A Long-Term and Long Baseline Multi-Constellation GNSS All In View Test - Using CGGTTS 2.E Files

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***Abstract*—We combined the GPS P3 and Galileo E3 CGGTTS files for All in View (AV) [1] time transfer to make the results more representative, redundant and stable. The GPS P3 AV is the most popular time comparison technology between national measurement institutes (NMIs), occupies more than 60% UTC time links [2]. As the use of Galileo satellite system (GAL) is getting popular and already demonstrates excellent performance, in this paper, we calculated the GAL to GPS time offset [3] (GAGP) from several GNSS sites which hardware delays were directly calibrated by BIPM, the Galileo system time (GST) and GPS system time (GPST) were associated via GAGP to be the new pivot clock for AV time transfer. We calculated one year long-term (2023, MJD 59945-60309) and cross-continental baseline GNSS AV to verify the performance of the combined GNSS E3+P3 AV. The results showed the short-term stability of GNSS E3+P3 AV was a slightly more stable than GAL E3 AV but better than GPS P3 AV, and all were consistent in long-term.**

***Keywords*—GNSS P3+E3 All in View; GGTO; GAGP; CGGTTS; Long Baseline Time comparison;**

I. Introduction

The GPS P3 (L1P+L2P ionosphere free combination) all in view (AV) is the most popular time transfer technology for the time comparison between each National Measurement Institute (NMI), due to it's practical, inexpensive, easy installation and free to use, the GPS P3 (hereinafter P3) occupies more than 60% UTC time links [3]. Most of the P3 time links of NMIs are directly or indirectly calibrated by BIPM [4] to ensure its traceability. As the use of Galileo satellite system (GAL) is getting popular and already demonstrates excellent performance, BIPM start to calibrate the hardware delays of Galileo receivers of NMIs since 2018, that we can implement the traceable GAL E3 (E1+E5a ionosphere free combination, hereinafter E3) time transfer.

The P3 or E3 AV uses GPS system time (GPST) or Galileo System Time (GST) as the pivot clock to compare the reference time of GNSS sites which observe P3 or E3. Typically, we use the CGGTTS (Common GNSS Generic Time Transfer Standard) [5] files for code-only clock solutions and time transfer. The last version of CGGTTS is 2E [5], which covers all the constellations presently available, and could include the calibrated and traceable codes GPS P3 and GAL E3.

Many studies have already considered using more than one GNSS constellation to implement AV or common view [6] (CV) time transfer, and compared the difference between the time transfer results of each constellation [7-13], S. Lin had been studied combining the GPS and GAL constellations to implement multi-constellation multi-code time comparison but focus on CV [14]. In this paper, we combined the calibrated P3 and E3 links for code-only AV to make the time comparison results more representative and expect it would improve the short-term stability of AV results. To combine the P3 and E3 to implement AV, we associated the GST and GPST via GAL to GPS time offset (GGTO, or GAGP in BRDC daily broadcast ephemeris files [15], denoted GAGP hereinafter) to be the new pivot clock for AV time comparison, The GAGP we used in this study was calculated from several BIPM directly calibrated GNSS sites [16][17] to ensure its traceability and improve the short-term stability relative to BRDC GAGP.

In section II, we described our GAGP calculation procedure and compare the results with respect to the BRDC GAGP. In section III, we associated the GPST and GST with calculated GAGP and implemented the GPS P3 + GAL E3 (P3E3 hereinafter) AV using traditional AV weighting algorithm. We chose the very long baseline links which cross continentals for AV time comparison tests. Due to the number of GPS and GAL satellites in common view is very small, the tested AV results would as far as possibly include the noises of the atmosphere effect, broadcast navigation messages ... etc. The result of this study would be discussed and concluded in section IV.

II. The GAGP Calculation

The GAGP values can get from the daily broadcast ephemeris file published as BRDC navigation messages, but they are 1-day linear function only and lack of the short-term detail (Fig 1), cannot reflect the true short term fluctuation.

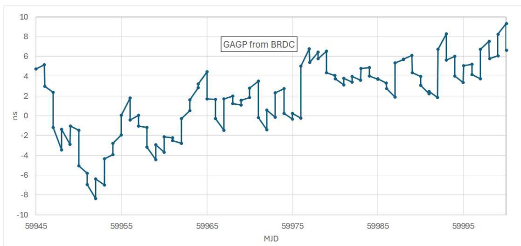

Fig. 1. The 2023 GST-GPST time offset from BRDC navigation message files.

