TIME TRANSFER USING P-CODE MEASUREMENTS FROM GPS/GLONASS RECEIVERS

F. Roosbeek, P. Defraigne, C. Bruyninx
Royal Observatory of Belgium
Avenue Circulaire 3, 1180 Brussels, Belgium
tel +32-2-3730246 fax +32-2-3749822
e-mail f.roosbeek@oma.be

Abstract

Time and frequency transfer using the GLONASS P-Code from geodetic receivers is investigated. Our results are based on data sets collected by combined GPS/GLONASS receivers driven by a hydrogen maser, and involved in the IGEX campaign. A first comparison is performed between the results obtained from the data collected by different types of receivers (R100 from 3S-Navigation or Z18 from Ashtech). The improvement of the technique related to the use of precise GLONASS ephemerides, computed within the frame of the IGEX campaign, rather than the broadcast ephemerides, is also investigated. When correcting the results for the receiver hardware delays, which are different for each satellite, the final precision of the time transfer is about 10 nanoseconds (ns) (peak to peak). Finally, the use of the GLONASS P-code is compared with the frequency transfer using GPS code and carrier phase measurements.

INTRODUCTION

The GLONASS P-code is not perturbed by antispoofing (AS) and is transmitted on both the L1 and L2 carriers, allowing high precision ionospheric delay corrections. Furthermore, the wavelength of the GLONASS P-code is about five times shorter than the one of the GPS C/A-code, leading to a measurement noise approximately five times smaller than the corresponding noise for GPS C/A-code measurements. For all these reasons, the use of the the GLONASS P-code for time transfer is very promising, as already shown by different studies ([1] [2] [3] [4] [5]). This paper presents a preliminary study about the capabilities of using the full set of GLONASS observations on the L2 P-code collected by geodetic receivers R100 from 3S-Navigation, and Z18 from Ashtech.

The Royal Observatory of Belgium operates at the same time as Time Laboratory, participating in the realization of TAI and as GPS station belonging to the IGS network.

Our institute is also equipped with a combined GPS/GLONASS multichannel receiver (BRUG) from 3S-Navigation, involved in the IGEX campaign ([6]). We use the advantages of this collocation to study the efficiency of GPS and GLONASS measurements for time transfer. The other data sets used in the present study are coming from two Z18-Ashtech receivers (WTZZ in Wettzell, about 640 km far from Brussels, and OS0G in Onsala, 920 km far from Brussels), and two 3S-Navigation R100 receivers (WTZG in Wettzel and NPLC in London, 336 km far from Brussels). All these receivers are driven by H-masers.

The present study is based on analyses of the RINEX files provided by those combined GPS/GLONASS receivers in order to determine the receiver clock offsets.

MODELLING

This section presents the procedure we use for computing the code residual from the pseudorange equations. The pseudorange measurement between a receiver p and a satellite prn can be written as:

$$P_p^{prn} = c\tau_p^{prn} + c\,(dt_p - dt^{prn}) + \epsilon_p \tag{1}$$

dt_p and dt^{prn} are respectively the receiver and the satellite clock offsets with respect to UTC(USNO) for GPS and UTC(SU) for GLONASS, c is the speed of light, and ϵ_p is the measurement noise. The code travel time τ_p^{prn} can be detailed as:

$$\tau_p^{prn} = \frac{D_p^{prn}}{c} + \delta R^{prn} + \delta R_p^{prn} + T_p^{prn} + I_p^{prn} + \frac{\delta M_p^{prn}}{c} \tag{2}$$

with D_p^{prn}, the receiver-satellite geometric range, equal to $\left|\vec{X}_p - \vec{X}^{prn}\right|$. $\vec{X}_p$ is the receiver antenna position at the reception time and $\vec{X}^{prn}$ stands for the satellite position at the emission time. I_p^{prn} and T_p^{prn} are, respectively, the ionospheric and tropospheric delays; δR^{prn} and δR_p^{prn} are the satellite and receiver hardware group delays. Note that, in the case of the GLONASS observations, the receiver hardware delay depends on the satellite, because the frequency emitted is different for each satellite. δM_p^{prn} is the code error due to multipath.

