Three Years of GLONASS Use for UTC

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Abstract—GPS has been used in accurate time transfer for near 30 years. TWSTFT (Two-Way Satellite Time and Frequency Transfer) has been applicable for the last 10 years. On the other hand, the first GLONASS satellite was launched in 1982 and became operational some years after. Although efforts have been made to use GLONASS since the 1990s, only in November 2009 was the first GLONASS time link introduced in the generation of UTC. At present, there are 6 GLONASS links contributing to UTC. This marked the start of the epoch of GNSS multi-technique time transfer in the history of UTC.

In the frame of the UTC computation, we investigate the evolution of the GLONASS measurements used in UTC and the calibration uncertainties in the accurate time transfer with respect to GPS and TWSTFT. We review the advantages and disadvantages of different techniques and the combination of the two systems.

Key words: UTC, Time transfer, GLONASS, GPS

I. INTRODUCTION

The first GLONASS (GLN) satellite was launched in 1982 and the system became operational some years after. Efforts have being made since the 1990s to use GLONASS in accurate time transfers [1,2,3,4]. In 2005, the BIPM proposed an operational method to enable GLN used for the UTC generation [5]. In 2009, the international Consultative Committee for Time and Frequency (CCTF) recommended the use of multi-techniques in time transfer to ensure the precision, the accuracy, and the robustness in UTC. To complement the existing GPS and TWSTFT time links, in November 2009 the first two GLONASS time links were introduced into the UTC world-wide time link network [6]. Since 2011, 6 GLONASS time links are used in the UTC computation. These marked the epoch of GNSS multi-technique time transfer in the history of UTC.

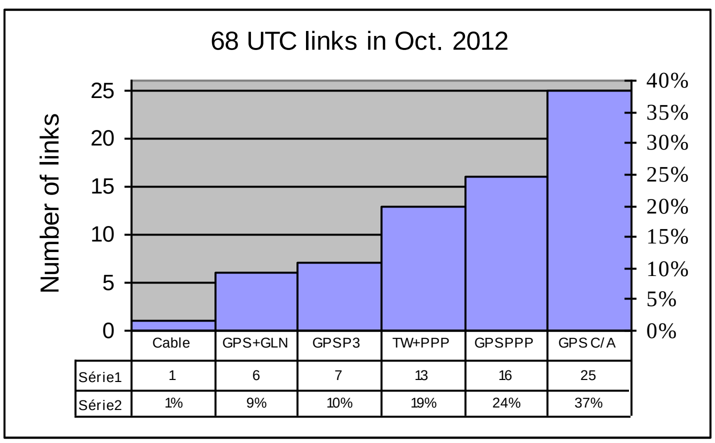

Figure 1. Status of the time transfer techniques used in UTC.

Figure 1shows the status of the UTC time links in October of 2012. The numbers and percentages of the different types of the time links are illustrated in the plot. There are 68 official UTC time links, of which 6

GLN and GPS combined links take 9% of the total. In addition, the GNSS code links take 56%, of which the C/A and L1C codes have 46%. The coarse codes are still the major observations in the UTC generation.

In the frame of the application of GLN in UTC computation, we outline in the following discussion the technical features of GLONASS time transfer: the short- and long-term stabilities, the calibration, the impact of the multiple GLONASS frequency biases and the combination of GPS and GLN.

II. GLN TIME TRANSFER AND THE FREQUENCY BIASES

Aiming at the application in the UTC computation, investigations in the use of GLN carried out at the BIPM experienced four stages:

1) Efforts have being made to use GLONASS since the 1990s. Major efforts were to correct the frequency biases by frequency calibrations [1,2,3,4];
2) In 2005, an exhaustive numerical experience was made using the 3S Navigation GPS/GLN receivers. GLN L1C and P codes data were collected from the UTC laboratories of AOS, VSL, CSIR and IT [5]. It resulted in an operational method for GLN time transfer to be used in the UTC generation. Related computer programs were developed and installed in the UTC/TAI computation software package TSoft;
3) In 2008 and 2009, further numerical analyses were carried out using the new versions of the TTS3 and TTS4 GPS/GLN receivers. Data were collected from the laboratories of INPL, NIS, OP, PTB, SG, SU and UME etc. The consistence with GPS and long-term calibration stability up to 9 months were studied and the conclusion supported to that of the 2005 study. In November 2009, the first GLN UTC time links, SU-PTB and UME-PTB were introduced in UTC computation [8]. Meanwhile, the ionosphere delay by IGS map and the precise ephemeris by IAC (Russia) [7] were also carefully investigated and they are used in UTC at present;
4) Since January 2011, the combination of the GPS and GLS was used in circular T computation [9]. Six GLN in total have been used in the UTC computation. On the other hand, GLN All in View (AV) and the use of the P codes are also under study for the UTC time transfer.

