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SCHEDULING AND SIMULATION OF VLBI MEASUREMETS FOR THE DETERMINATION OF EARTH ORIENTATION PARAMETERS

S. Nistor [a], *, A. S. Buda [a]

[a] University of Oradea, Faculty of Civil Engineering and Architecture, Department Cadastre-Architecture, Romania,
* e-mail: sonistor@uoradea.ro

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ABSTRACT:

The article aims to present the results obtain from the scheduling and simulation of VLBI measurements in October 2010 for a period of three days for 24 hour continuous observations. To be sure that we will obtain good VLBI observation we have to do an optimization of the network. This can be done quite accurately by using the new modules that are part of the VLBI processing software's, the modules scheduling and simulation. This can be considered the first step in preparation of the VLBI experiment. Very Long Baseline Interferometry (VLBI) it is a primary space-geodetic technique that it is able to determine precise coordinates on the Earth, by monitoring the variable of Earth orientation parameters (EOP) with high precision. Also Very Long Baseline Interferometry plays an important role for determination of celestial and terrestrial reference frame. It is also a technique that each year is more developed form a software and hardware point of view. To obtain the scans we used a set of eight different VLBI antennas and as a source we used different quasars. In the scheduling we used the source based strategy contrary to the station based approach and the radio sources where from updated catalogues according to the requirements of the VLBI2010 system, which means that we are able to obtain a best coverage of the celestial sphere. The results show that scheduling and simulation are very good tools in preparing real VLBI experiments.

1. INTRUDUCTION

One of the space-geodetic techniques involved in determining the Earth Orientation Parameters (EOP) is the Global Navigation Satellite Systems (GNSS) but also other technique are used like: Satellite and Lunar Laser Ranging (SLR, LLR) and the Doppler distance measurement technique DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite), and not the last - Very Long Baseline Interferometry (VLBI) (Heinkelmann 2013).
The VLBI technique is a geometric one, where the time of the arrival at two Earth-based antennas it is measured to obtain the difference time in arrival. The antennas monitor the emitted wavefront by a distant quasar. Using a global VLBI network antennas and measuring many time differences, the VLBI it is able to determine an inertial reference frame which is defined by the quasars, and also to determine with high precision the antennas position (Nilsson et al. 2014).

VLBI determines the relative positions of the antennas to a few millimetres due to the fact that the time difference measurements are precise to a few picoseconds, and also the followed quasar presents only a fraction of a milliarcsecond position. Since the antennas are fixed to the Earth, their locations track the instantaneous orientation of the Earth in the inertial reference frame. Do to the fact that the position can be determined to a few millimetres, a relative change in antenna position can indicate a tectonic plate motion, a regional deformation, or a local uplift or subsidence.

Scientist's observing the capabilities of the very long baseline interferometry (VLBI) make's this technique to be employed in geodesy for over 40 years and plays an important role for the realization of global geodetic reference frames (Sun et al. 2014). With the help of this system we can consider that VLBI helps in stability of the terrestrial reference frame (TRF), and it is the only capable system that determines the celestial reference frame (CRF) (H. Schuh and Behrend 2012). For the realization of reference frames – terrestrial and celestial, the VLBI system it is considered to be an essential technique. By using the VLBI technique the observed object in space are the quasars, which are distant extragalactic radio sources which appear fixed in angular position.

The geometric principle of Very Long Baseline Interferometry (VLBI) is simple and straightforward. The radiation from extragalactic radio sources arrives on Earth as plane wave fronts. This is different from nearby Earth satellites such as those of the Global Navigation Satellite Systems (GNSS) where the finite distance to the emitter produces parallactic angles (Harald Schuh and Böhm 2013). VLBI, uses the frequencies of about 8.4 GHz (X-band) and 2.3 GHz (S-band).

The VLBI presents an unchallengeable characteristic because it can provide the full set of Earth orientation parameters, which in turn are an integrant part in positioning and navigation on Earth and in space. In addition VLBI allows access to important information concerning interactions within the Earth system. The nutation parameters, and the Earth rotation angle (UT1−UTC) can be only provide by VLBI technique. Furthermore, several other geodynamic, atmospheric, and astronomical parameters can be derived from the long history of VLBI measurements starting in the late 1970s (Harald Schuh and Böhm 2013).

