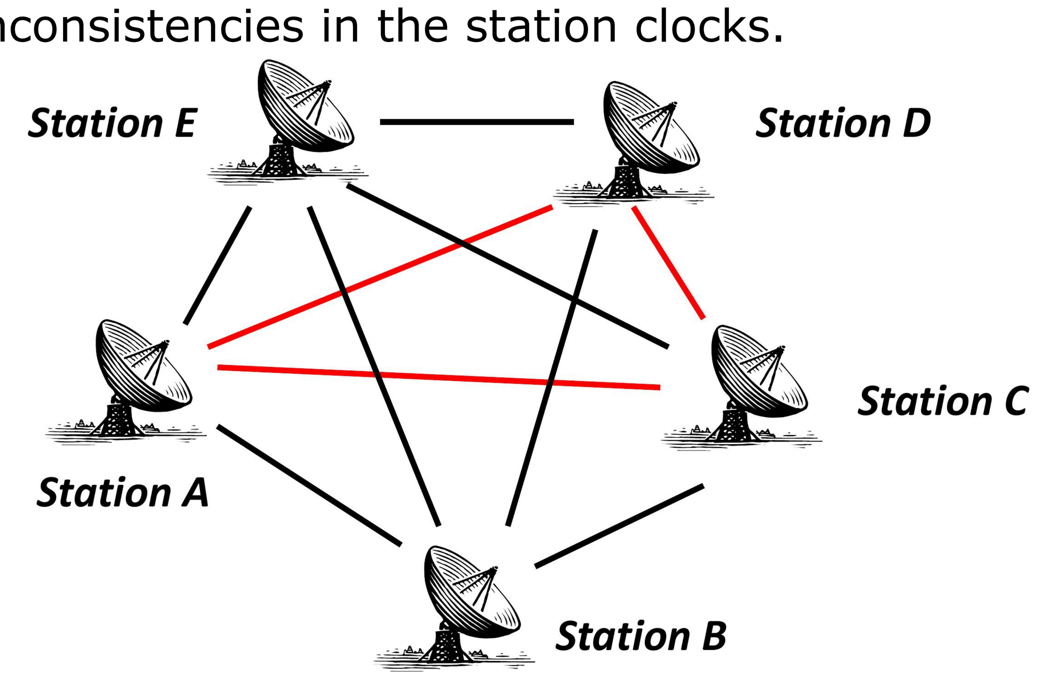

Figure 1: *Sketch of a five station VLBI network where all possible baselines are observed. The tricky part of ambiguity estimation is to align the ambigites in a way that does not only match the observed delays, but also considers all closure conditions (one example for such a condition: ambiguities must be aligned in a way which closes the triangle spanned by stations A,C and D).*

A new ambiguity estimation method

Usually, the ambiguities are assigned to the ionosphere free linear combination, which has the drawback that the ambiguity spacing becomes a non-integer number. The c5++ implementation of the ambiguity estimation algorithm does not follow this procedure, but introduces X- and S- band delays as independent observations. Thus, the integer nature of the ambiguities does not change, but the ambiguity shifting based on the residual must be split according to the spacing of each band. Moreover, instead of considering closure conditions all ambiguities are implicitly assigned by iterativ least-squares estimation. By neglecting troposphere delay effects we can write each X- and S-band observation as a function of a station clocks i and j.

$$\tau_x = \tau_{th} + a_{0,i} + a_{1,i}(\tau-\tau_0)+a_{2,i}(\tau-\tau_0)^2 - [a_{0,j} + a_{1,j}(\tau-\tau_0)+a_{2,j}(\tau-\tau_0)^2] \qquad (I)$$

$$\tau_s = \tau_{th} + b_{0,i} + a_{1,i}(\tau-\tau_0)+a_{2,i}(\tau-\tau_0)^2 - [b_{0,j} + a_{1,j}(\tau-\tau_0)+a_{2,j}(\tau-\tau_0)^2] \qquad (II)$$

Thereby τ_{th} denotes the a-priori delay which should contain a basic atmosphere propagation model with an accuracy better than 25% of the smallest ambiguity spacing. Since this requirement is fullfillled even with very basic troposphere delay models, automated ambiguity resolution can be performed in the following way:

1. Estimate all clock parameters ($a_{0,i}$, $a_{1,i}$, $a_{2,i}$, and $b_{0,i}$) by means of least squares.
2. Use the residuals to assign X- and S-band ambiguities to each observation.
3. Repeat (1) until all residuals are smaller than the minimum ambiguity spacing.

