The Carrier Phase Time Transfer with Broadcast Ephemeris

WANG Xiang-lei*, SHI Feng-feng, WANG Jiang-ting, FANG Jia-min
Beijing satellite navigation center, Beijing, 100094, China
*e-mail: chxywxl@163.com

Abstract. Time transfer method PPP is restricted by the real-time and precision of IGS production, and the real-time application have not been widely implemented. Standard Point Positioning(SPP) can satisfy the application for the real-time customer, but the precision is low and is not satisfy the high precision customer. So a new algorithm which have real-time and high precision performance is given. The algorithm dose not need the external orbit and clock error, and can be used for the real-time time transfer because of getting rid of the reliance on IGS production. In this paper, the analysis for the new algorithm is given by using the real measurement data. The results show that the algorithm could improve the time transfer results and frequency stability significantly; the time transfer precision of the new algorithm relative to SPP is improved from 10 ns to 1-2 ns, and dose not need the external precise ephemeris production; the new algorithm can be realized in the receiver conveniently.

1. Introduction
The high precision time transfer is the key of realizing high precision time system, and high precision time synchronization dose not realize without high precision time transfer[1-2]. The technology of high time transfer is the key moment of keeping time laboratory synchronization and establishing time scale, it is very important for uniform the standard time[3].

Now, two way satellite time and frequency transfer(TWSTFT), laser time transfer, fiber time transfer and GNSS carrier phase(GNSS CP) are the main technology of high precision long distance time transfer[4-5]. TWSTFT is used for long-range time transfer, but expensive communication satellite needs to be leased to establish communication links and specialized manipulation equipment; laser time transfer is mainly used for the synchronization between earth and satellite clock, with high accuracy and stability, but is affected by light and climatic conditions easily, and can’t work all the clock, while the technology is difficult and the equipment is expensive; fiber time transfer have the advantage of low loss and high stability, and the precision is better than 0.1ns, but the transmit distance is short and coverage is limited; the precision of GNSS CP and TWSTFT is quite, the short stability of GNSS CP is better than TWSTFT, GNSS CP time transfer have the advantage of high precision, low cost, all earth coverage, all the clock, and have became the key method of uniform time transfer[6-9].

Usually, GNSS CP use PPP technology, PPP time transfer method is limited by the real-time of and precision of satellite precision clock production, and the real-time application have not been widely implemented. Standard point positioning(SPP) based broadcast ephemeris can satisfy to the real-time customer, SPP uses the pseudo distance measurement, have the low time transfer precision, and not satisfy for the high precision customer. This paper combines the advantage of PPP and SPP gives a new time transfer method which add the carrier phase measurement base on the pseudo distance measurement. This method is not need the external orbit production and the satellite clock error...
production, get rid of the reliance on the IGS of afterwards precision satellite clock error, and realize
the real-time time transfer, the realize of the new method relative to the afterwards PPP method is
easier independently.

2. Basic principle
SPP time transfer using pseudo range measurement, elimination of ionospheric combinations is used
for eliminating the influence of ionospheric[10-11]. The equation of measurement is followed.

\[
P^j = \rho^j + c \cdot \delta t - c \cdot \delta t^j + T^j + \varepsilon^j
\]  

Where, \(P\) is the measurement which eliminating the influence of ionospheric, \(j\) is the satellite
NO., \(\rho\) is the distance between the center of antenna phase and the the center of satellite antenna
phase, \(c\) is light speed, \(\delta t, \delta t^j\) are the clock error that the receiver clock and satellite clock relative
to the reference time respectively, \(T\) is tropospheric delay, \(\varepsilon\) is the measurement noise.

SPP algorithm using pseudo range as the measurement, have the low time transfer precision. The
frequency of carrier phase is higher than phase, and the noise of carrier phase is lower than the phase,
so the precision of carrier phase observation is higher than the phase, the accuracy of clock error can
be improved by using carrier phase observation. The equation of eliminating the influence of
ionospheric is followed.

\[
\Phi^j = \rho^j + c \cdot \delta t - c \cdot \delta t^j + \lambda N^j + T^j + \varepsilon^j
\]  

Where, \(\Phi\) is observation that eliminating the influence of ionospheric effect, \(\lambda, N\) are the
combination wavelength and integer ambiguity, the mean of other parameters is same with formula (1).