Here we calculated the GAGP by combined GPS/Galileo receivers using measurements from both systems at the same time, the GAGP calculated by site k at the time t is:

$$GAGP_k(t) = \sum_i REFGPS_{k,i}(t) \bullet w_{k,i}(t,\ \theta_i) -$$

$$\sum_j REFGAL_{k,j}(t) \bullet w_{k,j}(t, \theta_i) \qquad ..... (1)$$

Where

$REFGPS_{k,i}(t)$: the time difference between the reference time of site k and the GPST of satellite PRN i, read from the CGGTTS files which site k observed at time t.

$REFGAL_{k,i}(t)$: the time difference between the reference time of site k and the GST of satellite PRN j, read from the CGGTTS files which site k observed at time t, and

$$w_{k,i}(t,\ \theta_i) \propto \frac{1}{cos^2(t,\theta_i)}\ ,\ \sum_i w_{k,i}(t, \theta_i) = 1,$$

is the normalized weight of each observed GPS PRN i at time t, θ_i is the elevation of GPS satellite PRN i observed by site k at time t,

$$w_{k,j}\big(t,\ \theta_j\big) \propto \frac{1}{cos^2(t,\theta_j)}\ ,\ \sum_j w_{k,j}(t,\theta_j) = 1,$$

is the normalized weight of each observed GAL PRN j at time t, θ_k is the elevation of GPS satellite PRN k observed by site k at time t.

To reduce the uncertainty of GAGP, we calculated GAGP using the 6 GNSS sites which hardware delays were directly calibrated by BIPM [16][17] (Table 1)

TABLE I. THE G1 SITES USED FOR GAGP CALCULATION

Lab /Location	*Station*	*Antenna*	*Receiver*	*BIPM Cal ID*
PTB /Germany	PTBB	LEIAR25.R4	PolaRx5TR	1001_2020
TL /Taiwan	TLT5	SEPCHOKE_ B3E6	PolaRx5TR	1001_2020
USNO /USA	USN7	Trimble TPSCR.G5	PolaRx5TR	1001_2020
OP /France	OP73	SEPCHOKE_ B3E6	PolaRx5TR	1001_2020
NIST /USA	NIST	NOV750.R4	PolaRx5TR	1001_2020
ROA /Spain	ROAG	LEIAR25.R4	PolaRx5TR	1001_2020

Then we set the average GAGP of 6 sites to be:

$$GAGP_{ave}(t) = \sum_{k=1}^{6} GAGP_k(t)\ /6 \qquad .... (2)$$

Fig. 2 is the graphs of $GAGP_{ave}$ and the GAGP from the 6 sites $GAGP_k$ in 2023 (MJD 59945-60309). We found that their trends and patterns were almost the same. Furthermore, Fig 3 is the difference of $GAGP_{ave}(t) - GAGP_k(t)$, it showed all $GAGP_k(t)$ were consistent within -0.8 ~ +0.7 ns and dominated by white noise, and the floor of time deviation was around at the average time 16 hours (Fig. 4).

To further reduce the white noise of GAGP, we use moving linear fit every 16 hours:

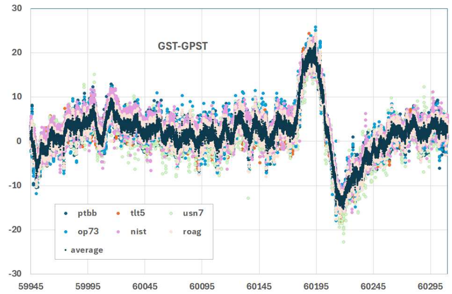

Fig. 2. The graphs of $GAGP_{ave}(t)$ and $GAGP_k(t)$. we noted their trends and details were almost the same.

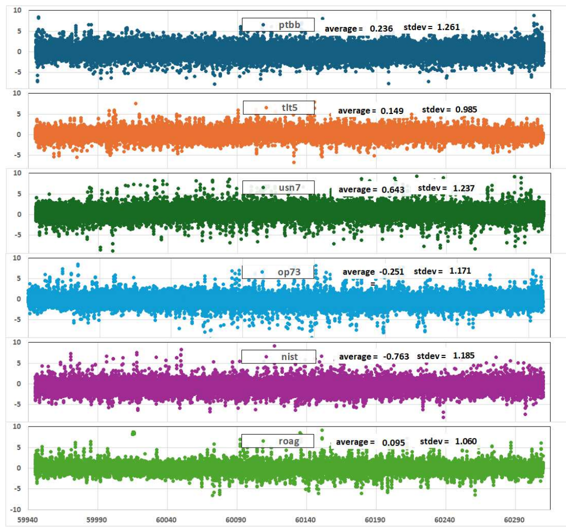

Fig. 3. The double difference of all 6 sites of $GAGP_{ave}(t) - GAGP_k(t)$, it showed all GAGPk(t) were consistent within -0.8 ~ +0.7 ns and dominated by white noise.