The common-view method consists of differencing between code observables from the same satellite, simultaneously measured at two receivers (called p and q). The satellite clock offset and the satellite hardware delay are then cancelled.

$$P_{pq}^{prn} = D_{pq}^{prn} + cdt_{pq} + c\delta R_{pq}^{prn} + c\,(T_{pq}^{prn} + I_{pq}^{prn}) + \delta M_{pq}^{prn} + \epsilon_{pq} \tag{3}$$

When fixing the station coordinates for the two receivers p and q (and, hence, the geometric range D_{pq}^{prn}), we get finally the code residual Pc_{pq}^{prn} in which the multipath term is considered as additional noise :

$$Pc_{pq}^{prn} = P_{pq}^{prn} - D_{pq}^{prn} - c\,(T_{pq}^{prn} + I_{pq}^{prn}) - c\delta R_{pq}^{prn} = cdt_{pq} + \epsilon_{pq} \tag{4}$$

At each epoch, simultaneous observation of several satellites allows the determination of the differential receiver clock offsets by a least-squares method. The corrections (D_{pq}^{prn}, T_{pq}^{prn}, I_{pq}^{prn}, δR_{pq}^{prn}) have been applied a priori on P_{pq}^{prn} in order to get the code residual; this is in opposition to the a posteriori determination from the code residual, which is performed in a global least-squares fit which includes the receiver clock offset determination as well as the other corrections. The station positions used in this study have been either provided by the AUIB (Astronomical Institute of the University of Bern) or by Dr. Altamimi (IGNF). The ionospheric delay I_{pq}^{prn} is estimated from the ionospheric parameters given in the GPS navigation message file. The tropospheric delay T_{pq}^{prn} is estimated with the Hopfield's model, which splits the delay into two parts: one contribution from the 'dry' atmosphere and one contribution from the 'wet' atmosphere. Standard atmospheric parameters have been used: ambient air temperature of 15°, ambient air pressure of 1013.25 mb, and ambient air vapor pressure of 8.5 mb, corresponding to 50% of relative humidity. The broadcast ephemerides are taken from the RINEX navigation file for which the precision is estimated at a few-meter level. The precise ephemerides are obtained from the AUIB, which computes these orbits within the frame of the IGEX campaign. They have a value every 15 min. and the precision is estimated at a few-centimeter level.

For the GLONASS P-code, the receiver hardware delays are estimated from the systematic biases between the code residuals obtained for the different satellites.

COMPARISON BETWEEN DIFFERENT RECEIVERS

Figure 1 presents the receiver clock offset (difference between the receiver time driven by a H-maser clock and UTC(SU)) for two R100 receivers from 3S-Navigation (BRUG and WTZG) during the GPS week 1022. The third part of the graph is the time transfer between the two receivers. It appears clearly that both receivers jump regularly. This is due to the recalibration of the receiver clock offsets which occur, on the one hand, after the daily reboots of the R100 receivers and, on the other hand, after each tracking interruption. These jumps do not occur with the Ashtech receivers. Due to these jumps, it is not possible to perform precise time transfer for more than one day.

Figure 2 shows the receiver clock offset for two Z18 receivers from Ashtech (WTZZ and OS0G) during the GPS week 1016. The third part of the graph is the time transfer between the two receivers. One immediately sees on this figure that the two Ashtech receivers show an important noise level (a few hundred of *ns*) in comparison to the few-*ns* noise level given by the R100 receivers. At the present time, we do not know where this noise does comes from. In what follows, we only use data from R100 receivers in order to avoid the use of noisy data as provided by the Z18 ones.

A further remark concern the GLONASS satellite number 20. On Figure 3, we have plotted the time transfer between BRUG and WTZG, with and without the contribution of that satellite. The third part of the graph is the time transfer with only the satellite 20. From this figure, it appears clearly that the satellite 20 is unusable in time-transfer applications.