The clock error precision is influenced by the observation precision of pseudo range and carrier
phase, if the formula (2) replace the formula (1), the precision of time transfer can be improved two
orders of magnitude, the key problem of using carrier phase observation is how to determine the
integer ambiguity accurately, integer ambiguity and observation noise are relate to transmit delay.
Usually, the combination that eliminating the influence of ionospheric effect is used, reduce the
influence of tropospheric using the tropospheric zenith delay parameter, the hardware delay which
changes slowly could be corrected using the IGS production which will be released monthly, tide,
earth rotation, relativity are corrected by modeled, the integer ambiguity can be got accurately after the
error corrected, a better result could be got. But the receive parameter and integer ambiguity parameter
have correlation, and can’t be separated, the receiver error includes integer ambiguity error, this makes
the observation equation have many results, so the receiver error could not be got using the carrier
phase measurement only, but the pseudo range can got the receiver error result directly, so the results
can be got using the formula (1) and the formula (2), but give pseudo range the litter weight for
reducing the influence of pseudo range measurement noise.

3. Example analysis
For analysis the precision of the carrier phase time transfer with broadcast ephemeris, IGS observation
data use for analyzing the time transfer precision, this select PTBB and CRO1 which are IGS satiation
have high precision frequency reference, and the interval is 30s. the relative results received using the
carrier phase time transfer with broadcast ephemeris and SPP separately, REFT is the reference time
of satiation. The precision of clock error result that from IGS production is 75ps, so take the IGS
production to the true value, but the reference of IGS and broadcast ephemeris have different time
reference which have some influence to the result. In fig.1 give the time error between IGS production
and PTBB-REFT result which use two different methods, in fig.1 give the time error between IGS
production and CRO1-REFT result which use different methods, SPP is the result of standard single
point positioning, CSPP is the result of carrier phase time transfer with broadcast ephemeris.
From Fig.1 shows that time synchronization results have a good consistency between PTBB-REFT and the IGS afterwards production, from Fig.2 shows that time synchronization results have a good consistency between CRO1-REFT and the IGS afterwards production. The result of SPP is discrete, and the carrier phase time transfer with broadcast ephemeris is stability, have a better consistency with IGS afterwards precision production.

For analyzing the precision of two methods, making difference between the clock error result and IGS afterwards precision production, the results are show in Fig.3 and Fig.4, the error statistics results is show in table1, the A unaccuracy results are show in table2.
Fig. 4, Table 1, Table 2 show that the method of carrier phase time transfer with broadcast ephemeris can improve the time synchronization precision, the precision of PTBB-REFT from 9.24 ns to 1.57 ns, the precision of CRO1-REFT from 8.11 ns to 1.22 ns, and the A unaccuracy of PTBB-REFT from 0.54 ns to 0.07 ns, the A unaccuracy of CRO1-REFT from 0.54 ns to 0.07 ns, so it is obvious that the frequency stability of time synchronization can be improved. The result of carrier phase time transfer with broadcast ephemeris is more stability relative to SPP, and the patterns of change is describe to the station receiver.

The time transfer result between the station PTBB and CRO1 is got by make difference single result between PTBB and CRO1 for analyzing the time transfer effect. Fig. 5 gives the time transfer result of PTBB-CRO1, Fig. 6 gives the time transfer result of PTBB-CRO1. Table 3 gives the precision statistics result of time transfer, table 4 gives the A unaccuracy of time transfer.

![Figure 5. PTBB-CRO1 link time synchronization result](image-url)
Figure 6. PTBB-CRO1 link time synchronization result

Table 3. The precision of two time transfer methods (ns)

| Method   | Mean  | STD   | RMS   |
|----------|-------|-------|-------|
| SPP      | -2.14 | 12.48 | 12.64 |
| CSPP     | -0.24 | 1.55  | 1.57  |

Table 4. The A unaccuracy of two time transfer (ns)

| Method   | SPP | CSPP |
|----------|-----|------|
| PTBB-CRO1| 0.73| 0.09 |

It is known that the time transfer precision of carrier phase time transfer with broadcast ephemeris is improved obviously from the Fig.5, Fig.6, Table3 and Table4, the time transfer precision of PTBB-CRO1 can get 1.57ns from 12.64ns, the A unaccuracy can get 0.09ns from 0.73ns.

In Fig.7 gives the frequency stability results of PTBB-CRO1 with two methods, the time interval is 300s. it is known that the frequency stability of two methods have a good consistence, the carrier phase time transfer with broadcast ephemeris can improve the frequency stability.

4. Conclusion
Some preliminary conclusions can be getten from the data analysis result in this paper: the real-time transfer could be realization with carrier phase time transfer with broadcast ephemeris, carrier phase time transfer with broadcast ephemeris can get rid of the reliance on IGS afterwards production and clock error production. The precision of time transfer can be improved relative to SPP. The carrier phase time transfer with broadcast ephemeris can improve the accuracy and frequency stability obviously, the precision could get 1-2ns from 10ns which relative to SPP. Carrier phase time transfer
with broadcast ephemeris is not need the external precision production, and can realization in receiver easily.

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