An Un-differenced Carrier Phase Time Transfer Method Between Stations

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Abstract. GNSS carrier phase time transfer use PPP technology generally, has become the satellite two-way time comparison (TWTFT) widely used high precision time comparison method, due to its simple equipment, high precision, the global time become the important means of backup TWTFT of lab. An un-differenced carrier phase time transfer method between stations is proposed. Using the relations between un-differenced observation equations which established through common view satellites, the results of the satellite clock offset and inter-station time transfer can be calculated jointly. It is not limited by the accuracy and real-time performance of the satellite clock. As long as there is enough total station between apparent satellite can gain standing time transfer as result, the precision clock difference from satellite product precision and real limit, time pass accuracy can reach the nanosecond level, good real-time, more suitable for real-time and high precision time transfer. Experimental results show that the time transfer accuracy of the proposed algorithm can reach sub-nanosecond magnitude, and it can be applied to high precision real-time time transfer.

1. Introduction

GNSS carrier phase time transfer use PPP technology generally, has become the satellite two-way time comparison (TWTFT) widely used high precision time comparison method, due to its simple equipment, high precision, the global time has become the important means of backup TWTFT of lab[1,2]. The PPP is single station operation, unable to effectively eliminate the time passed relevant error between standing over short distances, and the PPP need to use the IGS provides poor precision orbit and clock products, the lack of real time, its application mainly stay in post-processing model[3]. Satellite orbit changes due to gently can forecast, the IGS provides super quick forecast precision of orbit is 5 cm, basic can meet the demand of real-time Dagoberto (2010)[4], however, because of the satellite clock change is complicated and difficult to accurately forecast, make the low precision ultra fast clock difference product is only about 3 ns[5,6,7], far below the precision clock difference products, can achieve the effect of the result of the time passed a number of nanoseconds, and will extend linearly increase with time, the error can't satisfy the need of real time transmission[8,9,10].

Based on the deficiency of the PPP in the application, An un-differenced carrier phase time transfer method between stations is put forwarded, this method is compared with the traditional PPP algorithm for time transfer, do not need to use satellite precision clock difference product, without being limited by the clock difference interpolation and sampling rate; Depending on the time relay algorithm, compared with the traditional although precision clock difference don't need the product, but a slightly different processing methods, the traditional common depending on the time relay algorithm is through the station intercropping differential elimination the satellite clock error parameters, this
method is not eliminated by stand poor intercropping would satellite clock error, but the satellite clock error as unknown parameters online, via satellite were apparent to establish the connection between the two station observation equation and calculating the satellite clock difference between parameters and standing time passing results. Finally using WTZR, GRAZ, GOPE and BOR1 4 IGS stations such as actual data are analyzed, and the analysis results show that the algorithm of time transfer accuracy can reach the nanosecond level, can be applied in real-time and high precision time transfer.

2. The Traditional Model of PPP

The error equation based on GNSS carrier phase time transmission is as follows [4, 7]:

\[ v_{i,\phi}^{l} = \delta t_{k}^{l} - \delta t_{j} + \delta \rho_{k,\text{trop}} / c + \lambda \cdot N_{k}^{l} / c + \rho_{k}^{l} / c + \varepsilon_{i,\phi}^{l} - \lambda \cdot \Phi_{k}^{l} / c \] (1)

\[ v_{i,p}^{l} = \delta t_{k}^{l} - \delta t_{j} + \delta \rho_{k,\text{trop}} / c + \rho_{k}^{l} / c + \varepsilon_{i,p}^{l} - P_{k}^{l} / c \] (2)

Where, \( k \) is station number, \( j \) is satellite number, \( \delta t_{k}, \delta t_{j} \) are relative clock difference between the receiver and the satellite clock relative to the reference time, \( \delta \rho_{k,\text{trop}} \) is Tropospheric delay, \( N_{k}^{l} \) is fuzziness of the ionospheric combination, \( \Phi_{k}^{l}, P_{k}^{l} \) are respectively represents the phase and pseudo-distance combined observations, \( \varepsilon_{i,\phi}, \varepsilon_{i,p} \) are measurement error, \( \varepsilon_{i,\phi}, \varepsilon_{i,p} \) are the unmodeled error.

Through PPP calculation, the results of the clock difference can be obtained for the reference time of each station, and then the single station results of different stations will be reduced, and the reference time can be eliminated to realize the time transfer between stations.

3. A Difference Model Based on Satellite Clock Error

In order to overcome the PPP algorithm for IGS satellite precision clock difference products rely on, put forward the difference between a station GNSS carrier phase time transfer methods, this method via satellite were apparent to establish the connection between the different station observation equation, transfer time between satellite clock error and station real-time estimation results as unknown parameters.

