The 6-Year Long Term Total Delay Variations Investigation of TL GPS Stations – According to a Virtual Ensemble Receiver

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***Summary*—We use a virtual ensemble GPS receiver [1] which CGGTTS outputs are the weighted average of all calibrated physical receivers in ensemble to monitor the GPS C1/P1/P2 total delays' (TOTDLY) [2] variation of each physical receiver. Since the virtual ensemble receiver is the collective representation of all receivers in ensemble and the outliers and divergent measurements from the physical receivers in ensemble would be filtered out by weighting procedure, the equivalent TOTDLY of the virtual ensemble receiver would be more stationary and qualified as a reference. A co-location 6-year long-term common clock difference (CCD) was calculated to examine the trends and variation ranges of the GPS C1/P1/P2 TOTDLY of physical receivers. We found, even the co-location CCD procedure cancelled out the most known common noises, the CCD results showed the 6-years P1/P2 TOTDLY variation ranges of all receivers were about -0.5 ~ 0.5 ns with different trends. Since the GPS P3 we used for GPS Time Transfer (GPSTT) is the ionosphere free combination of P1 and P2, there would cause about 1.5 ns time instability for GPSTT. We also found each receiver's C1/P1 trends were similar, it may imply the TOTDLY variation is related to the carrier frequency of GPS signal.**

Keywords—GNSS calibration; Total delay; CGGTTS; Virtual GPS Ensemble Receiver

I. INTRODUCTION

The Global Positioning Systems time transfer (GPSTT) is one of the major inter-continental time and frequency comparison technology, about 85% UTC (Coordinated Universal Time) laboratories use GPSTT as their UTC time links [3]. The typical GPSTT uses two single-receiver stations (including antenna, cables, time and frequency reference signals and a GPS receiver) at both sites. If the GPS satellite instrument delays, relativistic effects, Sagnac effect, ionosphere delay, tropo-sphere delay, etc. are perfectly modeled and compensated; therefore, the two realized GPS time both stations observed are identical. When the total delay (TOTDLY, the total electronic delay between the phase center of the antenna and the time reference point of the GPS station, including REFDLY, CABDLY, and INTDLY) [2] of the two GPS stations are finely calibrated; the GPS system time could be the common reference and get the accurate time difference between the reference time of two stations. But in practice, except it's difficult to perfectly model and compensate the noises from GPS satellite clock and atmosphere effects; in recent years, some studies [4-10] showed the TOTDLY of GPS station is not stationary but might be affected by environmental conditions or some unknown factors up to 1~3 ns per year. Consequently, the TOTDLY variations of a GPS station would be introduced into its GPSTT results, and besides, if the GPSTT/TWSTFT (Two Way Satellite Time and Frequency Transfer) stations are calibrated by the traveling GPS calibrators, the TOTDLY variation of the traveling GPS calibrators would also be introduced into the calibration results, further affect the time comparison of the calibrated GPSTT/TWSTFT stations.

The BIPM (Bureau international des poids et mesures) gave the minimum GPS link uncertainty (including the calibration uncertainty and measurement uncertainty) of UTC time links to be 1.8 ns, and the calibration uncertainty, uCal, contribute most of the link uncertainty (BIPM Circular T [3], Section 5) The time instability of the TOTDLY of GPS station is one of the key factors affect the GPSTT results.

To investigate the long term TOTDLY variation of the GPS receivers, we use the virtual ensemble GPS receiver of TL, named to be TLE1, as the reference receiver to measure the TOTDLY fluctuation of the GPS C1/P1/P2 code of 4 physical receivers in ensemble. The C1/P1/P2 CGGTTS outputs of TLE1 is the weighting results of the C1/P1/P2 CGGTTS [11] outputs of all the physical receivers in TLE1. The TLE1 of all receivers in ensemble, the CCD results of physical receivers versus TLE1 can be treated as the CCD results of physical receiver with respect to their collective average representation, and relatively reflect their C1/P1/P2 TOTDLY variations.

The brief description of the virtual ensemble receiver model and the CCD test were illustrated in section II. A very long-term CCD test of 4 GPS receivers versus TLE1 from 2016 to 2022 were investigated, the results would be discussed in section III.