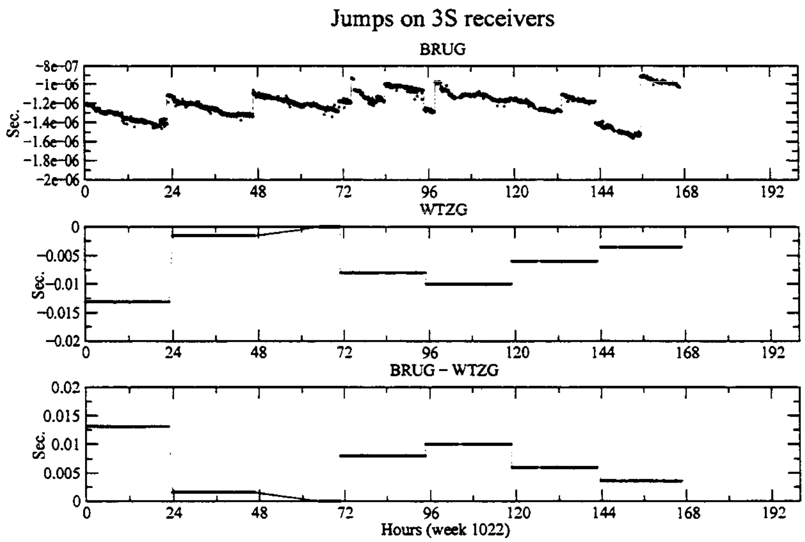

Figure 1: BRUG & WTZG Time transfer.

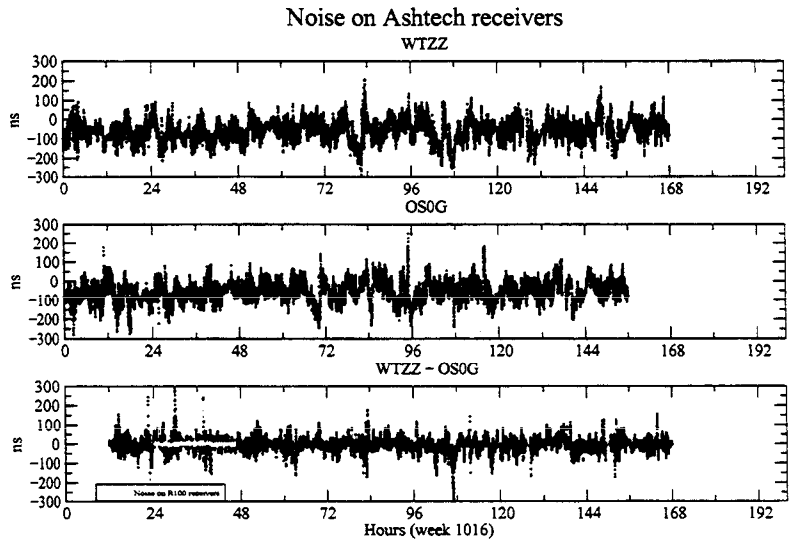

Figure 2: WTZZ & OS0G Time transfer.

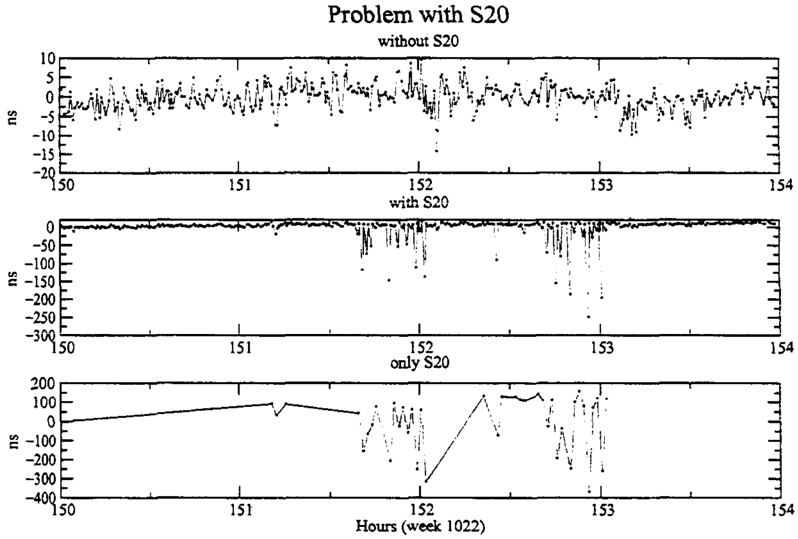

Figure 3: BRUG & WTZG Time transfer.

TIME TRANSFER USING R100 RECEIVERS

A first test consists in using precise ephemerides rather than the broadcast ephemerides. On Figure 4, the time transfer between BRUG and WTZG is performed for the week 1022. It is based on the broadcast ephemerides for the upper part and on the precise ephemerides COX for the lower part. A first improvement allowed by the precise ephemerides concerns the noise level, reduced by a factor of about 2 (as shown by the enlargement in the time interval between 4h and 8h). The second improvement allows the elimination of the outliers.

