Chapter 26
The Application of Smoothed Code in BeiDou Common View

Wei Guang and Haibo Yuan

Abstract The time transfer based on satellite navigation system is adopted widely in the international time comparison. The main methods of time laboratories comparison are GPS common-view and GPS PPP in the international comparison links. Because of its mature technology and standard specification in traditional method, GPS common view is the most convenient technology in the precise time transfer field. In this paper, four data processes methods are used to calculate the time difference between two time laboratories, such as direct common view, standard common view as CGGTTS, carrier phase smoothed code in direct common view and carrier smoothed code modifying the CGGTTS. At the end of paper, the comparison of these methods is analyzed on the precision and frequency stability. The results show that the phase smoothing method can get a better accuracy in time transfer.

Keywords Time transfer · Smoothed code · Slip detecting · BeiDou common view

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26.1 Introduction

In the international time comparison, the time transfer based on satellite navigation system and two-way satellite time and frequency transfer (TWSTFT) are adopted widely. With its advantage on high precise and real-time features, TWSTFT is the main link between the time laboratory, and the time transfer based on satellite navigation system is adopted as its backup link. At present, with the benefit of its stable, reliable and high precision characteristics, GPS become the main GNSS time transfer based on in the international time comparison on the four global satellite navigation system. GPS CV and PPP time transfer technology is In-depth researched and developed. The GLONASS system is not used as common as GPS, because its stability and precision is not as well as GPS. The Galileo system is being tested at present, the time transfer based on this system is not developed yet. The Asia Pacific region covered BeiDou satellite navigation system is in the regional service stage now, which can provide a high precision positioning and Timing application. The principle of BeiDou navigation system is similar to the GPS system. The differences is the satellite constellation, there are three types of satellite in BeiDou system,such as five geostationary orbit synchronous satellite (GEO), five inclined orbit synchronous satellite (IGSO) and many middle earth orbit satellites (MEO). The different data processing methods on three kinds of BeiDou satellite for time transfer application is used in this paper, and the analysis and comparison among these methods is provided at the end of the paper.

26.2 The Introduction of Time Transfer Principle

Time transfer method Based on the navigation system is often using common view (CV), all in view (AV) and the precise point position (PPP). In the traditional common view method, GPS CV is widely used for its data processing algorithm standard. Due to the complex algorithm, no unified standard and the precise obit and Clock bias product not being real-time, AV and PPP is not widely used as CV before. But with the development of IGS product, the PPP time transfer is becoming the popular method in the international time comparison [1]. As the precise obit and Clock bias product is unavailable in BeiDou for us, the traditional common view is adopted in this paper. The direct common view, CGGTTS standard algorithm and phase smoothing pseudorange coed methods are used in the data processing for the remote time comparison. At the end of the paper, the result is shown and compared on different data processing. The principle of BeiDou common view is similar as GPS CV which shown at follow figure (Fig. 26.1).

Two remote time laboratories receive the same satellite signal at the same time, and compute the time difference between the local time and the satellite clock time. Compared the clock bias between the two laboratories computed above, the time bias can be get for the two time laboratories. Supposing the timing receiver

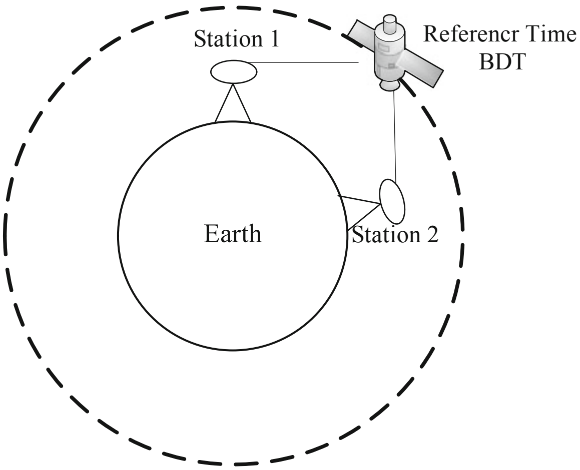

Fig. 26.1 The principle of common view

are placed on the two laboratories, such as station A and station B, and they receiving the signal of satellite S, the function can be written:

$$\Delta t_{AS} = (t_A - t_S) \tag{26.1}$$

$$\Delta t_{BS} = (t_B - t_S) \tag{26.2}$$

In the function, Δt_{AS} means the time bias between station A and the satellite S, t_S means the clock on satellite S, t_A means local time of station A; Δt_{BS} means the time bias between station B and the satellite S, t_B means local time of station B.

