Preliminary Implementation of Time and Frequency Transfer by BDS

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***Abstract*—Time and frequency transfer method using code and carrier phase by BDS has been developed by NIM. The CCD and long baseline results are comparable with GPS. The standard deviation of the BDS P3 code and carrier phase results in the CCD experiment could be better than 1 ns and 100 ps with one day measurement. The combination of BDS and GPS code measurement for time and frequency transfer led to the improved precision and robustness.**

Keywords- time and frequency transfer; GNSS; BDS

I. INTRODUCTION

Since 2003, the Beidou Navigation Satellite Demonstration System was officially brought into service. By the end of 2012, there are six GEO(Geostationary Earth Orbit), five MEO(Medium Earth Orbit) and five IGSO(Inclined Geosynchronous Satellite Orbit) satellites in orbit. Since 27th Dec 2012, BDS(BeiDou Navigation Satellite System) Signal in Space Interface Control Document-Open Service Signal B1I(Version 1.0)[1] has been released. The developing BDS system with the coverage of part of Asia-Pacific area at present has provided the official service and can be used for time and frequency transfer in this area.

II. TIME AND FREQUENCY TRANSFER BY BDS AND COMBINATION WITH GPS

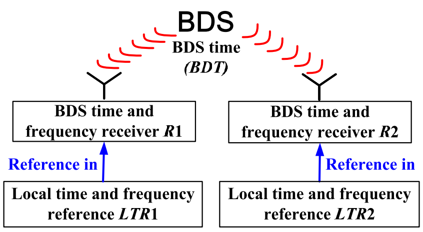

Figure 1. Time and frequency transfer by BDS

Time and frequency transfer methods by GPS(Global Positioning System) and GLONASS(GLObal Navigation Satellite System) are divided into three types that are C/A code, P3 code and carrier phase time and frequency transfer according to the measurement signals. The basic principles of time and frequency transfer by BDS are similar to those of them[2] as shown in Fig. 1.

Based on BDS OEM model with the first operation mode(mode 1)[2] with time and frequency directly synchronized to the local time and frequency reference by a internal phase lock loop, the original BDS observation can be acquired and the BDS code and carrier phase time and frequency transfer could be implemented preliminarily.

From the overall, BDS has more likeness with GPS. BDS has the similar communication mechanism to GPS, including the CDMA(Code Division Multiple Access) mode for all satellites. However, the GEO satellites that not are involved in the GPS space orbit generate one of the main differences in the error correction for BDS time and frequency transfer from GPS time and frequency transfer because of the difference of the calculation for satellite position between GEO and non-GEO satellites as shown in (1)-(5). In addition, the time difference from UTC is different from that of GPS.

$$\Omega_k = \Omega_0 + \dot{\Omega} t_k - \dot{\Omega}_e t_{oe} \tag{1}$$

$$\begin{cases} X_{GK} = x_k \cos\Omega_k - y_k \cos i_k \sin\Omega_k \\ Y_{GK} = x_k \sin\Omega_k + y_k \cos i_k \cos\Omega_k \\ Z_{GK} = y_k \sin i_k \end{cases} \tag{2}$$

$$\begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} = R_Z(\dot{\Omega}_e t_k) R_X\left(-5^\circ\right) \begin{bmatrix} X_{GK} \\ Y_{GK} \\ Z_{GK} \end{bmatrix} \tag{3}$$

$$R_X(\varphi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{bmatrix} \tag{4}$$

$$R_Z(\varphi) = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

For the users of GNSS(including BDS) time and frequency transfer, the user position that should be known precisely in advance is not cared about in the solution in generally. The most important job is processing for error correction and the solution of the receiver clock bias. In terms of different measurement signals, measurement methods and models of the error correction, the different measurement precision and accuracy could be obtained. For code measurement, ionospheric error, tropospheric error, Sagnac effect, relativistic effect and satellite clock error[3] would be taken into consideration and enough information can be acquired from navigation ephemeris of GNSS in real-time. If one doesn't have to or is not eager for the real-time processing, IGS(International GNSS Service)-like products that refer to precise ephemeris will provide him the better precision with the much more complicated post-processing. For carrier phase time and frequency transfer solution, we'd better use these kind of precise products to get the corresponding precision of error correction or we use the differential method to have the most errors cancelled, and the solution of the integer ambiguity and the detection of the cycle jump are the most difficult parts for the whole processing of carrier phase time and frequency transfer. There is some near real time precise product for real-time carrier phase processing, however, the more and deeper try and tests to apply product in carrier phase time and frequency transfer need to be implemented.

