Common-View Time Transfer Experiment based on COMPASS-M1 Satellite

Fenglei WU
Graduate University
Chinese Academy of Sciences
Beijing, China
National Time Service Center
Chinese Academy of Sciences
Xi'an, China
Wufenglei_sino@sina.com.cn

Xuhai YANG, Xiaohui LI
National Time Service Center
Chinese Academy of Sciences
Xi'an, China

Wenhai JIAO, Xiaolin JIA
China Satellite Navigation Project Center
Beijing, China

Fen Cao, Le Sun
Graduate University
Chinese Academy of Sciences
Beijing, China

***Abstract*—The COMPASS Common-View time transfer experiment was done between National Time Service Center (NTSC) and Shanghai Observation (SHAO) via COMPASS-M1 satellite (MEO) in December in 2007 for the first time. NTSC is about 2000 km away from SHAO, and Cs atomic clock is equipped at each station. Our data processing method is as follows. The troposphere delay is calculated based on meteorological data, and the ionosphere delay is calculated based on IGS TEC Map. The satellite orbit obtained is about 10m accuracy, and then the clock difference between NTSC and SHAO is calculated with Common-View method. After that, the clock difference from Common-View is compared with that from Two-Way Satellite Time and Frequency Transfer (TWSTFT). The experiment result and analysis indicate that the accuracy of Common-View time transfer via COMPASS-M1 satellite is better than 10 nanoseconds.**

I. INTRODUCTION

Since GPS CV was put forward the first time by ALLAN in 1980, the technology and its applications have been developed continually. GPS Common-View(GPS CV) and Two-way Satellite Time and Frequency Transfer(TWSTFT) are mainly methods used for international time comparing to realize high-precision time comparing among various labs and calculating TAI and UTC.

Now, COMPASS navigation system is being developed by China, which is planned to have a constellation of 5 geostationary orbit (GEO) satellites and 30 medium Earth orbit (MEO) satellites. It will offer complete coverage of the globe. There will be two levels of service provided; free service for those in China, and licensed service for the military. The free service will have a 10 meter location-tracking accuracy, and synchronize clocks with an accuracy of 50 ns, and measure speeds within 0.2 m/s. The licensed service will be more accurate than the free service, can be used for communication, and will supply information about the system status for the users.

A MEO test satellite of COMPASS satellite navigation system was launched in 2007. We set several test-tracking stations in China, which is similar to the station used by IGS system in function, but their main observation target is the COMPASS satellite. We can calculate the satellite orbit using the test-tracking stations. So we developed Common-View time transfer experiment with the pseudo-range data of the tracking stations.

About the experiment, we computed the orbit of the MEO test satellite firstly; and then based on this orbit we developed MEO test satellite Common-View time transfer experiment with the pseudo-range data of Lintong station and Shanghai station. After that, we compared the results with those of TWSTFT and analyze them.

II. COMPASS SATELLITE ORBIT DETERMINATION

We used five tracking stations in China to observe the MEO satellite from March 16th to March 18th in 2008. Each station was equipped with COMPASS receivers and high performance atomic clock. Two kinds of observation data were collected. They were pseudo-code ranging data and carrier phase observation data. We got the precise orbit determination result based on pseudo-code data smoothed by carrier phase observation data. The residual (O-C) of orbit determination can reach meter-level. The residual data of Lintong station are shown in Figure 1.

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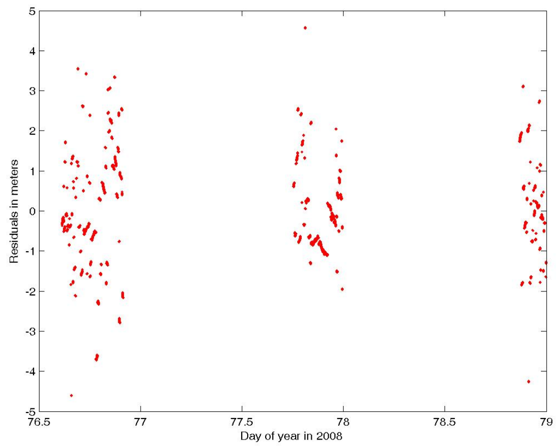

Figure 1. Orbit determination residuals (O-C) of Lintong Station

III. COMPASS Common-View Time Transfer Method

Common-View time transfer experiment was developed using pseudo-code ranging data of Lintong and Shanghai station on the basis of precise orbit elements of the satellite COMPASS MEO-1.