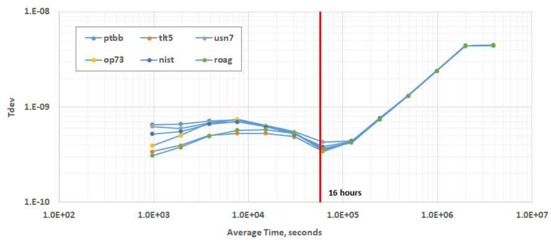

Fig. 4. The Time Deviation of $GAGP_k(t)$. The floor of Time deviation is around at the average time 16 hours.

GAGPave_lsr(t) = midpoint of Linear fit of

[$GAGP_{ave}$ (t-8 hours)~$GAGP_{ave}$ (t+8 hours)] ….. (3)

Fig. 5 is graph of the BRDC GAGP and the $GAGP_{ave\_lsr}$, it's obvious that the $GAGP_{ave\_lsr}$ reflected more detail than the BRDC GAGP.

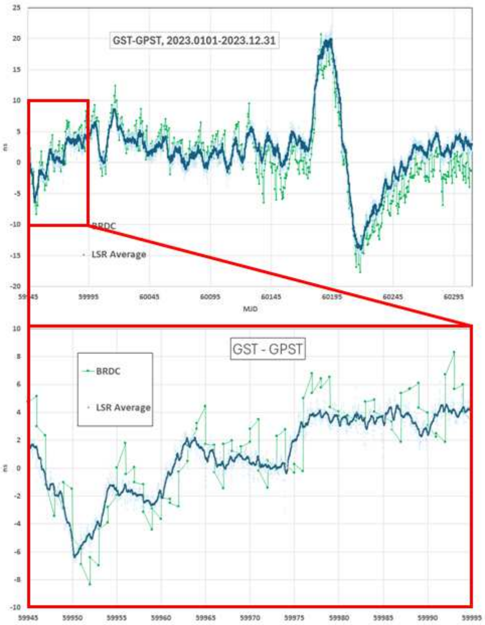

Fig. 5. The GAGP got from BRDC navigation messages (green dots) and $GAGP_{ave\_lsr}$ (Blue dots).

III. GPS P3 + GAL E3 All In View

When we combine the GPS P3+GAL E3 AV to implement AV, we can associated GPST with GST with $GAGP_{ave\_lsr}$ or vice versa, and set the new pivot clock to be GPST or GST,

$$GPST(t) = GST(t) - GAGP_{ave\_lsr}(t),$$

$$GST(t) = GPST(t) + GAGP_{ave\_lsr}(t) \qquad \ldots.. (4)$$

Here we set the GPST to be pivot clock, the time difference between local reference of site k $REF_k(t)$ with pivot clock GST at time t:

$$REF_k(t) - GST(t)$$

$$= \sum_{i,j}^{n+m} [(REFGAL_{k,i}(t) - GAGP_{ave\_lsr}(t)) \cdot w_{k,i,j}(t,\ \theta_j)$$

$$+(REFGPS_{k,j}(t) \cdot w_{k,i,j}(t,\ \theta_i)] \qquad \ldots.. (5)$$

Where $REFGPS_{k,i}$ and $REFGAL_{k,j}$ are the time difference between the reference time of site k and the GPST, GST read from the CGGTTS files of site k, and

$$w_{k,i,j}(t, \theta_{i,j}) \propto \frac{1}{cos^2(t, \theta_{i,j})}\ , \qquad \sum_{i,j} w_{k,i,j}(t, \theta_{i,j}) = 1$$

is the normalized weight, θ_i is the elevation of GPS PRN i which site k observed, and θ_j is the elevation of GAL PRN j which site k observed. The time difference between the local time reference of site k $REF_k(t)$ and k' $REF_{k'}(t)$ is:

$$REF_k(t) - REF_{k'}(t)$$

$$= [REF_k(t) - GST(t)] - [REF_{k'}(t) - GST(t)] \quad \ldots.. (6)$$

We implemented the time comparison between selected GNSS sites using 1 short baseline link (ROAG-OP73, 1,500 Km) and 3 very long baseline links (PTBB-TLT5, Europe-Asia 9,000 Km; TLT5-USN7, American-Asia, 10,000 Km; and USN7-PTBB, American-Europe, 6,600 Km) over one year long period (MJD 59945-60309) to verify the performance of P3E3 AV with respect to the regular P3 and E3 AV time transfer (Fig. 6).

