Performance of Time Transfer Using Compass Satellite

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Abstract—**The impact of satellite position error on satellite common-view time transfer was analyzed. The impact varies depending on the elevation of users and the baseline distance between two users. Some extents of the impact were figured out for several elevations and different baseline. Furthermore, actual results from several common-view time transfer links in mainland of China via compass satellite were given.**

I. INTRODUCTION

In a satellite common-view time transfer, two users, A and B, simultaneously receive a one-way time signal from the same satellite, and each user records the difference between its clock and the satellite time. After that, by exchanging the data and performing a subtraction, the time difference between the two users is obtained [1, 2]. The method takes advantage of the common mode cancellation of the satellite clock in determining time difference. The accuracy of this method is approaching several nanoseconds [3], therefore the impact of systematic errors on accuracy must be studied in detail. An important factor affecting accuracy is the satellite position error.

II. IMPACT OF SATELLITE POSITION ERROR ON TIME TRANSFER

If the recorded times of users A and B are denoted by T_A and T_B, we have:

$$T_A = \frac{1}{C}\sqrt{(x-x_A)^2+(y-y_A)^2+(z-z_A)^2} + \text{satellite time} - \text{clock A} \quad (1)$$

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$$T_B = \frac{1}{C}\sqrt{(x-x_B)^2+(y-y_B)^2+(z-z_B)^2} + \text{satellite time} - \text{clock B} \quad (2)$$

where (x, y, z) is the satellite coordinate, (x_A, y_A, z_A) and (x_B, y_B, z_B) are the coordinates of users A and B, and C is the speed of light.
From (1) and (2), we obtain

$$\Delta AB = \text{clock A} - \text{clock B} = \frac{1}{C}\left(\sqrt{(x-x_A)^2+(y-y_A)^2+(z-z_A)^2} - \sqrt{(x-x_B)^2+(y-y_B)^2+(z-z_B)^2}\right) + (T_B - T_A) \quad (3)$$

Using knowledge of the user and satellite positions, we can compute the distance between the satellite and each user. However, the satellite position error causes error in the time transfer.

If the satellite position error is denoted as (*dx, dy, dx*), we can obtain a relation between the satellite position error and the error of the time transfer by using the first order differential of (3):

$$d\Delta AB = (l_A - l_B)\frac{dx}{C} + (m_A - m_B)\frac{dy}{C} + (n_A - n_B)\frac{dz}{C} \quad (4)$$

where

$$l_A = \frac{x-x_A}{\sqrt{(x-x_A)^2+(y-y_A)^2+(z-z_A)^2}},$$

$$m_A = \frac{y-y_A}{\sqrt{(x-x_A)^2+(y-y_A)^2+(z-z_A)^2}},$$

$$n_A = \frac{z - z_A}{\sqrt{(x-x_A)^2 + (y-y_A)^2 + (z-z_A)^2}},$$

$$l_B = \frac{x - x_B}{\sqrt{(x-x_B)^2 + (y-y_B)^2 + (z-z_B)^2}},$$

$$m_B = \frac{y - y_B}{\sqrt{(x-x_B)^2 + (y-y_B)^2 + (z-z_B)^2}},$$

$$n_B = \frac{z - z_B}{\sqrt{(x-x_B)^2 + (y-y_B)^2 + (z-z_B)^2}}.$$

From (4), we easily obtain:

$$|d\Delta AB| \le \sqrt{(l_A - l_B)^2 + (m_A - m_B)^2 + (n_A - n_B)^2} \cdot \frac{\sqrt{(dx)^2 + (dy)^2 + (dz)^2}}{C} \tag{5}$$

Making:

$$\text{KAB} = \sqrt{(l_A - l_B)^2 + (m_A - m_B)^2 + (n_A - n_B)^2}$$

$$ds = \sqrt{(dx)^2 + (dy)^2 + (dz)^2}$$

KAB is an impact factor that shows the extent of the impact of the satellite position error (*ds*) on the time transfer error ($d\Delta AB$).

Note that (l_A, m_A, n_A) is the directional cosine in the direction from user A to the satellite, and (l_B, m_B, n_B) is the directional cosine in the direction from user B to the satellite. Based on the baseline distance and the elevations of the two users, the two directional cosines can be computed through elementary mathematics. Thus, KAB can be obtained.

Since the effects of the troposphere and ionosphere on the time transfer are also considered in practice, the elevation should not be too small and the baseline should not be too long. We thus consider the case in which the elevation is greater than 15° and the baseline is less than 5000 km.

(a) Equal elevations

When the elevations of two users are the same, we compute KAB using different baselines. Typical results are shown in Fig. 1. As the baseline becomes longer, KAB rises. In fact, KAB is approximately directly proportional to the baseline length. Moreover, there is not a big difference between KAB with a large elevation and that with a small elevation. When the baseline is less than 2000 km, KAB is less than 0.1; this means that the time transfer error is at least one order lower than the satellite position error. When the baseline is 5000 km, the KAB is about 0.22.

