BDT Performance and Time Offset Analysis

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Abstract. The nature of satellite navigation can be seen as a time measurement. Time measurement is the basic for satellite navigation. First, the time scale of satellite navigation system is the basic for the system operation, and the accuracy of time measurement determines the accuracy of satellite orbit. It can be said that the accuracy of the time determines the accuracy of satellite navigation to a certain extent. BDT is the system time of the beidou satellite navigation, It is established and maintained by the ground operation control system, BDT is the reference time of the entire ground operation control system and is also the reference time of satellite, thus ensuring the consistency of the satellite time and the ground time. The definition and realization of the BDT are introduced. The time and frequency system to maintain BDT and its performance are briefly described. The measurement methods of BDT/GPST time offset are introducted, the measurement results are analysed, the prediction modelling time offset is studied, the 1st, 2nd and 3rd order polynomial model are given, 1~2ns precision could be got in BDT-GPST prediction, if the system time stability or the receiver observation precision are improved, the higher precision could be reached in future.

1. Introduction
All we know that time system plays a significant role in Beidou system, Accurate and reliable time is the base of PNT service. How is about the performance of Beidou system time? It is a very concered question for many GNSS users, so it is beneficial and indispensable to evaluate the BDT Performance[1-2]. The information of time offset is important for the user, satellite is invisual some time during the day, so the time offset information is depend on the prediction when the satellite is not in the visual field of user. In the following sections the definition and realization of BDT is introduced and its performance is described, then the BDT evaluation is analyzed which from GPS CV, BD CV and TWSTFT, and then the measurement and prediction of time offset is studied. Finally the results and conclusions are detailed.

2. Definition and realization of BDT
Analogous to GPS system time — (GPST) and different from UTC, the BDT is an internal and continuous uniform navigation time scale without any leap second. The basic unit of BDT is the SI second, and the largest unit is one week defined as 604,800 seconds. BDT is counted with the week number (WN) and the second of week (SoW), from 0 to 604,799. The zero point of BDT is January 1, 2006 (Sunday) UTC 00h 00m 00s, which means all the numerical values of WN and SoW are equal to zero at that time.

BDT is realized in the “composite clocks” approach and maintained by TFS located at MCS. According to the functions, TFS is mainly composed of 5 parts: the clock ensemble (CE), the iner
measurement element (IME), the outer comparison element (OCE), the data processing element (DPE) and the signal generation element (SGE). The structure of TFS is illustrated in Figure 1.

**Figure 1.** The Structure of the BDT and Frequency System

The clocks used in time keeping are more than ten hydrogen masers, which form a clock ensemble to provide time and frequency signals. The inter measurement element provides measurements to the original time and frequency signals from CE, and gives out the clock differences both in time and frequency in a circular pattern. The deviations of BDT with respect to other time scales, especially to UTC, are obtained by the outer comparison element. The data processing element completes the calculation with the given algorithm to give a relative uniform time scale, based on all the information from IME and OCE, which is called BDT which works as the time reference for the whole navigation system. In line with BDT, the signal generation element exerts a frequency adjustment to the frequency signal from the Master Clock (MC), and generates all the real physical time and frequency signals required in the Master Control Station[3-5].

The algorithm used in BDT calculation is well designed to form a good composite clock. The frequency offset, drift and instability of the free clocks have been taken into account. The weight of clock is determined by its Allan variance (the frequency drift is taken off) and a limited weight is also used based on the robust estimation principle. In order to be as consistent as possible with UTC, BDT may be steered with a interposed frequency adjustment after a period of time (more than 30 days) according to the situation, but the quantity of the interposed frequency adjustment is not allowed to be more than $5 \times 10^{-15}$. At present, the performance of BDT is as follows[5]:

- Time (frequency) accuracy: $< 2.0 \times 10^{-14}$
- Time (frequency) stability: $< 2.0 \times 10^{-14}/$1 day
  $< 1.4 \times 10^{-14}/$7 days

Time deviation: $|\text{BDT-UTC}| < 100$ns (modulo one second).

3. BDT performance evaluation
The BDT time comparison links are illustrated in figure 2.

**Figure 2.** BDT time comparison links
Time offset can be attained via TWSTFT, GPS CV, and BDT CV, and the precision of TWSTFT is the best, the precision of GPS CV and BDT CV are comparative. The principle of TWSTFT, GPS CV, and BDT CV would be introduced in the following section.

The basic principle of two way time transfer is as follows: the satellites and stations generate and transmit pseudo range signals to be controlled by their local clocks, then the uplink pseudo range \( \rho_u \) and downlink pseudo range \( \rho_d \) are measured by the satellites and the stations respectively, the clock offsets between satellites and stations are computed in the master station by using the uplink pseudo ranges and the downlink pseudo ranges.