The time difference between station A and B can be got by formal (26.1) misusing (26.2):

$$\begin{aligned} \Delta T_{AB} &= \Delta t_{AS} - \Delta t_{BS} \\ &= (t_A - t_S) - (t_B - t_S) = t_A - t_B \end{aligned} \tag{26.3}$$

26.3 Data Processing Methods

The directing common view, CGGTT standard and carrier phase smoothing code data processing methods are implemented for the time transfer based on BeiDou navigation system.

26.3.1 The Direct Common View

Navigation system is by measuring the signal from the source from the known satellites to the user received to complete distance measurements and for the geometric positioning. This can be say that using TOA distance measurement to determine user location.

$$P_i = \rho + cdt_r - cdT_s + d_{orb} + d_{trop} + d_{ion/Pi} + d_{mult/Pi} + \varepsilon_{pi} \tag{26.4}$$

P_i means the pseudo-range code observation from frequency i. ρ means geometrical distance between station and satellite. cdt_r is the Receiver clock bias correction (m). cdT_s is satellite clock bias correction (m). d_{orb} is satellite orbit error correction (m). d_{trop} is tropospheric delay (m). $d_{ion/Pi}$ is ionospheric delay (m). $d_{mult/Pi}$ means Multipath delay (m). ε_{pi} means noise of pseudo-range phase and measurements.

In the direct common view calculation, we just need to take the acquisition date into the observation equations mentioned above to calculate the time bias between the local receiver's clock and the system time. Two time laboratory have got this result at the same time, then the difference between the two stations can be get by a simple subtraction.

26.3.2 Standard Common View Data Processing Method

The standard common view (CGGTTS file format formation) data processing procedure can be described as follows [2]: The satellites' elevation angle should be more than 20° on each Tracking in 16 min (two minutes for preparation, one minute for processing). Then, continuously record the data for 13 min, collecting 780 code pseudo-range observations (one per second) for a group as a common view data. Make the 780 data points into 52 groups, each group have 15 points. The 52 sets of each points (15 points) respectively be used the quadratic polynomial fitting values at the midpoint of the selected data. A linear fit applied to the results (shown on the following figure) the tropospheric delay, Ionospheric delay, Multipath delay and other delay are considered in the data processing to get time bias between the local time and the GPST(REFGPS) or satellite time (REFSV). For the two time laboratory clock difference can obtain by the REFGPS subtraction at the same time (Fig. 26.2).

26.3.3 Phase Smoothing Code Data Processing Method

In the traditional common view data processing, the code observations is used for calculation. The precision is limited on the code measurement. In order to improve

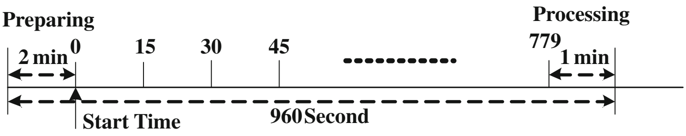

Fig. 26.2 The data and its group of once common view

the precision of the time transfer, here the phase observation is adopted into smoothing the code observation. The slip of the phase data may cause mistake without preprocessing, so the slip detecting is an indispensable procedure. In the paper the combination of Melbourne—Wübbena and ionospheric residual is used to detect the phase slip [3]. The combination of the equation (M-W) is as follow:

$$L_M = L_w - P_n = \frac{(f_1L_1 - f_2L_2)}{f_1 - f_2} - \frac{(f_1P_1 + f_2P_2)}{f_1 + f_2} = -\lambda_w N_w \tag{26.5}$$