For code based BDS time and frequency transfer, we use the combination of C1 code(civil code modulated in L1 carrier 1561.098 MHz(f_1)) and P2 code(some undocumented civil code modulated in L2 carrier 1207.140 MHz(f_2) that can be measured by BDS receiver we used) as shown in (6), and we can simply name the combination as P3 code.

$$P3 = \frac{f_1^2}{f_1^2 - f_2^2} C1 - \frac{f_2^2}{f_1^2 - f_2^2} P2 \tag{6}$$

III. Experiment Setup and Numric Results

To verify the performance and feasibility of BDS for time and frequency transfer, on the basis of Fig. 1, the CCD(Common Clock Difference) experiments, the zero baseline experiments with the different references and the long baseline(straight-line distance between two receivers) experiments with the different references have been implemented, using the two BDS OEM modules(BD01 and BD02, both involving GPS measurements) and the other GPS time and frequency transfer receivers including IMEU, and IMEN sites(NIMTFGNSS-1 receivers[2]), IMPR and BJNM sites(Septentrio PolaRx2eTR and PolaRx3eTR receivers respectively) of NIM located at NIM.

CCD experiment reflects the noise level of the time and frequency transfer link. Fig. 2 and 3 show CCD results of BDS code and carrier phase time and frequency transfer and the standard deviation of the data averaging one day are 639 ps and 17 ps separately. GPSTFP software[4] for GPS carrier phase time and frequency transfer was modified to be adapted for BDS. BDS has the comparable performance with GPS for time and frequency transfer in code and carrier phase.

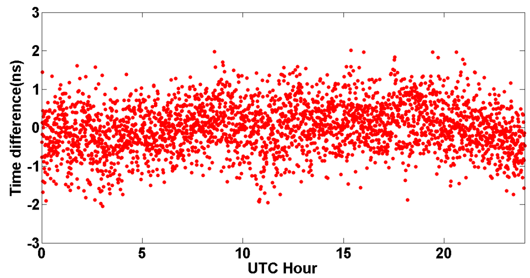

Figure 2. CCD by P3 code of BDS

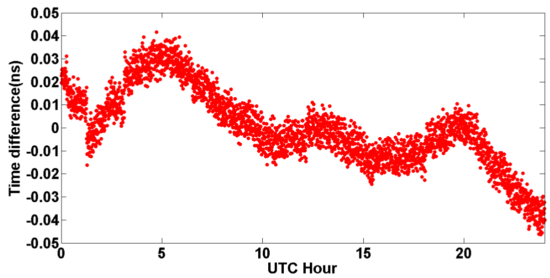

Figure 3. CCD by carrier phase of BDS

The development of multiple techniques for time and frequency transfer has generated the redundancy, so the combination of multiple techniques by data fusion principle that is one of the focuses by BIPM should be one good choice to convert the redundancy to the precision. We take the simple mean value *GBC* of GPS P3 code and BDS P3 code result by (7) as their combination. From the results of CCD experiments using BDS, GPS and the combined method at the same time, the standard deviations of them are 0.9 ns, 0.7 ns and 0.6 ns respectively. When we combine BDS with GPS to transfer time and frequency, the advantage of robustness over either of GPS and BDS thanks to the complementation of GPS and BDS and improvement in noise level have been acquired as shown in Fig. 4. Corresponding to these, we could get the better short term stability from the combined results. As well, we could get the weighted mean as (8) by figuring out the weights W_B for BDS and W_G for GPS using the noise level of each technique according to the basic principle of date fusion. The noise level would be thought as the standard deviation of the results for each type of link in the CCD experiments. However, from our CCD results, BDS has the quite comparable noise level with GPS, and we might get the quite negligent difference between using (7) and using (8).

$$GBC = \frac{1}{2}(P3_{GPS} + P3_{BDS}) \tag{7}$$

$$GBC = W_G \cdot P3_{GPS} + W_B \cdot P3_{BDS} \tag{8}$$

We compared the differences between NIMDO(UTC(NIM) disciplined oscillator) and UTC(NIM)hepingli(one Cesium clock with one micro-stepper steered by UTC at Hepingli campus of NIM) in the zero baseline experiments using the corresponding BDS, GPS and the combined links. From Fig. 5, the results are quite similar to those of GPS time and frequency transfer. GPS1 link consists of BD01 and BD02;

GPS2 link consists of IMPR and IMEN. As expected, these show that the combined GPS and BDS link is more stable than either of the single GNSS links. It is less noisy and robust maybe because the impacts of the atmosphere errors and the other effects have been reduced to some extent.