The second test consists in correcting the results for the hardware delays, different for each satellite. Because there is no calibration available at the present time, we have estimated the corrections of each satellite directly from the time-transfer results produced by each of the satellites separately. We choose the satellite 17 as an arbitrary reference and adjusted the other ones on it. However, this adjustment is not perfect for different reasons. The first one is that the offset between the results of the different satellites is of the same order of magnitude as the noise level of the clock differences computed with any satellite. Furthermore, for unknown reasons, the data show anomalous behavior of some satellites which affect the determination of the differential biases. On Figure 5, we have plotted the clock differences (WTZG-NPLC) obtained with the satellites 7 and 8. It appears that each of them presents small jumps and, as a consequence, while the satellite 8 is below the satellite 7 in the first part of the figure (time interval around 60), it is above the satellite 7 in the second part (time interval around 83). At the time of writing this paper we still do not understand this kind of behavior of some of the satellites. However, this occurs regularly and leads to a determination of the differential biases very imperfect.

On Figure 6, we have plotted the time transfer between BRUG and NPLC for the first day of the GPS week 1016. The first part of the graph shows the results not corrected for the frequency dependent receivers hardware delays. The middle part is corrected

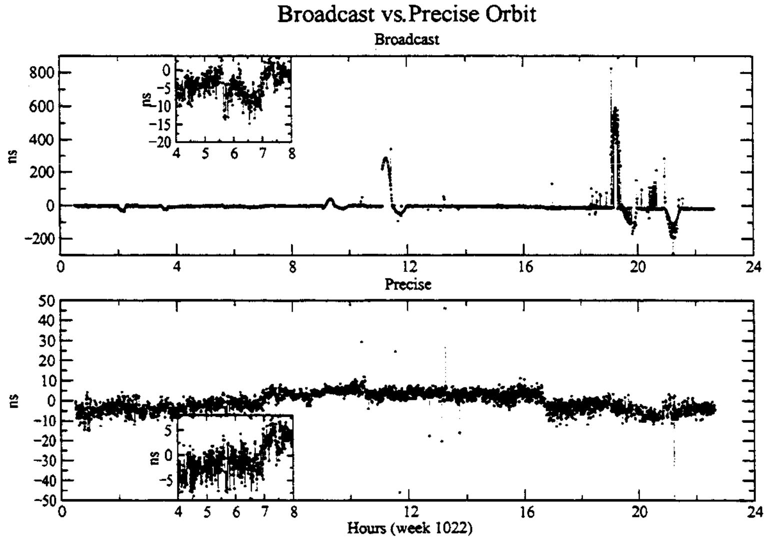

Figure 4: BRUG & WTZG Time transfer.

for the receivershardware delays by calibrating the satellites as explained here above. The last part of the graph shows the noise on one satellite (sat. 17). It is evident that the calibration can not reduce the noise level which corresponds to the noise on satellite. The correction for the receiver hardware delays only removes the variations of the curve induced by the variable 'mean' hardware delay corresponding to the mean of the biases of the observed satellite at each time.

COMPARISON BETWEEN GLONASS AND GPS RESULTS

OnFigure 7, we have plotted the time transfer between WTZG and NPLC for the GPS week 181. We see that the use of the GLONASS P-code reduces the noise level with a factor of 5. Note that the GLONASS P-code results showed here are not corrected for the receiver hardware delays. With a calibration, we expect the removal of all the jumps. We have also plotted the results of the GPS phase time transfer. In that case, the noise level is reduced to a few hundred of picoseconds. The jumps in the GPS phase results come from hourly resets of the L1 and L2 phase measurements on the NPLC receiver.

CONCLUSION

This paper presented preliminary results of time / frequency transfer using geodetic data provided by combined GPS / GLONASS receivers. A first part was based on the different problems encountered when dealing with these data: there is a high noise level on the Z18 Ashtech receivers; there are frequent clocks jumps for the R100 3S-Navigation receivers due to daily data download and receiver reboot or due to the lack of visible satellites; the GLONASS satellite 20 is unusable due to unknown reasons; multi-channel receiver calibrations are unavailable at the present time, and

