

**PHYSICAL INSTRUMENTS FOR ECOLOGY,
MEDICINE, AND BIOLOGY**

**TIME TRANSFER STABILITY USING DIFFERENT
MULTIPATH MITIGATION TECHNIQUES**

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Multipath reflections degrade considerably the precision of positioning and timing services introduced by the Global Navigation Satellite Systems (GNSS). Various techniques were introduced to mitigate the effect of multipath errors. One of the most commonly used techniques is weighting the received data according to the elevation angle of the observed satellite. Another technique was proposed by the author in which the optimum elevation mask (OEM) concept was introduced. In this paper, the author compares the efficiency of both the weighting and the OEM techniques. Moreover, the author proposes a mix between the two techniques to be more efficient than using either of the two techniques separately.

Keywords: Multipath, satellite elevation, weighted elevation, Time transfer, precise timing.

1. INTRODUCTION

GNSS became irreplaceable in hundreds of applications. Maritime, aviation, space, agriculture, urban development, infrastructure, safety-critical, and scientific applications are examples of these applications [1]. So, the market of earth observation and GNSSs is huge. In 2021, the outcome from using GNSS devices and services exceeded 2×10^{11} Euro. During 10 years, it is expected that this outcome will exceed double the number achieved at 2021. Hence, the world will need about 10^{10} GNSS receivers after about six years [2].

All the GNSS applications in all sectors are mainly based on Positioning, Navigation, or Timing (PNT) services. So, the research for improving the quality of the PNT services is essential and becomes mandatory if we target precise services.

Positioning and timing are both linked in the basic ranging equation in any GNSS receiver. This means that an improvement in quality of timing leads to an improvement in quality of positioning and vice versa. So, in the applications that need precise timing we use a stationary

receiver that has a very well-known position. On the other hand, in the applications that need precise positioning, we use receivers equipped with precise frequency sources [3, 4].

One of the troublesome phenomena that affect the stability of both positioning and timing services is the multipath reflections. This phenomenon degrades the precision of determining the transmission time delay between the transmitter and the receiver. Since this time delay is a parameter in the same ranging equation of any GNSS receiver, both positioning and timing are affected by multipath reflections.

A lot of multipath mitigation techniques have been introduced through either the hardware of the GNSS receiver or processing the received data. The hardware techniques are expensive and affect mostly large delays due to reflections from far objects or multiple reflections on near objects [5–7]. The processing of the received data for mitigating multipath errors is cheap and can be done either in the real-time mode or in the post processing modes [8, 9].

One of the famous processing techniques used for mitigating multipath errors is weighting the received data according to the elevation angle of the observed satellite [10–12]. The optimum elevation mask (OEM) is another technique proposed by the author [13]. In the OEM technique, we apply different elevation masks on the observed satellites and the optimum elevation mask is the one at which we got the best stability for the processed data.

In this paper, the author compares the weighting and the OEM techniques and their efficiency in improving the stability of timing service. Moreover, the author proved that mixing the two techniques gave better timing stability than applying either of them individually.

2. THE WEIGHTED DATA TECHNIQUE VERSUS THE OPTIMUM ELEVATION MASK TECHNIQUE

In general, multipath errors cannot be modeled because they depend on dynamic parameters such as the reflection coefficient of the ground under the receiver's antenna and the movement of the satellite vehicle. The reflection coefficient of the ground under the receiver's antenna is varying depending on the material covering it (dry material, water, snow etc.). The movement of the satellite vehicle makes it see the receiver through different windows. Additionally, changing the elevation angle of the satellite during its movement in the sky was considered a very effective parameter that affect multipath errors [5].

In the weighted technique, the received data is multiplied by a weight proportional to the elevation of the observed satellite. Data received from a high elevation satellite are considered of higher quality than those received from low elevation satellite. The elevation-weight relation is calculated according to the following equation [1]:

$$W_i = \sin^2 E_i ,$$

where W_i is the weight given to the data received from an observed satellite having an elevation angle E_i . This weight can be applied on either timing or positioning data for mitigating the effect of multipath errors.

The author studied the effect of applying different elevation masks on the stability of the timing data received from GPS and Galileo satellites [13]. It was found that using a fixed elevation mask can only improve a part of the data. Moreover, the differences between GPS and Galileo make their response to the multipath reflections not similar even if the two receivers were connected to the same antenna. Based on these observations, the concept of the OEM was introduced. According to this concept, we apply different elevation masks to the received signal and then, for each mask, we calculate the daily stability of the timing data provided that the number of remained data points after applying the mask is greater than 10. The elevation mask at which the best daily stability is achieved is the OEM.

In the following sections, we will apply both the weighted and the OEM techniques, individually, on the timing data of both GPS and Galileo, then we will mix the two techniques to see the effect on both GPS and Galileo.

The mixed technique will not be applied to GLONASS because its time transfer stability is significantly worse than that of GPS and Galileo. Furthermore, GLONASS lacks an approved, standard procedure for calibrating the internal delay of its receivers. Consequently, GLONASS is not yet ready for inclusion in the time transfer network [10].