After the last iteration X- and S-band data can be combined in order to obtain the ionosphere free linear combination from which the geodetic target parameters can be estimated. The suggested method is straightforward to implement as it does not require methods from graph theory to consider closure conditions. Such conditions are meet implicitly by the least-square parameter estimation which tries to minimize the residuals w.r.t the functional model. Thus the least squares method forces the sum of all ambiguities (separately at each frequency band) to be zero, which is another way of expressing the closure conditions over the whole network.

Testing the approach

In order to rigorously test and debug the automated analysis methods it is necessary to include auxiliary data, i.e. station log files, which have to be merged with the observations in order to apply proper geophysical site dependent corrections and models. Moreover, a direct interface to the correlator output should be implemented in the analysis software, in order to access the data automatically without human interaction. All this has been implemented in a dedicated c5++ VLBI module which is thought to be used operationally for real-time EOP experiments (see next section).
The ambiguity estimation approach has been tested with data from three station experiments in 2007 including the sites Onsala, Tsukuba and Metsahovi. Figure 2 shows an example how the algorithm resolves ambiguites.

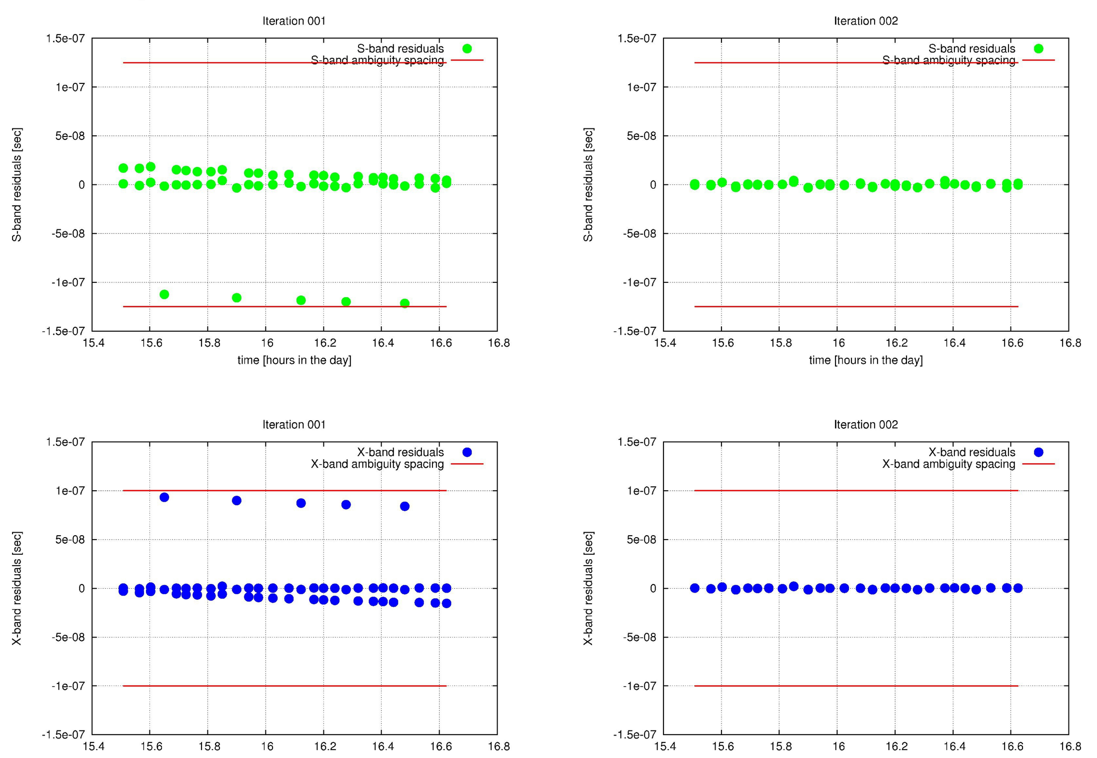

Figure 2: *S-band (top) and X-band (bottom) residuals after the first (left) and second (right) iteration using the automated ambiguity resolution strategy applied to data from a three station experiment (Onsala, Tsukuba & Metsahovi) on Sep. 4th, 2007. One can see that all ambiguities are resolved properly after two iterations*

After ambiguities were aligned across all baselines, ionosphere corrections were computed, the observation databases could be updated and the target parameters, i.e. UT1 for the selected sessions, were estimated. The algorithm has been successfully tested with three 3-station experiments and one network containing 4 VLBI stations. In all cases ambiguities could be estimated after less then 5 iterations without human interaction directly from the correlator output.