Table 1. GLN Frequency L1C biases in increasing order of the nominal frequencies (GLN PRN/Fr L1C biases relative to GPS PPP on the baseline OP-PTB. Here Fr is the GLN frequency, δ_F is the bias in time delay of a GLN frequency and σ_F is its standard deviation).

Fr	Fr′/MHz	N	δ_F/ns	σ_F/ns
-7	1598.0625	753	-4.76	0.65
-4	1599.7500	751	-5.33	0.98
-3	1600.3125	759	-5.76	0.69
-2	1600.8750	757	-6.79	0.98
0	1602.0	750	-7.14	0.66
1	1602.5625	727	-6.70	0.67
2	1603.125	740	-7.12	0.70
3	1603.6875	754	-5.70	0.70
4	1604.25	745	-8.28	0.74
5	1604.8125	220	-6.16	0.74
6	1605.375	710	-6.81	0.71

The major difficulty of the use of GLN for accurate time transfer is the frequency biases which are believed come from the signals of the GLN satellites associated with the ground receiver-antenna system (cf. Table 1). There are two methods to deal with this issue in time transfer:

1) The first method (before 2004) is to ***correct*** frequency biases [3] by the frequency-biases calibrations. To do this we need a "standard link" as a reference, e.g. the GPS, or better, the precision GPSPPP. Meanwhile the hypothesis should be held that a particular frequency bias due to a satellite-receiver is hardware based and dependent only on a corresponding frequency and should have no change with time. This was the dominant opinion in the timing communication before the BIPM study in 2005. The advantage of this method is its consistency with the traditional calibration concept. One of the disadvantages is that the required stable and precise reference for the frequency calibration, i.e. GPSPPP, did not exist in most cases. In fact, if a UTC laboratory has the GPSPPP, the GLN code data will not be used. Even if every frequency is calibrated, it is complex to use them in the monthly UTC time transfer computation. In addition, the hypothesis that the frequency biases keep constant is not sure to hold. This method has therefore not been practically used in any accurate time transfer;

2) The second method (since 2005) is to ***cancel*** the frequency biases in the common view (CV[1]) time link configuration [5,9]. It works at least for the L1C code and for the 3S and the TTS receivers. Earlier studies seem to not pay enough attention to this simple method, likely because it was believed that the frequency biases could not be cancelled completely in the CV procedure. However, large scale of the data analysis proved that the major part of the frequency biases effects are cancelled and the non-cancelable impacts are well averaged out and the residuals are less than the GLN L1C measurement noise, saying 1 ns. The L1C code is hence used in UTC CV links.

Table 2. Standard deviations of the GLN time transfer using 3S Navigation receiver without frequency biases calibrations for the codes L1C, L1P and L2P on three baselines of different distances.

Baseline	Distance	σ_{L1C}/ ns	σ_{L1P}/ ns	σ_{L2P}/ ns
AOS-VSL	1200km	1.5	1.3	1.3
CSIR-VSL	9000km	1.5	1.8	1.8
CSIR-AOS	9200km	1.6	1.7	2.2

Table 2 gives the standard deviations (σ) of the smoothing residuals of the GLN time transfer using 3S Navigation receiver without frequency bias calibrations for the codes L1C, L1P and L2P for short and very long baselines. These values are even slightly better than the GPS C/A code time links. The measurement data were collected from the 3S Navigation GPS/GLN receivers submitted to BIPM by the laboratories of AOS, CSIR and VSL in 2004. We observe that 1) Calibration of L1 codes (L1C and L1P) are the same but different to L2 code (L2P); 2) Long baselines are not worse than short baselines; 3) P codes are not better than the L1C code. The data set however was not big enough to draw a conclusion.

Table 3. Gains in the standard deviation before and after corrections for the frequency biases for the TTS3 link OP-PTB.

yymm	σ /ns bias non calibrated	σ /ns bias calibrated	Gain%	Gain/ns
1009	1.260	1.150	9%	0.11
1109	1.180	1.134	4%	0.05

[1] The GPS Comment View [10] has been abolished in UTC generation since 2006 and replaced by GPS All in View [11].

Table 4. Gains in the standard deviation before and after corrections for the frequency biases for the TTS3 link OP-PTB

yymm	σ /ns bias non calibrated	σ /ns bias calibrated	Gain%	Gain/ns
1009	1.066	1.022	4%	0.04
1109	1.150	1.177	-2%	-0.02

The latest TTS results support those obtained in the 2005 study. Tables 3 and 4 give the results of 2010 and 2011 using the data collected from the TTS GPS/GLN receivers over the UTC baselines. The biggest gain is 9% for the baseline OP-PTB, which is identical 0.11 ns that is much smaller than the GLN noise about 1 ~ 1.5 ns. However, this gain is reduced to 4% or 0.04 ns one year after. This suggests that hypothesis of the frequency biases fixed with the frequency may not be held. As for the UTC baseline SU-PTB, there is no gain (Table 3). The analysis based on the Time Deviations give the same conclusion.