L_1, L_2 means the phase with the unit m, $\lambda_w = {}^{c}\!/_{f_1 - f_2}$ is the wide combination wavelength, $N_w = N_1 - N_2$ means the wide ambiguity of the combination observation.the variance of the observation is:

$$\sigma^2_{L_M} = \frac{(f_1^2\sigma^2_{L_1} - f_2^2\sigma^2_{L_2})}{(f_1 - f_2)^2} - \frac{(f_1^2P^2_{P_1} + f_2^2P^2_{P2})}{(f_1 + f_2)^2} \tag{26.6}$$

In the practical data processing, the follow equations are used to remove unsuitable phase and code observation data, and for the wide ambiguity calculation.

$$\left.\begin{aligned} \langle N_w\rangle_i &= \langle N_w\rangle_{i-1} - \frac{1}{i}\left[N_{w,i} - \langle N_w\rangle_{i-1}\right] \\ \sigma_i^2 &= \sigma_{i-1}^2 + \frac{1}{i}\left[(N_{w,i} - \langle N_w\rangle_{i-1})^2 - \sigma_{i-1}^2\right] \end{aligned}\right\} \tag{26.7}$$

$$\left|N_{w,i} - \langle N_w\rangle_{i-1}\right| \geq 4\sigma_i \tag{26.8}$$

$$\left|N_{w,i+1} - N_{w,i}\right| \leq 1 \tag{26.9}$$

If the formula (26.8) is satisfied, means the slip may be found, at the same time the formula is also satisfied, the data must be slip. Then, we mark this data point. One of these conditions appears, it means the data is gross.

Ionospheric residual combination is the difference between the adjacent epochs of phase observation, which is interrelated with the ionospheric noise and the noise of phase measurements. As the change between the adjacent epochs of phase observation is small, the slip can be detected more easily. The combination observation function can be written:

$$\left.\begin{aligned} L_{ion} = \lambda_1\phi_1 - \lambda_2\phi_2 = \lambda_1 N_1 - \lambda_2 N_2 + I_{f1} - I_{f2} \\ I_{diff} = L_{ion}(t_{i+1}) - L_{ion}(t_i) \end{aligned}\right\} \tag{26.10}$$

When the ionosphere is stable, and data sampling interval is short, the ionospheric changes is at cm level, then decision threshold is close to zero, if the residual value is greater than the threshold, the data can be mark as slip data. For the GEO and IGSO, the satellite moves slower than other navigation system satellites, the variation between each epoch is in a small scale [4]. The Ionospheric Residual combination is very suitable for GEO and IGSO carrier phase data processing.

The Ionosphere-free combination of pseudo-range and phase observations can be expressed as:

$$\left.\begin{aligned} \lambda(\varphi + N) = \rho + \Delta\rho_L + \varepsilon \\ P_{IF} = \rho + \Delta\rho_P + \varepsilon \end{aligned}\right\} \tag{26.11}$$

According to the relationship of the code and phase observation, two formals minus each other the combined ambiguity can be got, and then take the average of some epoch [5].

$$\left.\begin{aligned} &P_{3smth} = \frac{1}{i}P(i) + \frac{i-1}{i}\left(P_{3smth}(i-1) + L_3(i) - L_3(i-1)\right) \\ &P_{3smth}(1) = P_3(1) \end{aligned}\right\} \tag{26.12}$$

In the practical data processing, the formal (26.13) is adopted.

$$\left.\begin{aligned} &\langle \lambda N \rangle_i = \frac{i-1}{i}\langle \lambda N \rangle_{i-1} + \frac{1}{i}(P_i - L_i) \\ &P_{i,smth} = L_i + \langle \lambda N \rangle_i \end{aligned}\right\} \tag{26.13}$$

26.4 The Analysis and Comparison of the Result

According to the principle and algorithm, five days data from 2012.09.01 to 2012.09.05 of BeiDou geodetic receivers at NTSC and other time laboratories is selected in this experiment, the observation data of BD satellites (No.1 to No.10) are calculated. The following figures show the result of GEO satellites and IGSO satellites on 2012.09.03 (Figs. 26.3, 26.4, 26.5, and 26.6).