II. Virtual Ensemble Receiver Model and CCD Test

The virtual ensemble receiver, which we named as TLE1, is the weighted result of the physical receivers in ensemble. At initial, we first compensated the TOTDLY of each receiver in TLE1 according to the result of 2016 BIPM G1 calibration campaign (calibration ID 1001_2016) [12], then generated the CGGTTS files of each receiver using the r2cggtts software [13]. Due to the time and frequency reference sources of all TOTDLY aligned receivers in TLE1 are all the same (UTC(TL), see Table I) and the antennae are located in a small area (2.5 m × 6 m, Fig. 1) that the noises from satellite clocks, atmosphere effects, and local time and frequency references are almost the same, the P3 (ionosphere combination of P1 and P2) REFGPS values of each receiver's CGGTTS output at each epoch of each GPS satellite should be the same. The standard deviation of their P3 REFGPS can be used to pick up and remove the outliers. We set the weighting function of each C1/P1/P2 code of each receiver *k* at each epoch *t* of each GPS satellite *i*:

$$w_{k,j}(t, i) = 1/N(t, i),$$

$$\text{if } |REFGPS_{k,P3}(t, i) - \mu REFGPS_{P3}(t, i)| \le 1\,\sigma$$

$$w_{k,j}(t, i) = 0,$$

$$\text{if } |REFGPS_{k,P3}(t, i) - \mu REFGPS_{P3}(t, i)| > 1\,\sigma \quad (1)$$

where j = C1/P1/P2, $\mu REFGPS_{P3}(t, i)$ is the average of P3 REFGPS at epoch t of GPS satellite i, σ is the standard deviation of $REFGPS_{k,P3}(t, i)$. $N(t, i)$ is the total number of receivers which $w_{k,j}(t, i) \neq 0$.

Here we used a harsh conditions because the expected $REFGPS_{k,P3}(t, i)$ with respect to $\mu REFGPS_{P3}(t, i)$ is always 0 and the weight equation (1) is just used for removing the outliers.

The $REFGPS_{TLE1,j}(t, i)$is the weight average of all physical receiver in ensemble:

$$REFGPS_{TLE1,j}(t, i) = \textstyle\sum_k w_{k,j}(t,i) \bullet REFGPS_{k,j}(t, i) \quad (2)$$

The P3 REFGPS of TLE1 at each epoch t of each GPS satellite i are ionosphere free combination of P1 and P2:

$$REFGPS_{TLE1,P3}(t, i)$$

$$= \alpha \bullet REFGPS_{TLE1,P1}(t, i) - \beta \bullet REFGPS_{TLE1,P2}(t, i) \quad (3)$$

Where α=2.545 and β=1.545 are the ionosphere free combination coefficients.

From 2016 to 2022, the TLE1 was composed of 4-6 aligned receivers, except some traveling GPS calibrators had been temporarily joined and retreated, TLE1 had 4 main physical receivers (Table I).

TABLE I. The 4 Main Receiver in TLE1

Station	Components			
	Antenna	***Antenna Cable***	***Receiver Model***	***Reference***
TLT1	Sepchoke_B3E6 SPKE	FSJ1-50A	Ashtech Z12T	20 MHz/ 1PPS
TLT2	JAV_Ringant_G 3T	FSJ1-50A	TTS-4	5 MHz/ 1PPS
TLT3	Sepchoke_B3E6 SPKE	FSJ1-50A	GTR-50	10 MHz/ 1PPS
TLT4	ASH701945C_ M SCIS	FSJ1-50A	PolaRx4 Pro	10 MHz/ 1PPS

The receiver TLT2 was under fixing from April to June 2019 and March to April 2021, failed and retreated from TLE1 at Jan 2022; the TLT3 was under fixing at April 2018 and re-joined TLE1 at September 2018; the TLT4 retreated from TLE1 in October 2020. The receiver TLT1 is kept in TLE1 in whole period.