The basic principle of GPS CV is as follows: two time and frequency laboratory, which the distance is far, observe the same satellite at the same time, and the GPS satellite clock time is their common reference, the time offset between GPS satellite clock time and the laboratory is measured, then, the time offset of two laboratories is received via make difference for the measurement result of two laboratories.

Analogous to GPS CV, the time offset of two laboratories can be received, the only different is the reference, the reference time is Beidou satellite clock time.

The result of time offset between BDT and UTC(NTSC), which using GPS CV, BD CV and TWSTFT, are given in Figure 3.

![Figure 3. The time offset between BDT and UTC(NTSC)](image)

The change direction of BDT relative to UTC(NTSC) is conformably, and BD CV and TWSTFT have the higher precision. The result of GPS CV is bad, and it is confirmed that the reason is the receiver of GPS CV is single frequency, and the correct error of ionosphere is larger. The time offset between UTC and UTC(NTSC) is given in Figure 4.

![Figure 4. The time offset between UTC and UTC(NTSC)](image)

So, the time offset between BDT and UTC can be received via make plus for BDT-UTC(NTSC) and UTC(NTSC)-UTC, and the result is given in Figure 5.
The max of time offset between BDT and UTC is 64.8ns. The performance evaluation results of BDT relative to UTC(NTSC) is given in Table1, and the frequency stability is given in Figure6.

Table1. Performance evaluation results of BDT relative to UTC(NTSC)

| Measurement method | Frequency accuracy | Frequency stability | Time |
|--------------------|--------------------|---------------------|------|
| GPS CV             | 8.89E-14           | 2.58E-14/d          | Aug.-Sept. |
| BDS CV             | 7.67E-14           | 1.75E-14/d          | Aug.-Sept. |
| TWSTFT             | 6.90 E-14          | 2.16 E-14/d         | 6.33E-15/7d | Aug.-Sept. |

So, the day frequency stability is 2.16E-14/day, and the seven days frequency stability is 6.33E-15/7days.

4. BDT/GPST time offset measurement
The measurement principle of BDT/GPST time offset is given in Figure7, BDT is reference, and GPST is measurement, the result is BDT-GPST.

The data come from the Septentrio 4 GPS CV receiver. The measurement result is given in Figure8.
Figure 7. The measurement principle of BDT/GPST time offset

The measurement data is from 2 Oct. 2013 to 10 Oct. 2013. The time offset is not measured when the satellite is not in visual, so the time offset will be predicted during the satellite is invisual. The different prediction model will give the different prediction result, and the different result will be given using different fitting data. In this section, time offset prediction algorithms based different ploynomial models: 1st model, 2nd model, 3rd model are studied, and the different fitting data will be analyzed. The different case are given in Table 2.

Table 2. Time offset data modelling and prediction

| Model          | 1st order model | 2nd order model | 3rd order model |
|----------------|-----------------|-----------------|-----------------|
| Data usage     | Prediction: 1 day | Prediction: 1 day | Prediction: 1 day |
|                | Based on: 3 days | Based on: 3 days  | Based on: 3 days  |
|                | Prediction: 1 day | Prediction: 1 day | Prediction: 1 day |
|                | Based on: 6 days | Based on: 6 days  | Based on: 6 days  |

4.1. Three days → one day

Prediction error comparation of three models are given in Figure 9 and Figure 10.

Figure 9. the fitting results and the prediction results

Figure 10. Prediction error comparation of three models

4.2. Six days → one day
Prediction error comparison of three models are given in Figure 11 and Figure 12, and the comparative results are given in the Table 3.

Figure 11. the fitting results and the prediction results

Figure 12. Prediction error comparison of three models

Table 3. Result comparison and analysis

| Prediction model | Std Dev(3 days’ data => 1 day) | Std Dev(6 days’ data => 1 day) |
|------------------|-------------------------------|-------------------------------|
| 1st order poly   | 1.19                          | 0.72                          |
| 2nd order poly   | 1.57                          | 0.80                          |
| 3rd order poly   | 1.54                          | 1.05                          |

The followed conclusions can be given from the above experiments:
(1) The longer the data used, the better the prediction precision. 6 days’ data is enough for the prediction in the above experiments.
(2) Low order (1-2 order) polynomial could get good precision for modelling and prediction. Higher order (over 3 order) polynomial is not necessary.
(3) 1 ~ 2 ns precision could be got in BDT-GPST prediction. If the system time stability or the receiver observation precision are improved, higher precision could be reached in future.

5. Conclusion

Beidou system have been supplied service for users, BDT is the basic of Beidou system. BDT is stated by WN and SoW from Jan.1, 2006 UTC 00h 00m 00s. BDT is maintained by the Time and Frequency System of the master station. The frequency accuracy of BDT is superior to 2.0E-14 and its stability is better than 6.0E-15/30 days. The time offset between BDT and UTC was kept within 100ns and the frequency stability of BDT is about 3.0E-14.

Reference
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