(b) Different elevations

When the elevations of two users are different, we compute KAB for baselines ranging from 1000 km to 5000 km. Typical results are shown in Fig. 2. When the baseline is less than about 2500 km, the smaller the difference between two elevations is, the smaller the KAB is. For baselines from about 2500 km to 5000 km, there is not a big difference in KAB between large and small differences in elevation. In addition, when the baseline is about 3000 km or longer, KAB increases with baseline length. The largest KAB is less than 0.25, so the time transfer error is no more than a quarter of the satellite position error.

(c) Actual results

KAB has been computed for several common-view time transfer links in mainland of China via compass satellite; i.e., Beijing-Wuhan, Xian-Changchun, Beijing-Kashi, and Shanghai-Urumqi links (there are time stations in these cities). These baselines are about 1083 Km, 1919 km, 2665 km and 3455 km. Typical results are shown in Fig. 3, which shows the relation between elevation and KAB when one of the two elevations was 45°. For the 4 links, when the difference between two elevations was less than 10°, the KAB was stable. For Beijing-Kashi and Shanghai-Urumqi links, the elevation difference almost not affect KAB. These actual results are consistent with the results of section (b).

III. CONCLUSIONS

An important factor affecting the accuracy of satellite common-view time transfer is the satellite position error, and the extent of this impact depends on the elevation of users and the baseline distance between two users. When the two elevations are the same, a longer baseline increases the impact of the satellite position error on the time transfer. In fact, the impact is approximately directly proportional to the baseline length. However, the elevation itself has little impact on the time transfer error. When the baseline was less than 2000 km, the impact factor was less then 0.1, showing that the time transfer error was at least one order lower than the satellite position error. When the two elevations differed, a smaller difference in elevation led to a smaller impact for

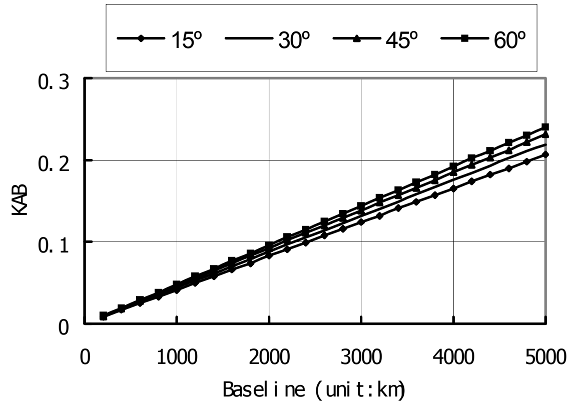

Fig. 1 Relation between baseline and KAB at equal elevations

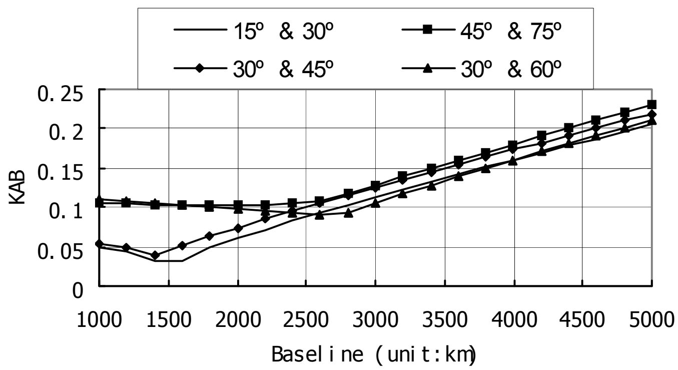

Fig. 2 Relation between the baseline and KAB at different elevations

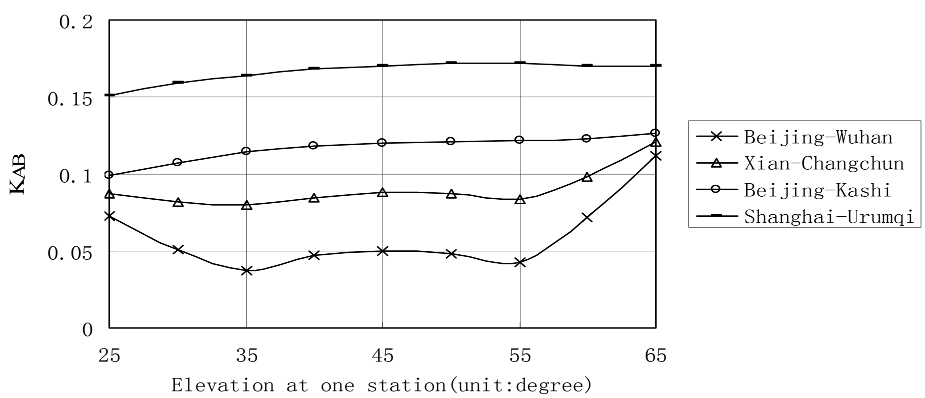

Fig. 3 Relation between elevation and KAB for several links (one of the two elevations is 45^{o})

baselines less than 2500 km. For longer baselines, there was little difference in the effect of large or small elevation differences. In addition, we found that for baselines longer than 3000 km, a longer baseline led to a larger impact factor. Whatever elevations were used, the impact factor was less than 0.25 for a baseline less than 5000 km, meaning that the time transfer error was no more than a quarter of the satellite position error. Results from actual links were consistent with these findings.

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