In these figures, 30 s CV means direct common view with the data interval of 30 s, STCV stands for standard common view method (that is, CGGTTS format formation method), SMCV means using phase smoothing code menthod before common view to process the data with the interval of 30 s, SMSTCV means using phase smoothing code method before standard common view. Base on the result of

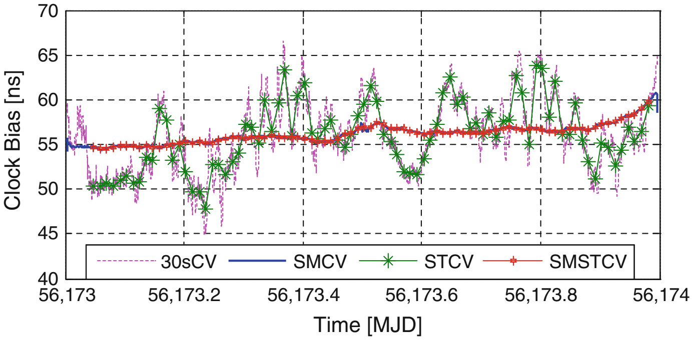

Fig. 26.3 The result of satellite GEO-03 on different method

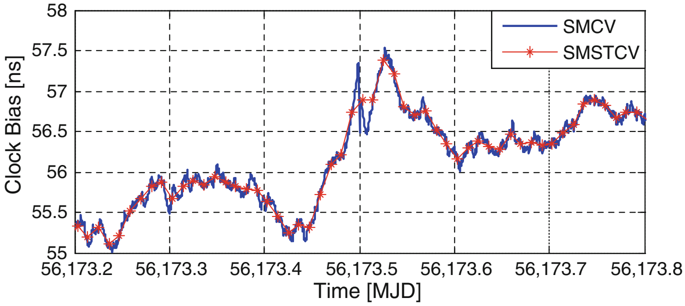

Fig. 26.4 The result of satellite GEO-03 between smoothed and standard method

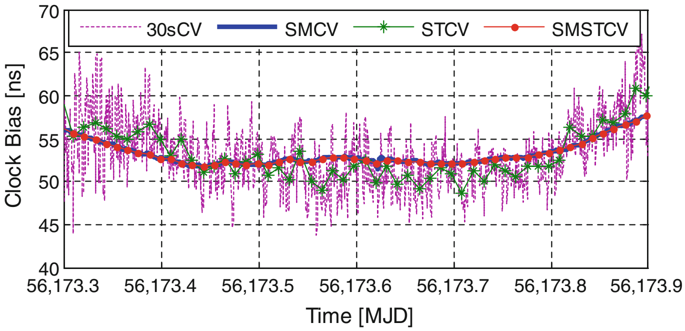

Fig. 26.5 The result of satellite IGSO-04 on different methods

signal satellite, it can be seen obviously that the method of phase smoothing code before common view is superior to the method of direct common view, the method of SMSTCV is better than SMCV because SMSTCV can remove the coarse value, and the data file of SMSTCV is smaller than SMCV so that it is easy to transmission.