A. Compute the time transfer result of easch station.

That is to say, compute the clock error between Lintong station and the satellite firstly. And then compute that between Shanghai station and the satellite.

First, compute the clock error ΔT_1 between Lintong station and the satellite.

The pseudo-range data contains not only the geometric distance, but also the clock error, the troposphere delay, the ionosphere delay and the Sagnac effect.

Pseudo-range data = Geometric distance + Clock error + Troposphere delay + Ionosphere delay + Sagnac effect.

So we can get the clock error ΔT_1.

ΔT_1 = Pseudo-range data – Geometric distance – (Troposphere delay + Ionosphere delay) – Sagnac effect. (1)

To make the Common-View time transfer experiment easier, we don not subtract the ionosphere delay, but eliminate its effect by making difference.

Clock error ΔT_1 = Pseudo-range data – Geometric distance – Troposphere delay – Sagnac effect. (2)

Each components of equation (2) are described details as follows.

1) Geometric distance

It can be calculated by the satellite ephemeris, and the known position of the station, using the distance between two points formula.

2) Sagnac effect

$$\text{Sagnac} = -2\omega_E A_p / c^2 . \tag{3}$$

The sign: If the propagated direction of the electromagnetic wave is the same as the direction of the Earth's rotation, the value is positive.

In the equation (3), ω_E is the Earth's rotation angular velocity.

$$\omega_E = 7292115 * 10^{-11} \text{ rad/s.} \tag{4}$$

Ap is the projected area of the triangle consisted of the Earth station, the satellite and the center of the Earth to the equatorial plane

3) Troposphere delay

The troposphere delay in the direction of the local zenith can be calculated by weather station parameters, such as temperature, moderation and vapor pressure.

$$\Delta s = \Delta s_d + \Delta s_w = \frac{K_d}{\sin(E^2 + 6.25)^{1/2}} + \frac{K_w}{\sin(E^2 + 2.25)^{1/2}}$$

$$K_d = 155.2 \times 10^{-7} \times \frac{P_s}{T_s} \times (h_d - h_s)$$

$$K_w = 155.2 \times 10^{-7} \times \frac{4810}{T_s^{\,2}} \times e_s \times (h_w - h_s)$$

$$h_d = 40136 + 148.72 \times (T_s - 273.16)$$

$$h_w = 11000$$

Δs : Estimation of troposphere refraction delay

h_d : Height of troposphere upper edge

h_w : Height of troposphere lower edge

P_s : Atmosphere pressure of the observation station

T_s : Temperature of the observation station

e_s : Vapour pressure of the observation station

E : Station elevation to the Satellite

h_s : Altitude of the observation station

According to the angle between the satellite and the ground station, we can calculate the additional delay of the troposphere in the direction from the satellite to the ground.

The clock error ΔT_2 between Shanghai station and the satellite can be calculated by the same method.

B. Data processing of the Common-View time transfer experiment

We can get the clock error between the two stations by making difference between the two single time transfer results. So the result of the Common-View time transfer is $\Delta T_1 - \Delta T_2$.

IV. Results and Analyses

There is a C band TWSTFT link between Lintong station and Shanghai station, which can achieve time synchronization of the two stations on a subnanosecond level accuracy. What's more, the TWSTFT system and the COMPASS receiver of each station share the same atomic clock. Therefore, the accuracy of this Common-View time transfer experiment can be evaluated by comparing the result of it with that of TWSTFT, which has a higher accuracy.