The VLBI technique aims to be able to measure the station position from a 24-h observing session on the level of 1 mm accuracy, and station velocities to 0.1 mm $year^{-1}$ (Niell et al. 2005)(Charlot 2004). The current measurements on a 24-h observing session is 5 mm accuracy (H. Schuh and Behrend 2012). To be able to study the small changes like the station motions related to geo-hazards - earthquakes or long-term effects due to global changes such as sea level rise – it will be necessary that the VLBI system to rise up to the new demands (Plag and Pearlman 2009).

Traditionally, the stochastic behaviours of both the wet component of the atmosphere and the hydrogen maser reference oscillators have been extracted directly from the VLBI data. The separation of these effects from the geometric parameters of interest has been achieved through the use of optimized schedules in which source direction varies significantly during the course of each stochastic estimation interval.

New VLBI2010 operating modes will require a different conceptualization of scheduling strategies. In particular, the anticipated use of globally distributed networks and ultra-short source-switching intervals opens interesting new scheduling possibilities, two of which have been investigated to date (B. Petrachenko et al. 2009).

Being able to rise up to the new demands, an important role it is played by the development of scheduling algorithms which allows us to separate various geodetic parameters especially in in large multi-parameter adjustments (Steufmehl 1991).

A simulation study was been performed by (B. Petrachenko et al. 2009) who recommends to take into account three sources of stochastic noise: wet troposphere delay, station clocks and measurement error. After this simulation they concluded that the wet troposphere is the most important of these.

The observable of the VLBI technique represents the "delay" which roughly speaking is measured by cross-correlating the signals received at two stations and searching for a peak (Gipson, MacMillan, and Petrov 2008).

VLBI typically probes quasar structure on scales of 0.1 mas or larger. To reduce the shift of the estimated station position it is highly recommended to observe multiple quasars (Shabala et al. 2014). (Charlot 1990) was the pioneer in developing the formalism for estimating the effects of quasar structure on VLBI group delays.

The following performance-enhancing strategies was proposed for the next-generation VLBI system called VLBI2010 [and its corresponding global network the VLBI2010 Global Observing System (VGOS)]: (1) a reduction of random errors, (2) a systematic error, (3) development of the homogeneous geographic distribution of the VLBI networks, (4) increasing the observation density, (5)a reduction of susceptibility to external radio-frequency interference (W. T. Petrachenko et al. 2010) (Niell et al. 2005).

To reduce random and systematic errors in the delay observable it can be applied different strategies, in which it can be included an increasing number of antennas with homogenous distribution and reducing the susceptibility to external radio-frequency interference. Due to the structure or brightness of the quasars we have to deal with the unmodelled effects that are present in the analysis of geodetic VLBI observation. (A. L. Fey and Charlot 1997),(A. Fey and Charlot 2000) demonstrated that the unmodelled effects can produce delay in the observable from a few picoseconds (ps) - for compact sources, to several nanoseconds for the sources with extended structure. Taking into account the precise information about the distribution of the brightness of the sources, and using different algorithm's such effect can be kept under control.

The primary goal for the scheduling and simulation is to maximize the total number of observations in a session. Principal criteria for generating these schedules are:

- maximization of the number of stations in a scan,
- minimization of slew times between scans.

Although the latter condition results in sources being observed in clusters, it was reasoned that the short source-switching intervals would lead to sufficiently large clusters to achieve adequate sky coverage at each station over a short period of time (B. Petrachenko et al. 2009)

2. MATERIALS AND METHODS

Although the VLBI analysis presents large common parts for astrometric, astrophysics and geodesic scientists, they purpose differs significantly. In radio astronomy the scientists are investigating an extended variety of different astronomical objects and their characteristics, where geodesic and astrometric VLBI groups are more preoccupied by determining with high precision the coordinates and derivates - plate dynamics, long distances on Earth, and Earth orientation parameters (Heinkelmann 2013). The major difference between other space technique is that in VLBI, the observables results a posterior by the alignment in a processor (Turner 1987).