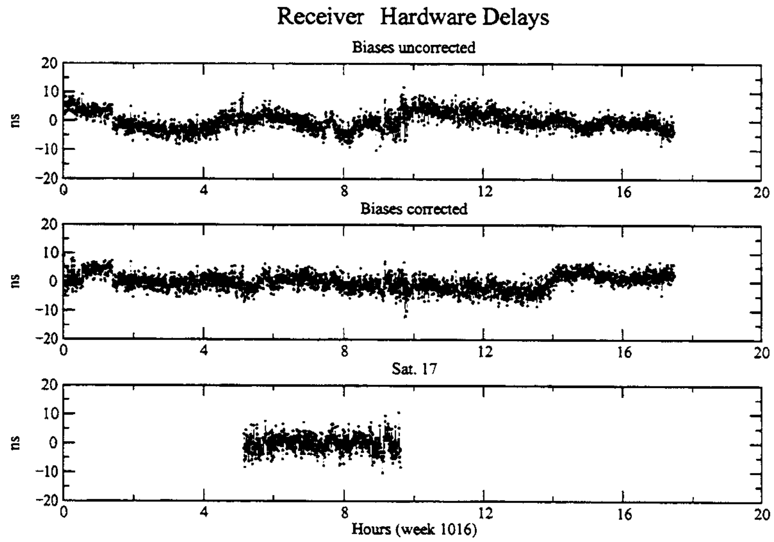

Figure 5: BRUG & NPLC Time transfer.

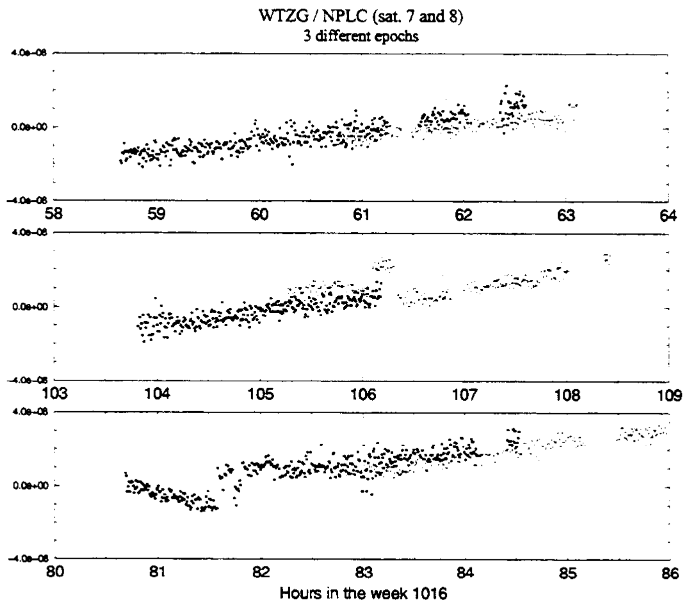

Figure 6: Clock offsets from satellites 7 and 8.

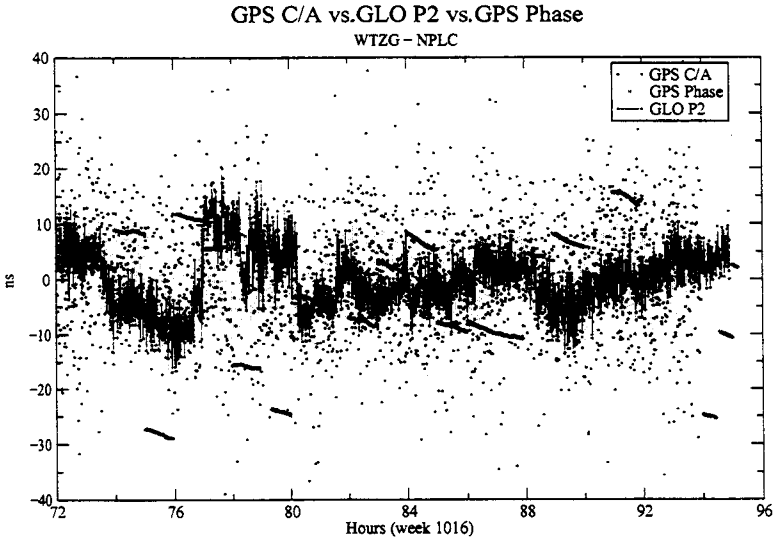

Figure 7: BRUG & NPLC Time transfer.

the determination of the receivers hardware delays for each satellite is very difficult due to the noise level of the observations and due to jumps not yet explained; different time tags are used in several stations, making the common-view computation impossible on these stations; there are a lot of holes in the data sets due to the small number of visible satellites.

However, the time transfer from RINEX files, with a sample rate of 30 seconds, allows the use of a high number of data per day (max. 2880 points), and the use of GLONASS P-Code reduces the noise level by a factor 5 compared to the GPS C/A code. Solving all the problems cited here above could then lead to very precise remote clock offset determination.

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