The result of Common-View time transfer, the result of TWSTFT and their comparisons are as follows using the data from March,16th to March,18th in 2008. The X axis of the following figure2, figure3 and figure4 represents the time of each day in the form of seconds. The Y axis of each figure represents the clock error.

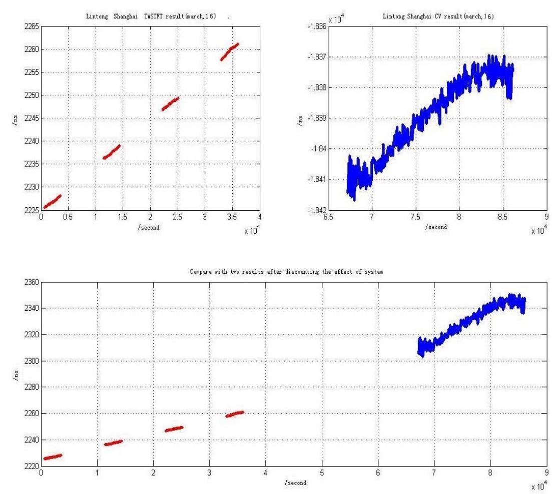

Figure 2. Comparing results of CV and TWSTFT on March 16th

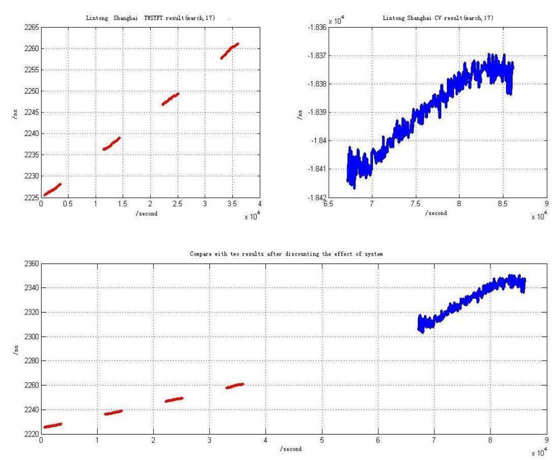

Figure 3. Comparing results of CV and TWSTFT on March 17th

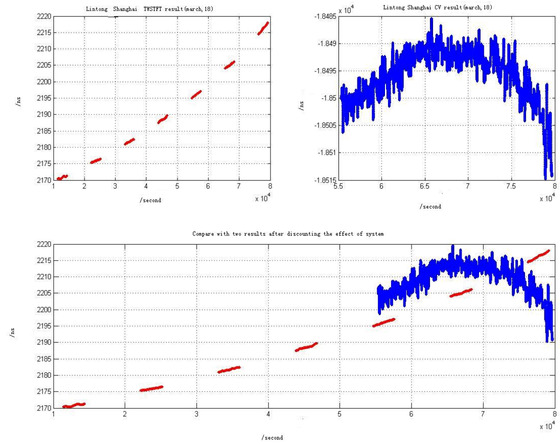

Figure 4. Comparing results of CV and TWSTFT on March 17th

The working frequency was C band when we performed TWSTFT with the commercial telecommunication satellite SINOSAT-1. When we were observing MEO satellite, the obstructed angle for the antenna of the Earth station is 5 degrees. Biases of receivers were subtracted in the Common-View time transfer system when we performed data-processing. We only provided the processing result per second without any smoothing, which did not strictly adopt the post-data-processing method recommended by CGGTS. The noise of COMPASS M1 Common-View result is a litter bigger than that of TWSTFT..

A big difference exists at the starting time or the ending time of the Common-View time transfer compared with TWSTFT due to the low observation elevation.

Only one or two arcs could be observed everyday because one MEO satellite was available in this Common-View time transfer experiment, while multi-day continuous observation to several satellites could be performed in GPS Common-View system.

The accuracy (RMS) of the Common-View time transfer is better than 10ns compared with TWSTFT as a standard after data-processing of this experiment.

Because of limited working time, there are some factors without being considered, and some detailed data-processing work need to do in order to improve the accuracy of Common-View.

Acknowledgment

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