The observation equation which represents the delay model can be written as:

$$-c * \tau = \vec{b} * \vec{k} + \Delta\tau_{retarded\ baseline} + \Delta\tau_{clock} + \Delta\tau_{trop} + \Delta\tau_{iono} + \cdots \quad (1)$$

where c is the velocity of light in vacuum, $\vec{k}$ is the unit source (quasar) vector defined in a space fixed, barycentric and equatorial celestial system, $\vec{b}$ is the baseline vector of the VLBI antennas defined in an Earth-fixed, geocentric, equatorial terrestrial coordinate system, $\Delta\tau_{retarded\ baseline}$ is the delay correction due to the motion of the second antenna (in geocentric celestial reference system, GCRS) during the propagation time of the wavefront between station 1 and station 2, $\Delta\tau_{clock}$ is the delay correction due to the synchronization and frequency discrepancies of atomic clocks at station 1 and station 2, $\Delta\tau_{trop}$ is the troposphere delay correction, $\Delta\tau_{iono}$ is the ionosphere delay correction.

2.1 Strategies for automatic scheduling

The schedule is generated scan by scan, until there is a scan that ends past the end of the session. The two methods for automatic scheduling are: station-based scheduling strategy, and source-based scheduling. By using the scheduling strategy on both methods we need the catalogues of the radio sources and stations.

The principle that is applied of the strategy in station-based scheduling is the uniform coverage of the sky i.e. the optimization of the sky coverage it is done in short intervals in which we have to consider the rapid atmospheric variability, even if the total number of observation are affected. For optimization it is essential to de-correlate the zenith wet delay (zwd), clock parameters, and station heights.

The problem is that there is not a definition what exactly means uniform sky coverage. There are some recommendation for obtaining a uniform sky coverage in which the nearby radio sources should be neglected for different time intervals and for the time for the observation that are done for identical source should exceed a defined interval (Sun et al. 2014).

One of the strategies that come up with a more global station distribution and fast moving antennas is the so called source-based scheduling. In this strategy the program used for scheduling selects radio sources from the catalogue without taking into account their direct impact on individual stations.

It can be applied a simplification of this for large globally distributed networks and greatly increases the efficiency of the scheduling software. This strategy includes forming different subnets in the entire process in order to optimize geometry and number of observations. Thus, all possible baselines of the network are observed. Roughly speaking, there won't be large holes in the distribution of observed sources on the sky.

3. RESULTS

The scheduling and simulation for the Earth orientation parameters (EOP) was done in Vienna VLBI software VieVs (Böhm et al. 2012).
The schedule and simulation was made using eight stations: BADARY, NYALES20, WESTFORD, WETTZELL, OBART12, TIGOCONC, HARTRAO, and KOKEE, for a period of 24 hours in 15, 16 and 17 October 2010. In fig. 1 we can observe the station plot network.

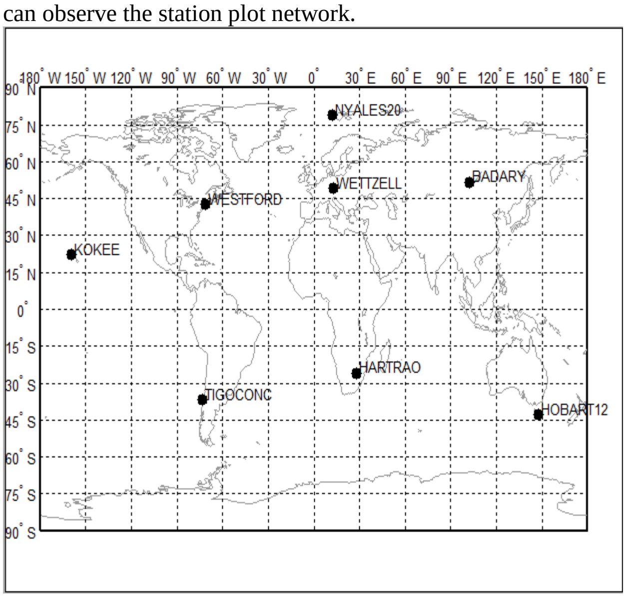

Figure 1. Plot network of simulated stations

Table 1 gives on overview of the key parameters of the three schedules. The number of the observed sources was decided by the scheduling strategy.

Day	Duration (h)	Band		Parameters		
		X SNR	S SNR	Sundist (deg)	Cut-off el (deg)	Source flux (Jy)
15 oct 2010	24	20	15	15	5	0.25
16 oct 2010	24	20	15	15	5	0.25
17 oct 2010	24	20	15	15	5	0.25

Table 1 – Schedules parameters

We mention the fact that because TIGOCONC it is a small 6 meter transportable telescope the SNR was 15 for X-band and 12 for S-band. For the simulation we chose to simulate: slant wet delay, clock and white noise.