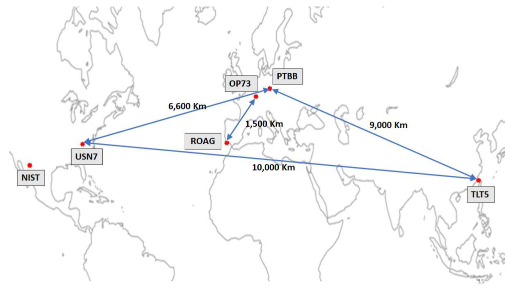

Fig. 6. The positions and link distances of the 6 GNSS sites we chose.

The time deviation of P3E3, regular P3 and E3 AV results were shown in Fig. 7, all 4 links showed their short-term stability of P3E3 AV were slightly more stable than E3 AV but better than P3 AV, and all were consistent in long-term. The time deviation of the 3 long baseline AV results are around 0.2 ns at the average time one day, and about 0.1 ns for the short baseline link ROAG-OP73.

We must mention that in our test, either choose GPST as pivot clock (GST associated with GPST via GAGP) or choose GST as pivot clock ((GPST associated with GST via GAGP) to implement P3E3 AV time transfer would have the same results, here we focus on using GPST as the pivot clock only.

IV. Concluseion And Discussion

In session III, we demonstrated the P3E3 AV showed the better short-term performance and kept the long-term consistence with respect to the regular P3 and E3 AV, the GAGP calculated from the 6 BIPM directly calibrated sites provide the good short-term details and ensure the traceability of P3E3 AV time transfer results.

We noted in Fig. 7, the time deviation of short baseline (ROAG-OP73) AV was stable than the 3 long baselines' (0.1 ns vs. ~0.2 ns), since the number of GPS and GAL satellites in view of both sites in short baseline are the more than the long baseline

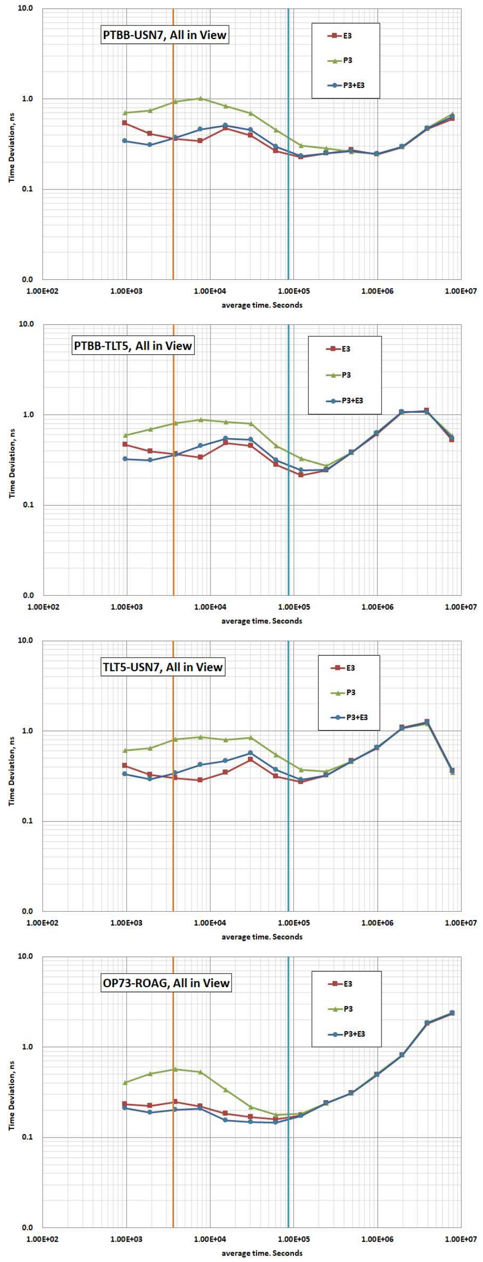

Fig. 7. The time deviation of time comparison results using E3 AV (red dots), P3 AV (green dots) and P3E3 AV (blue dots) of the links PTBB-USN7, PTBB-TLT5, TLT5-USN7, and ROAG-OP73.

AV, the time comparison errors due to the satellite orbits or clocks could be cancel out, it may imply that the some AV noise may be came from the inaccurate broadcast navigation messages.

The BIPM already announced the hardware delays calibration result of Beidou receivers [17], to extend our P3E3 AV including Beidou system and calculate GAGP using more BIPM directly calibrated sites are our next study interesting.

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