Once a new or fixed physical receiver joined TLE1, its C1/P1/P2 TOTDLY would be aligned and compensated with respect to TLE1, therefore we can make sure the TOTDLY variation of the new added receiver would be smoothly introduced into the TLE1. Since the outliers and irregular jumps of each physical receiver could be averaged out by the weighting processes, the C1/P1/P2 REFGPS of TLE1 can be treated as the average presentation of the physical receivers in ensemble and would be more stationary than any physical receiver in ensemble.

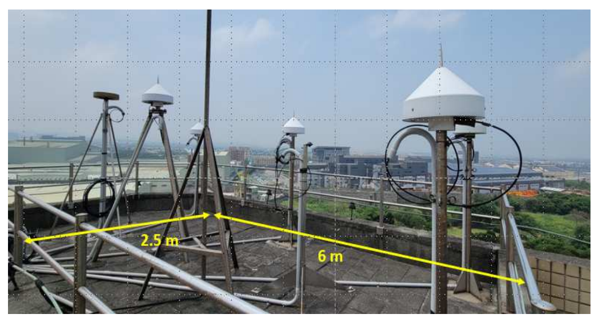

Fig. 1 The antennae of physical receivers in ensemble are loacted in a 2.5 m × 6 m area

The CGGTTS outputs of TLE1 were used as the reference to investigate the TOTDLY variations of the receiver TLT1, TLT2, TLT3, and TLT4. Since the TOTDLY of each physical receiver was aligned with respect to TLE1, we calculate their CCD with TLE1 using their C1/P1/P2 CGGTTS outputs and observed their CCD residues. The results will be shown and discussed in section III.

III. Result and Conclusions

The 6-years GPS C1/P1/P2 CCD of TLT1, TLT2, TLT3, and TLT4 versus TLE1 were shown in Fig 2. As we expected, all receivers' TOTDLY variations were not stationary. All variation ranges were about -0.5~+0.5 ns. Furthermore, the P1/P2 CCD variation trends were all different. That may imply the receiver hardware delay variations may not be directly

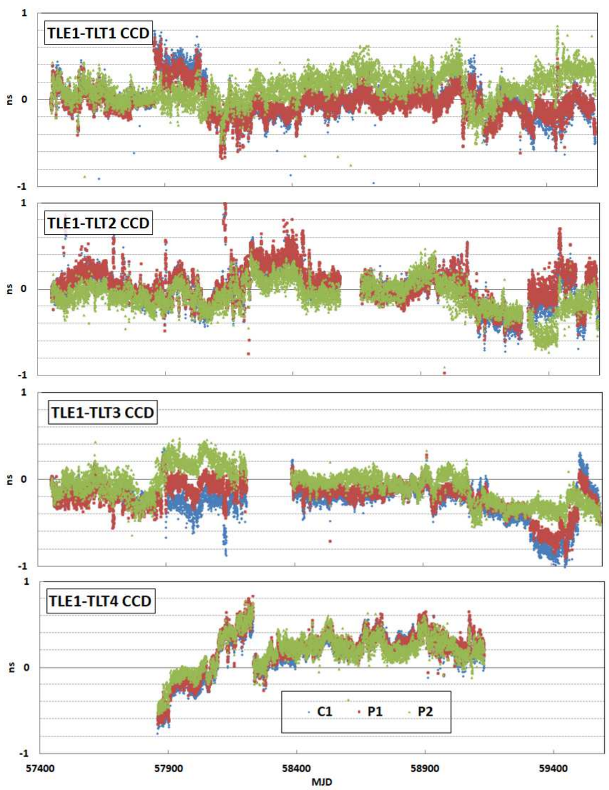

Fig. 2 The 6-years long term GPS C1/P1/P2 CCD of 4 physical receivers with respect to TLE1

affected by the common environment effects such as indoor/outdoor humidity and temperature or the external 1 PPS/10 MHz instability. We also noted there is no obvious periodical or seasonal pattern in the 6 years observation, that also implies the temperature is not the immediate cause of the TOTDLY variations.

We also noted, relative to GPS P2, the GPS C1/P1 TOTDLY variations seem to have the similar trends (Fig. 3 of TLT1 as example), that the TOTDLY variation probably correlate with the wavelength of carrier frequency (L1/L2).