In table 2 it is presented the statistics of the processed simulated files that is obtain from using VIE_LSM.

Day	No of scans	No. Of antennas	No. Of sources	No. Of obs
15 Oct 2010	909	8	64	3093
16 Oct 2010	888	8	65	3020
17 Oct 2010	928	8	62	3077

Table 2. Statistics of the processed files

The estimated parameters it is made using least square estimation which are modelled by piecewise linear offset function (Teke et al. 2009). The purpose of the estimation process in the simulation, was to investigate how to scheduling strategy impact the estimates of the geodetic parameters. In fig. 2, 3 and 4 there are five earth rotation parameters: polar motion (a) x-pole and b) y-pole), universal time - UT1-UTC and precession/nutation (celestial pole offset a) dx and b) dy.

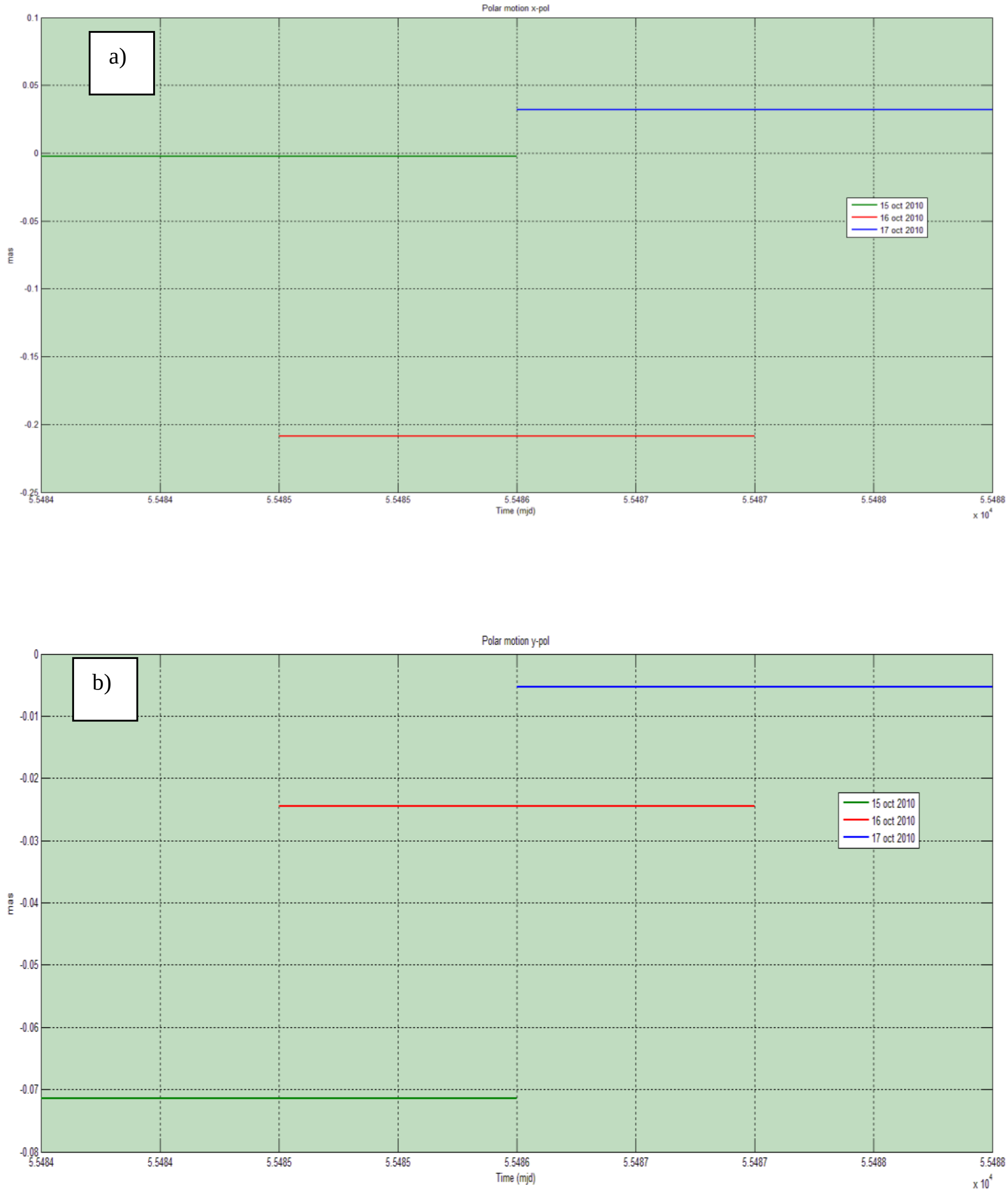

Figure 2. Polar motion

The polar motion (a) x-pole for the file from 15 October 2010 we obtain -0.002242 mas, and b) y-pole we obtain -0.07143.
The polar motion (a) x-pole for the file from 16 October 2010 we obtain -0.2089 mas and b) y-pole we obtain -0.02455.