We conclude:

- Frequency-bias impacts due to GLN satellites are well cancelled in the Common View time link configuration;
- Frequency-bias impacts due to receiver hardware is well averaged out in the Common View time link configuration;
- Frequency bias impacts << GLN time link measurement noises (1 ns);
- Frequency biases seem not independent with time;
- Monthly application of the frequency biases' corrections for UTC is complex and without significant gains.

We can therefore use the GLN L1C for UTC links without frequency bias corrections and the results are comparable with that of the GPS C/A.

III. THE STABILITY OF GLN CALIBRATION AND ITS CONSISTENCY WITH GPS AND TW

The GLN time link technique can be used in UTC only when 1) it is calibrated; 2) its short- term and long-term stabilities are proven; and 3) its consistency with the other existing techniques such as GPS and TW are proven.

Figure 2 illustrates the results of a 34-month comparison and shows the differences between the GPS AV C/A links and GLN CV L1C links on the five UTC baselines AOS-PTB, OP-PTB, NIS-PTB, SU-PTB and UME-PTB between May 2009 and February 2012. As shown, the calibrations of GPS and GLN links agree well with each other and are stable with time. The pick to pick disagreements are within their measurement uncertainties ±1 to ±1.4 ns for all the 5 baselines compared. The mean values of the disagreements of the calibrations between GPS and GLN and the standard deviations are respectively: 0.087±0.662 ns for AOS-PTB, 0.283±0.519 ns for NIS-PTB, 0.066±0.177 ns for OP-PTB, -0.173±0.268 ns for SU-PTB and -0.212±0.239 ns for UME-PTB.

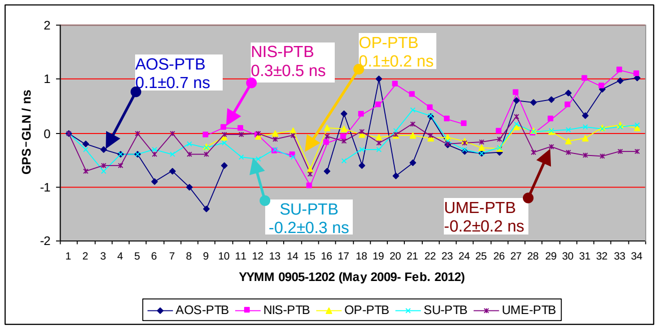

Figure 2. Consistency of the UTC links between GPS C/A and GLN L1C.

Figures 3 and 4 demonstrate the comparisons between the time links of GPS PPP and TW with that of GLN MC L1C on the UTC baseline OP-PTB. The standard deviations of the differences are 1.2 ns and 1.1 ns respectively. This suggests the perfect agreements between the calibrations of the GLN vs. the GPSPPP and TW.

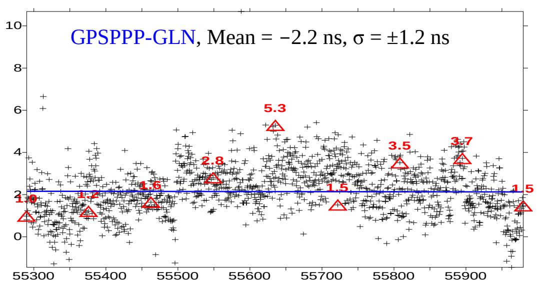

Figure 3. 26 months' comparison between the time links of GPS PPP and GLN MC L1C on the UTC baseline OP-PTB. The peak to peak variation is about 2 ns with Mean ±σ = 2.220±1.204 ns.

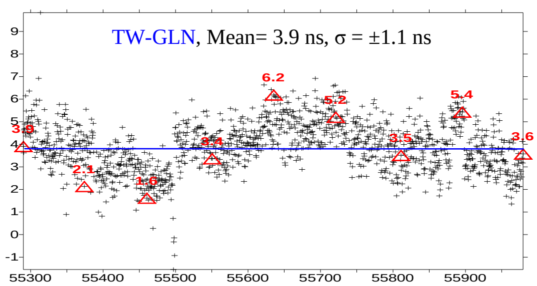

Figure 4. 26 months' comparison between the time links of GLN MC L1C and TW over the UTC baseline OP-PTB. The peak to peak variation is about 2 ns with Mean±σ = 3.882±1.125 ns.