Real-time EOP sessions

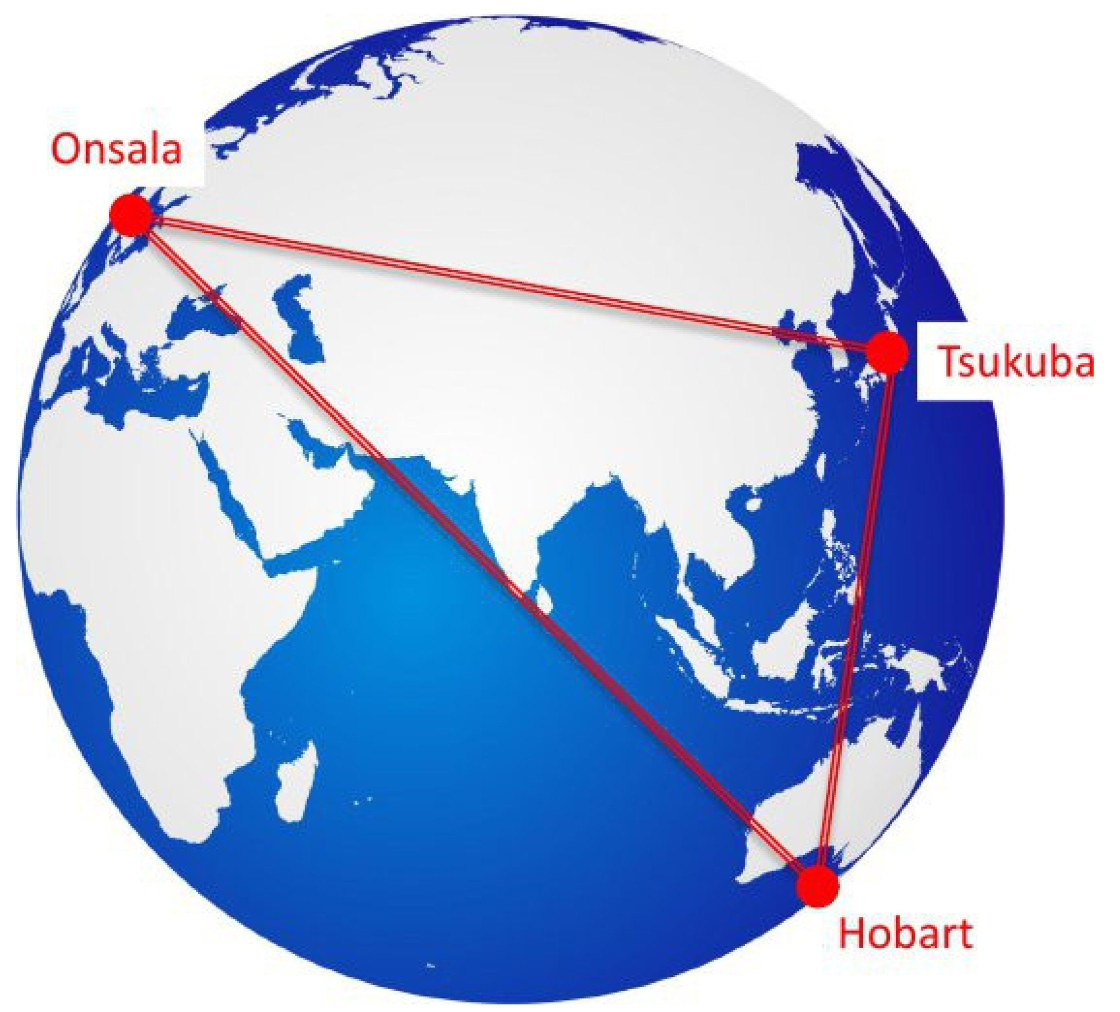

Figure 3: *A three station network (consisting of antennas at Tsukuba, Onsala and Hobart) regularly conducts real-time EOP experiments. Thereby geodetic analysis has been automated with c5++ including the ambiguity resolution algorithm described in the prior section.*

Summary and outlook

The concept of ultra-rapid VLBI sessions can be extended further to include additional, geometrical well distributed stations, in order to derive also polar motion components with a latency of a few minutes after the last scan has been observed. This allows to provide an up-to-date complete set of Earth orientation parameters for navigation of space and satellite missions. Moreover, our work demonstrates how future VLBI networks (VLBI2010) can be processed automatically in order to provide near real-time information about the Earth and its instantaneous orientation in the framework of GGOS.

Acknowlegments

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References

Hobiger T. et al., Fully automated VLBI analysis with c5++ for ultra-rapid determination of UT1, Earth Planets Space, 62 (12), pp. 933-937, 2010.

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