The polar motion (a) x-pole for the file from 17 October 2010 we obtain 0.03212 mas and b) y-pole we obtain -0.005335.

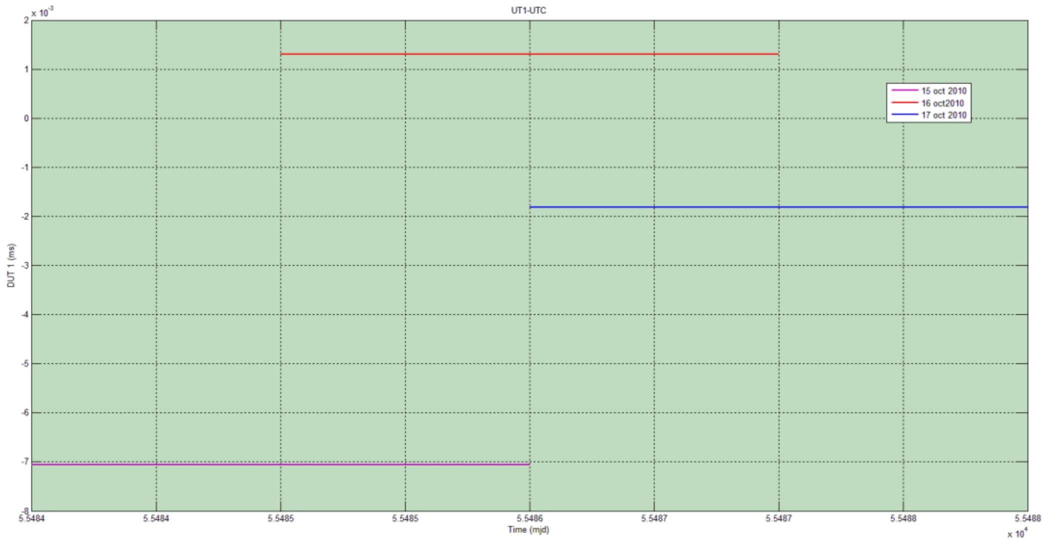

Figure 3. UT1-UTC

For the universal time - UT1-UTC for the file from 15 October 2010 we obtain -0.007061 ms.
For the universal time - UT1-UTC for the file from 16 October 2010 we obtain 0.001299 ms.
For the universal time - UT1-UTC) for the file from 17 October 2010 we obtain -0.001821 ms.