The GNSS measurement is the time delay between the station and the satellite, and the equation is singular when satellite clock difference parameters and receiver clock parameters are got from formula (1) and formula (2), and the solution is infinite, the time transfer results which the station and satellite clock relative to the reference can be got when one reference clock is fixed. Where \( t \) station clock error is \( \delta t_{i} \), and put it as the reference clock, \( \delta \tilde{t}_{i}^{l} \) is the relative clock error which satellite \( j \) relative to the reference clock error.

\[ \delta \tilde{t}_{i}^{l} = \delta t_{j} - \delta t_{i} \] (3)

After selection reference station clock, the observation equation of station no longer contains the receiver clock difference parameters, only satellite clock error, the troposphere, and the fuzzy degree of parameters, satellite clock difference is between satellite clock and benchmark clock. The error observation equation of the station is:

\[ v_{i,\phi}^{l} = -\delta \tilde{t}_{i}^{l} + \delta \rho_{k,\text{trop}} / c + \lambda \cdot N_{k}^{l} / c + \rho_{k}^{l} / c + \varepsilon_{i,\phi}^{l} - \lambda \cdot \Phi_{k}^{l} / c \] (4)

\[ v_{i,p}^{l} = -\delta \tilde{t}_{i}^{l} + \delta \rho_{k,\text{trop}} / c + \rho_{k}^{l} / c + \varepsilon_{i,p}^{l} - P_{k}^{l} / c \] (5)

\( \delta \tilde{t}_{k} \) is the relative clock error which is the station \( k \) relative to reference clock.

\[ \delta \tilde{t}_{k} = \delta \tilde{t}_{l} - \delta t_{l} \] (6)

Where \( \delta \tilde{t}_{k} \) is the time transfer result between station \( k \) and station \( l \), the error equation of station \( k \) can be got in the followed formula.
\[ v_{k,s} = \delta t_k - \delta t_s + \delta \rho_{k,\text{zwp}} / c + \lambda \cdot N_s / c + \rho_s / c + \epsilon_{k,\Phi} - \lambda \cdot \Phi_s / c \]  
\[ v_{k,p} = \delta t_k - \delta t_p + \delta \rho_{k,\text{zwp}} / c + \rho_s / c + \epsilon_{k,p} - P_s / c \]  

It is exactly the same form relative to the tradition form, except that the meaning of the difference between the satellite clock and the receiver clock in the error equation is changed, which is relative to the relative clock of the reference clock.

Standing between the differential GNSS carrier phase time transfer algorithm is to use common view satellite the relationship established between each station observation error equation, the satellite clock error as unknown parameters with standing time transfer between real-time estimation results. This method is free from the dependence on the precision and the sampling rate of the clock. This method only need to use the information on the precise orbit can be sent as a result, direct access to stand between the satellite orbit changes due to gently can forecast, the IGS provides super quick forecast precision of orbit is 5 cm, in the real time transmission, can use the ultra fast forecast track for calculating.

4. Test result anlysis
In order to verify the effectiveness of the proposed method, here taking WTZR, GRAZ, GOPE and plant area network composed of four IGS reference station observation data analysis, select station WTZR clock as reference clock, at the same time calculating result time passed between the station and satellite clock relatively poor, observation data sampling interval is 30 s. Here IGS provides the post precision clock differential product as the reference value.

Figure. 1, Figure. 2 and Figure. 3 respectively show the time transfer results of GRAZ-WTZR, GOPE-WTZR and BOR-WTZR link time transfer results minus IGS net solution results. Figure. 4 shows the sequence of difference between GRAZ-WTZR, GOPE-WTZR and BOR-WTZR link time transfer results minus IGS net solution results.

Figure. 1, Figure. 2 and Figure. 3 show that the time transfer sequence of the obtained stations is consistent with the change trend of IGS network solution, and the results are basically the same, which is in good agreement with the IGS results. It can be seen from figure 4 and table 1 that the time transmission accuracy of different time links can reach 0.16ns to 0.42ns, which is basically equivalent to the traditional GNSS carrier phase time delivery precision.

The Table 1 give the time transfer precision result of GRAZ-WTZR, GOPE-WTZR, BOR1-WTZR.

![Figure 1. The test result and IGS result on link GRAZ-WTZR](image_url)
Figure 2. The test result and IGS result on link GOPE-WTZR

Figure 3. The test result and IGS result on link BOR1-WTZR

Figure 4. Time passes the result of the difference sequence
Table 1. The time transfer precision on difference link

| Link          | Mean | STD  | RMS  |
|---------------|------|------|------|
| GRAZ - WTZR   | -0.05| 0.15 | 0.16 |
| GOPE - WTZR   | 0.07 | 0.30 | 0.31 |
| BOR1 - WTZR   | -0.21| 0.37 | 0.42 |

5. Conclusion
The proposed standing between the differential GNSS carrier phase time transfer methods through total depending on the satellite station, the difference between the observed equation between the satellite clock error as unknown parameters and standing time estimate deliver results. As long as there is enough total station between apparent between satellite can gain standing time transfer as a result, the precision clock difference from satellite product precision and real time limit, time pass accuracy can reach the nanosecond level, good real-time, more suitable for real-time and high precision time transfer.

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