Table 4 gives more examples on the baselines AOS-PTB and OP-PTB. It demonstrates 26 months comparisons between the major UTC time link types: GLN, TW and GPS (PPP and C/A). As seen, the standard deviations (σ) between any two techniques are round about 1 ns. The long-term GLN calibration is stable and consistent with that of GPS and TW. The disagreements are close to the GNSS code measurement uncertainty: ~1 ns.

As the short- and long-term stabilities of GPS and TW are well proven and TW, GPS and GLN are completely independent systems, this close consistency suggests that the GLN time transfer technique is as stable as GPS and TW in both the short and long terms. The same conclusion holds for the long-term variations in their calibrations, as discussed in last section.

Table 5. The GLN calibration is stable and consistent with GPS and TW.

Baseline	Link types	σ of the link dif. / ns
AOS-PTB	PPP-GLN L1C	1.128
	TW-GLN L1C	0.913
OP-PTB	PPP-GPS C/A	1.148
	PPP-GLN L1C	1.204
	TW-PPP	0.995
	TW-GPS C/A	1.067
	TW-GLN L1C	1.125

IV. COMBINATION GPS AND GLN

Given the condition that the calibrations of GPS and GLN links agree well with each other and remain stable, the combination of GPS and GLN (namely GPSGLN) can be the mean values computed by the following two methods:

1) The *simple mean values* of data sets of GLN L1C code CV kink and GPS C/A code AV link as: (GPS C/A+GLN L1C)/2;
2) The *weighted mean values*, depending on the measurement quality of GPS and GLN. We compute the weighted mean value combination by the equation: $[n\times(\text{GPS.C/A})+m\times(\text{GLN.L1C})]/(n+m)$. Here n and m are the weights of the GPS and GLN. The present weight ratio is correspondingly 2:1.

At present, only codes data are used in UTC time transfer. Because both of the GLN and GPS links are always computed monthly so as to back up each other, the combination is as simple as making the mean. No extra time links to be computed and no extra work is required.

Figure 5 illustrates the time deviations of the links of GPS-only, GLN-only and the combination GPSGLN on the baseline INPL-PTB. The short-term stability of the GPS-only link is slightly better than that of the GLN-only, probably as a result of the advantage of the AV technique against the CV. The stability of the combined solution GPSGLN is better in the short term than that of the GPS-only and the GLN-only. For averaging time beyond 20 hours, the curves of the three time deviation converge. More analysis in the comparisons with GPSPPP and TW gives the same conclusion.

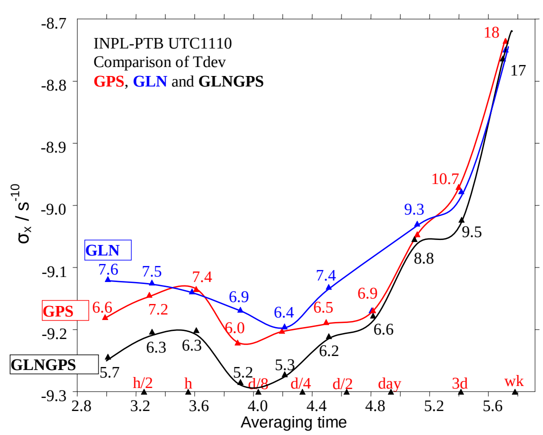

Figure 5. Comparison of the Time Deviations over the baseline INPL-PTB.

V. Conclusion

In this paper we reviewed the history, the evolution and the technical details of the GLN time transfer at BIPM since decades.

To guarantee the precision, the accuracy and the robustness of UTC generation, the multi-technique strategy for UTC time transfer is indispensable. Efforts towards introducing GLN to complement GPS and TW in the generation of UTC began in the early 1990s, and in November 2009 the first GLN time links were introduced into the UTC world-wide time link network. The major issue of accurate GLN time transfer was the frequency biases. The method used to resolve this problem is the old and simple Comment View proposed by [10].

We present the technical features of GLN time transfer for UTC: a study in the so-called frequency biases, the short- and long-term stabilities, the calibration and the combination GLN and GPS.

The present study is focused on the application of GLN L1C code in the generation of UTC and yields a short-term stability of 1 ns to 1.5 ns. The long-term stability in calibration is as same as that of GPS. The combination of the GLN L1C and GPS C/A codes makes sense in reducing the short-term stability and particularly in increasing the accuracy and the robustness in the UTC links.

The frequency biases increase the measurement noise in the GLN time links. Although corrections for estimated frequency biases leads to some slight gains for certain baselines, these gains are not seen ubiquitously. It has been decided not to apply such corrections for GLN links for the computation of UTC.

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