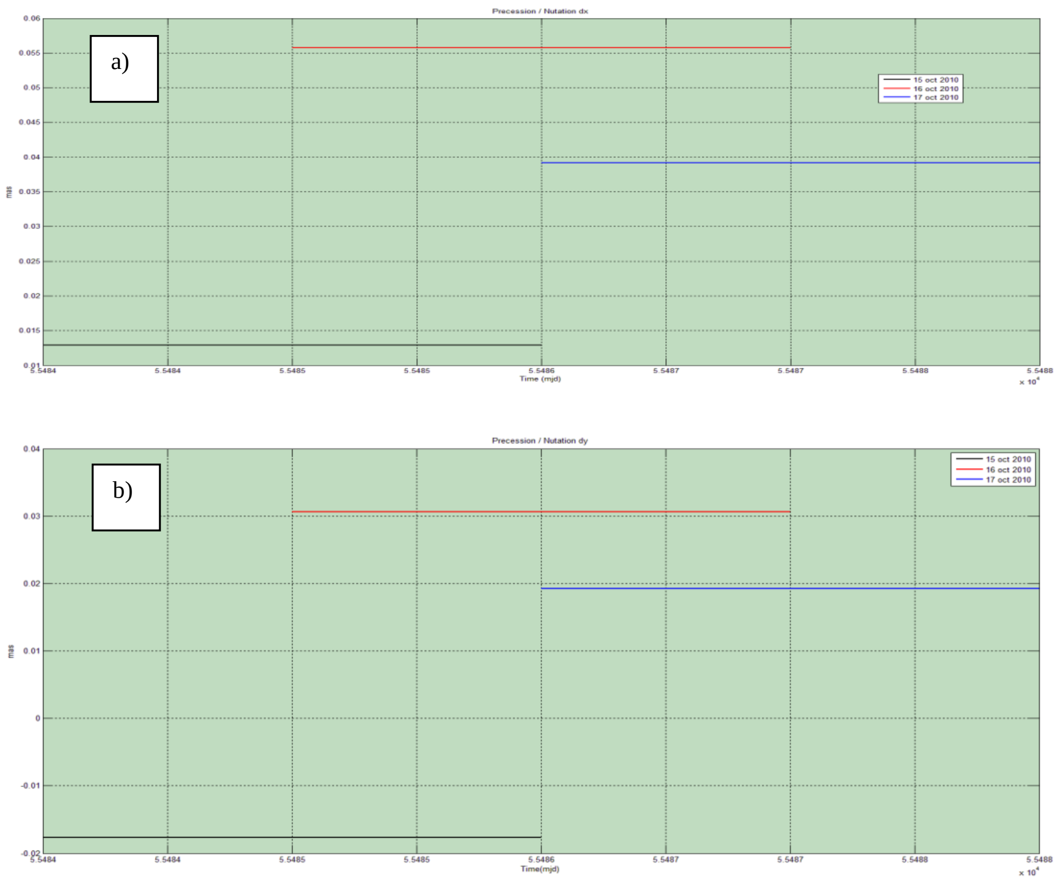

Figure 4. Precession/nutation (celestial pole offset a) dx and b) dy

For the precession/nutation for the file from 15 October 2010 we obtain 0.01291 mas.
For the precession/nutation for the file from 16 October 2010 we obtain 0.05575 mas.
For the precession/nutation for the file from 17 October 2010 we obtain 0.03915 mas.
Also we have done a detailed analysis on the total residuals, the first and main solution that resulted from the processing – Figure 4, Figure 5.