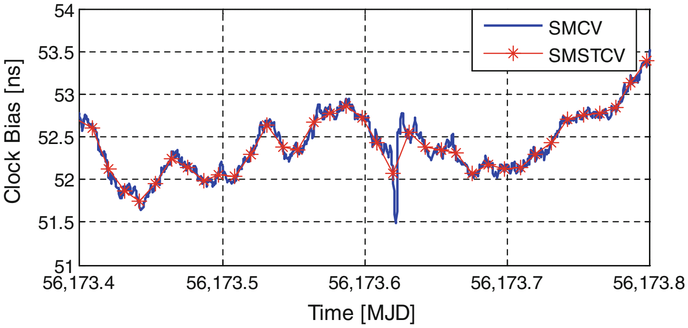

Fig. 26.6 The result of satellite IGSO-04 between smoothed and standard methods

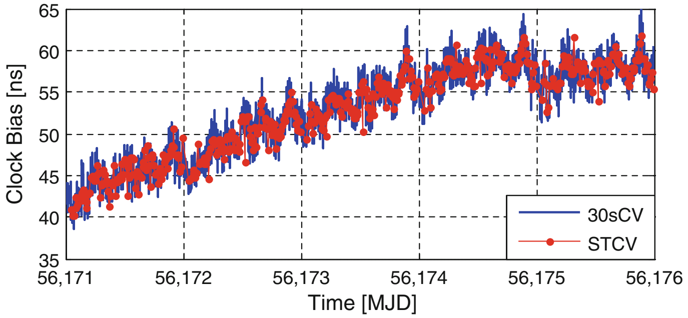

Fig. 26.7 Comparison between direct and standard common view

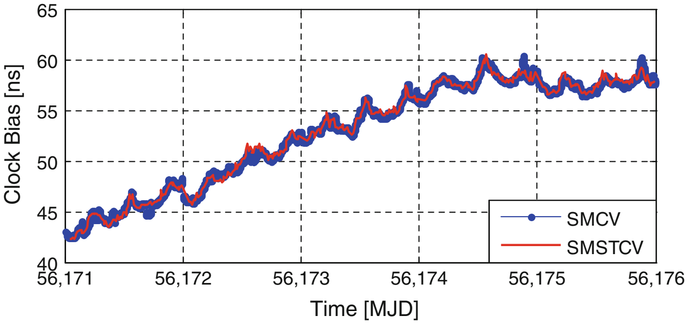

Fig. 26.8 Comparison between smoothed and modified common view

Following figure is the analysis on the stability of common view between two laboratories through averaging the result of No. 1 to No. 10 satellites in the 5 days. Figures 26.7 and 26.8 show that the in the common view between two laboratories, the result of phase smoothing code is superior than traditional common

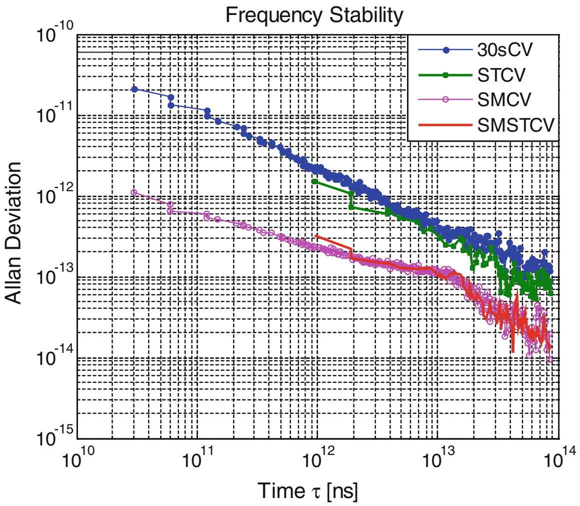

Fig. 26.9 The Frequency stability of all method

Table 26.1 The stability of different method

	30 s CV	Standard CV	Phase smoothed CV	Modified standard CV
1 min	1.65e–11	*	7.81e–13	*
1 h	8.52e–13	6.00e–13	1.44e–13	1.43e–13
1 day	8.75e–14	7.38e–14	9.27e–15	1.39e–14

Table 26.2 Comparison of the TIE RMS

	30 s CV	Standard CV	Phase smoothed CV	Modified standard CV
1 h	2.25 ns	1.87 ns	0.63 ns	0.61 ns

view, meanwhile the common view result corrected by phase data is better than traditional common view on the stability of time transfer link. In order to quantify the results, following tables give the time transfer stability (one minute stability, of hour stability, one day stability) and RMS of time interval error (TIE RMS). From Fig. 26.9, it can be seen that phase smoothing code method has obvious advantage in short-term stability, and its long-term stability is close to the pseudo-range method (Tables 26.1 and 26.2).

On the method of phase smoothing code, the minute stability is 7.8e–13, hour stability can reach 1.4e–13, and one day stability is 9.2e–15. The difference between the method of phase smoothing code and the method of modified standard common view by phase smoothing code is not obvious on the stability, however on the aspect of TIE RMS, the method of modified standard common view by phase smoothing code has some improvement than method of directly phase smoothing code, meanwhile it is superior to traditional common view method.

26.5 Conclusion

This paper gives the time transfer method between two time laboratories. Different data processing methods is used for BeiDou common view principle. From the comparison of the different results, it can be concluded that phase smoothing code method can improve traditional common view algorithm, this method can get better time accuracy, which can be beneficial for improving BeiDou standard common view algorithm.

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