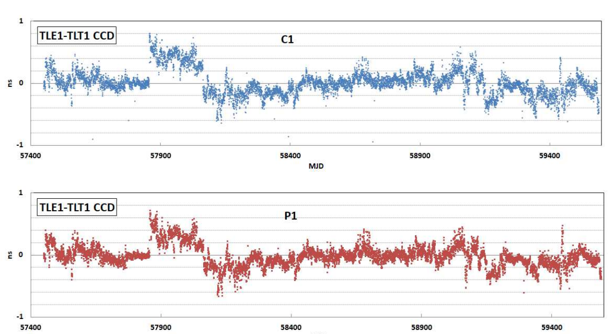

Fig. 3 The C1 and P1 CCD of TLT1 with respect to TLE1

One possibility is the impedance mismatch of antenna cable connectors induce reflection in antenna cable and cause group delay variation (which is wavelength dependent). It could be verified when we finish the long-term GPS C2/P2 CCD test.

Since the GPS P3 which we actually used for GPSTT is the ionosphere free combination of P1 and P2, the ± 0.5 ns P1/P2 TOTDLY variation would cause ± 1.5 ns GPSTT time instability, it roughly fit the minimum calibration uncertainty BIPM assigned [14] and might be the current limitation of long term GPSTT.

The TLE1 is the collective representation of all physical receivers in ensemble, we reasonably believe it's more stable than any physical receiver in ensemble. Unlike the physical receiver may fail, the time transfer using the virtual ensemble receiver could be continuously operated even if any receiver in ensemble retreats or disordered. That we could consider using the virtual ensemble receiver to be the reference receiver for time transfer or calibration to avoid the time scale jump caused by the change of physical reference receiver.

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REFERENCES

[1] S. Y. Lin and Z. Jiang, "GPS All in View Time Comparison using Multi-receiver Ensemble", Proc. EFTF 2017

[2] Z. Jiang, L. Tisserand and G. Petit, "Tests of the BIPM portable calibration station - METODE: MEasurement of TOtal Delay", Proc PTTI, 2012.

[3] ftp://ftp2.bipm.fr/pub/tai/Circular-T

[4] Z. Jiang, D. Matsakis, S. Mitchell, L. Breakiron, A. Bauch, D. Piester, H. Maeno and L. G. Bernier, "Long-term instability of GPS-based time transfer and proposals for improvements", Proc. PTTI 2011

[5] Z. Jiang et al., BIPM Technology Memorandum TM263

[6] Z. Jiang, D. Matsakis and V. Zhang, "Long-term instability in UTC time links", Proc. PTTI 2017.

[7] Z. Jiang, F. Arias, W. Lewandowski, G. Petit, "BIPM Calibration Scheme for UTC Time Links", Proc. EFTF 2011, pp 1064-1069

[8] S.Y. Lin et al., "A Modification of Z12T Metronome Time Transfer System", Proc. EFTF 2014

[9] S. Y. Lin et al, "The Status Report of TL", report of 2014 TWSTFT WG Meeting

[10] S. Y. Lin, W. H. Tseng, H. T. Lin, Y. J. Huang, and K. M. Feng, "Long-term Inconsistency between TWSTFT and GPS Time Transfer Results in PTB-TL and NICT-TL Time Links, Proc. EFTF 2010

[11] P. Defraigne and G. Petit, CGGTTS-Version 2E: an extended standard for GNSS Time Transfer, METROLOGIA May 2019.

[12] https://webtai.bipm.org/ftp/pub/tai/publication/time-calibration/Current/1001-2016_GPSP3C1_Group1-trip_V1-5.pdf

[13] ftp://bipm-ftp-01.ecritel.net/soft/r2cggtts

[14] https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/bipmcalibration_guidelines_v40.pdf

[15] D.W. Allan, M.A. Weiss., "Accurate Time and Frequency Transfer During Common-View of a GPS Satellite", Proc. Frequency Control Symposium, 1980, pp. 334-336.

[16] D.W. Allan and C. Thomas, "Technical Directives for Standardization of GPS Time Receiver Software", Metrologia, 1994, 31, pp. 69-79.

[17] Z. Jiang and G. Petit, "Time transfer with GPS satellites all in view", ATF2004: 18 – 19 Oct. 2004, Beijing