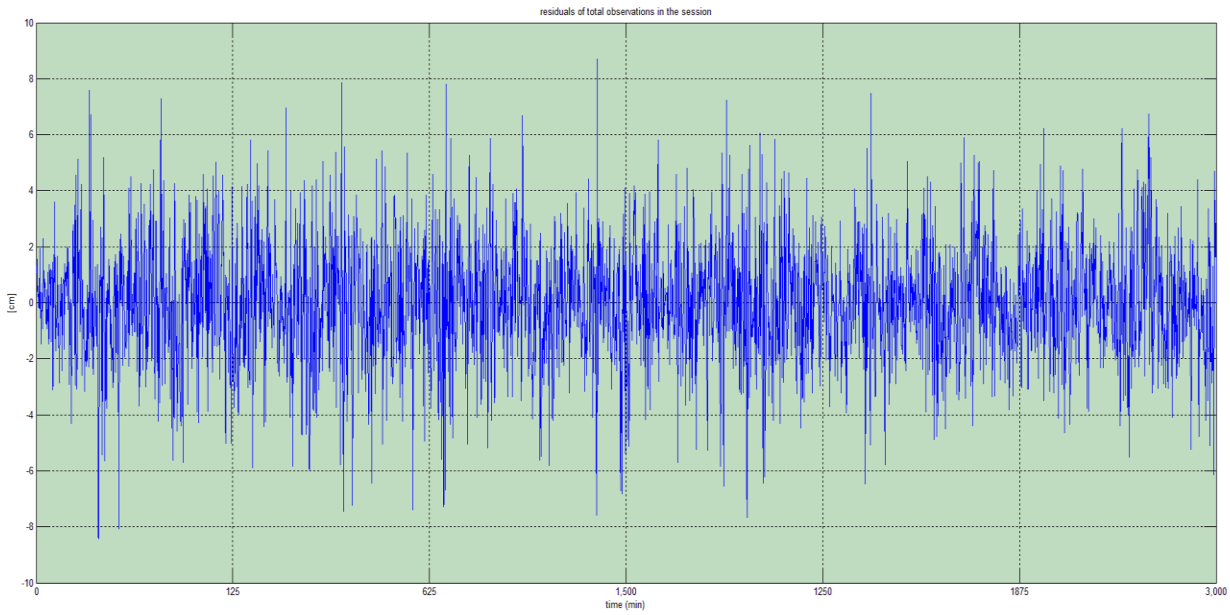

Figure 5. Total residuals

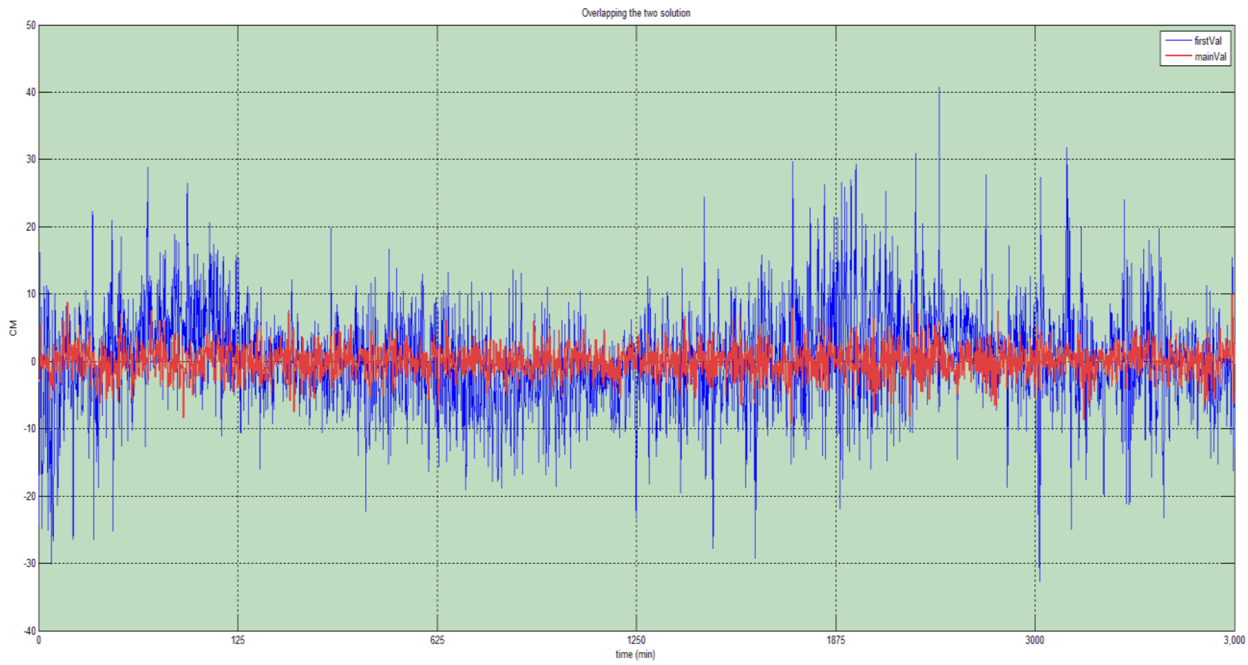

Figure 6. First and main solution

4. CONCLUSIONS

In recent years the requirements of lower antenna diameters it is possible because the receiver components like bandwidth or data recording rate has been improved significantly.

We have shown that the EOP can be estimated even if we use simulated observation with a high degree of confidence but only if we use adequate parameters in the scheduling and simulation. The optimization of the VLBI network is based on the simulation studies from which the path of the VLBI new systems will rely on.

Indeed, the earth orientation parameters cannot be defined by a simple session of VLBI observations, which depend on many factors, like the geometry of the network, the orientation of the baseline, scheduling parameters (optimization, recording mode and data rate, and source selection), station operation quality, etc. The results obtained in this paper demonstrate the fact the scheduling and simulation are power full tools for establishing geodetic VLBI campaigns, and none the less using the existing IVS network in an optimal way.

The schedules can be optimized by using the possibility that the new scheduling package from VieVs is offering – different parameters and criteria. The celestial sphere is uniformly filled by using the source –based scheduling with observation and as a side effect, also creates uniformly distributed observations at the stations.

In Vie_Sched, presents a very advantageous property where the necessary number implied in the calculation process defined by the source-based scheduling strategy are reduced dramatically in comparison with the conventional station-based approach. This lead to the fact that this strategy con be employed for global VLBI2010 networks.

The future VGOS network, which will operate much faster telescope and with higher data rates the precision of the EOP parameters estimated by VLBI, is expected to significantly improved.

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