The results of BDS carrier phase show the good agreements with those of both BDS P3 code and GPS carrier phase got from NRCan_PPP software in Fig. 6.

The long baseline experiment characterizes the remote transfer performance of the transfer. Fig. 7 shows the comparison of five links between UTC(NIM)hepingli and UTC(NIM)(at Changing campus), including one BDS link, two GPS links and two combined links of GPS and BDS in about 40 km baseline. GPS1 link is between BD01 and BD02; GPS2 link is between IMPR and BJNM. The BDS link has the similar trend with the GPS links and the combination had the effect on the improvement on noise level of the transfer. All results are normalized for better view; link calibration was not implemented, so the results are meaningful for frequency transfer indeed.

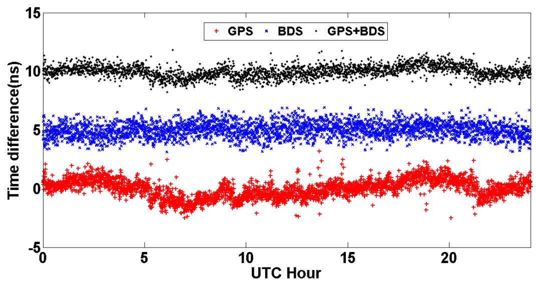

Figure 4. Comparison 1 among BDS, GPS and the combination

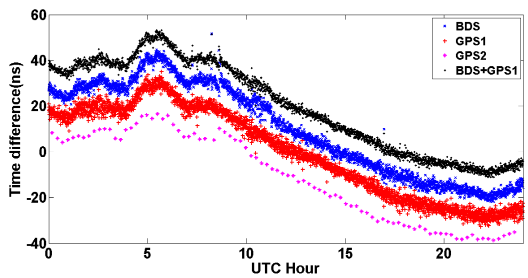

Figure 5. Comparison 2 among BDS, GPS and the combination

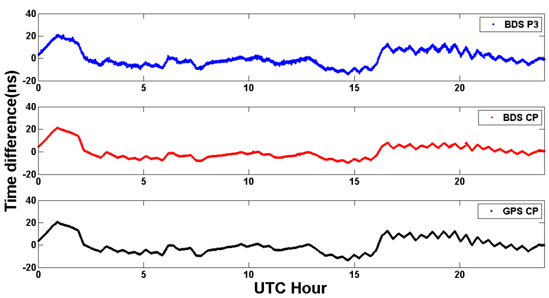

Figure 6. Comparison among BDS and GPS methods

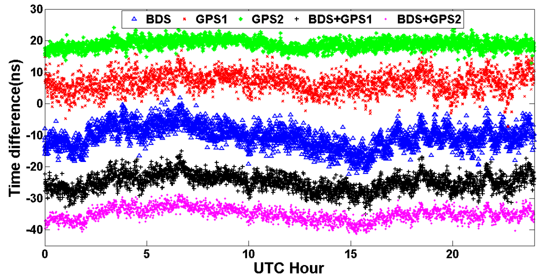

Figure 7. Comparison 3 among BDS, GPS and the combination

IV. UNCERTAINTY ANALYSIS

The uncertainty for time and frequency transfer usually includes the uncertainty evaluation of type A and type B. For type A, the only one item is the measurement jitter of the results for the time transfer link in the CCD experiment. For type B, uncertainty for calibration of GNSS time transfer link is the main part, which is usually better than 5.5 ns; the standard uncertainty components due to ionospheric and tropospheric errors are 0.3 ns and 0.7 ns respectively valid for baselines up to 5000 km[5]; due to the cables and the converters calibrated by VNA(Vector Network Analyzer), the standard uncertainty component is less than 0.1 ns. Thus we can get the combined uncertainty u_c by (9) as 5.7 ns, 5.7 ns and 5.6 ns respectively for GPS, BDS and the combination in our experiments.

$$u_c = \sqrt{u_A{}^2 + u_B{}^2} \tag{9}$$

V. CONCLUSION AND PROSPECT

From the results of our experiments, the performance of BDS by code and carrier phase can match those of GPS for time and frequency transfer. Anyway, more experiments especially in the longer baseline are needed for verification. With the development of the near real-time or real-time precise ephemeris products, near real-time BDS carrier phase time and frequency transfer will be studied and tested at NIM. The combination of two systems(GPS and GLONASS[6] or BDS and GPS) would improve the robustness and noise level of time and frequency transfer, the combination of GPS, GLONASS and BDS would be more interesting in the future with the completeness of the BDS global constellation.

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