3. EFFECTIVENESS OF WEIGHTING AND OEM TECHNIQUES ON IMPROVING THE TIME TRANSFER STABILITY OF GPS AND GALILEO

To compare the effect of applying the weighting and the OEM techniques on improving the stability of the timing data, we applied the two techniques on real timing data that were generated from a GPS receiver hosted by the National Metrology Institute of America (National Institute of Standards and Technology (NIST)) and a Galileo receiver hosted by the National Metrology Institute of Germany (Physikalisch-technische Bundesanstalt (PTB)). The two timing receivers have the same model, which is POLARX5TR. The ID of the receiver of NIST is NISG while the ID of the receiver of PTB is PT13. The timing data were generated during the period from MJD 59804 to MJD 59887 (84 days).

Both of the two techniques were applied on all the observed satellites of GPS and Galileo, then the daily time transfer stability was calculated. For every satellite, we calculated the number of days at which one of the two techniques could improve the timing stability more than the other. Fig.

1 shows the percentage of days at which every technique was better than the other in improving the stability of time transfer using GPS.

Fig. 1

Also, there was a discernable difference between GPS satellites. For example, G22 and G11 are having very different responses for the two techniques. Applying the weighting technique to G22 was more effective than applying the OEM technique for improving the time transfer stability of 80 days from a total of 84 observed days. For G11, applying the OEM technique was more effective than applying the weighting technique for improving the time transfer stability of 83 days from a total of 84 observed days.

Figure 2 shows the results of applying the same analysis on all the visible Galileo satellites. It is clear that the OEM technique was more effective than the weighting technique for a percentage exceeding 50% and being less than 75% of the total number of the observed days. Moreover, Fig. 2 shows that there are no large differences between Galileo satellites in their responses to both techniques. It was proven earlier in Ref. [10] that Galileo satellites have similar performance in the long-term time transfer stability (30 days) and Fig. 2 shows that this fact is also applicable for the daily time transfer stability when applying two different techniques for improving the stability of time transfer.

Fig. 2, 3

We noticed that the weighting technique may degrade the time transfer stability on some days, while the OEM technique never degraded the time transfer stability. For example, Fig. 3 shows the time transfer instability of G05 for the raw timing data, after applying the weighting technique and the OEM technique. This result is justified by the findings shown in Fig. 1 in Ref. [10], which shows that the time transfer stability varies among GPS satellites but remains consistent for Galileo satellites.

In the next section, we will mix the weighting and the OEM techniques and apply the mixed technique on GPS and Galileo satellites.

4. MIXING THE WEIGHTED AND THE OEM TECHNIQUES

In the mixed technique, we apply different elevation masks and calculate the daily time transfer stability, then we apply the weighting technique and calculate the daily stability. We select the best achieved stability from both techniques such that the number of data points used in calculating the standard deviation is greater than or equal to 10. In other words, when we apply five elevation masks, we can calculate the daily time transfer stability at each mask. When we apply the weighting technique, we can also calculate the daily stability. Then, we select the best stability achieved from the six calculated values provided that the number of data points used in calculating the standard deviation is not less than 10. This mixed procedure was applied on G22 and G11 satellites. Fig. 4 shows the daily time transfer instability of G22. It is clear that the results of the mixed technique are

Fig. 4

almost coincident to the results of the weighting technique. Fig. 5 shows the daily time transfer instability of G11. It is clear that the results of the mixed technique are coincident to the results of the OEM technique. Fig. 6 shows applying the mixed technique on one of Galileo satellites, E07. It is shown that the mixed technique selects the best stability calculated by either of the weighting or the OEM techniques.

Fig. 5, 6

5. CONCLUSION

Multipath reflections are troublesome phenomena that induce errors in both positioning and timing services introduced by GNSSs. It had been settled for a long time that the amount of these errors is inversely proportional to the satellite elevation angle. One of the proposed solutions to mitigate multipath errors was multiplying the timing or positioning data by a weight that is directly linked to the elevation angle of the observed satellite. In this paper, it was proven that the weighting technique is not effective all the time in improving the stability of time transfer using GPS and Galileo. The weighting technique may degrade the time transfer stability on some days for unknown reasons. There were large discrepancies between GPS satellites when applying the weighting technique, but this was not the case for Galileo satellites due to the differences in time transfer stability between GPS satellites and the consistency between Galileo satellites.

The OEM technique was more effective than the weighting technique in improving the stability of time transfer using all Galileo satellites, but it was less effective than the weighting technique for a few GPS satellites. Moreover, the OEM technique never degraded the time transfer stability for GPS and Galileo.

The author proposed a mix between the weighting technique and the OEM technique to get the benefits of both of them. The concept of the mixed technique is based on applying both of the two techniques and the technique that succeeds in improving the time transfer stability is the approved one. The mixed technique was more efficient than either of the two techniques in improving the daily timing stability of all the GPS and Galileo satellites.

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FIGURE CAPTIONS

- Fig. 1.** Percentage of days at which one of the two techniques was better than the other in improving the stability of time transfer using GPS.
- Fig. 2.** Percentage of days at which one of the two techniques was better than the other in improving the stability of time transfer using Galileo.
- Fig. 3.** The time transfer stability of G05 (blue line is the instability of the raw timing data, orange line is the instability after applying the weighting technique, and black line is the instability after applying the OEM technique).
- Fig. 4.** The daily time transfer instability of G22 satellite (blue line is the instability of the raw timing data, orange line is the instability after applying the weighting technique, black line is the instability after applying the OEM technique, and red line is the instability after applying the mixed technique).
- Fig. 5.** The daily time transfer instability of G11 satellite (the same color code as in Fig. 4).
- Fig. 6.** The daily time transfer instability of E07 satellite (the same color code as in Fig. 4).

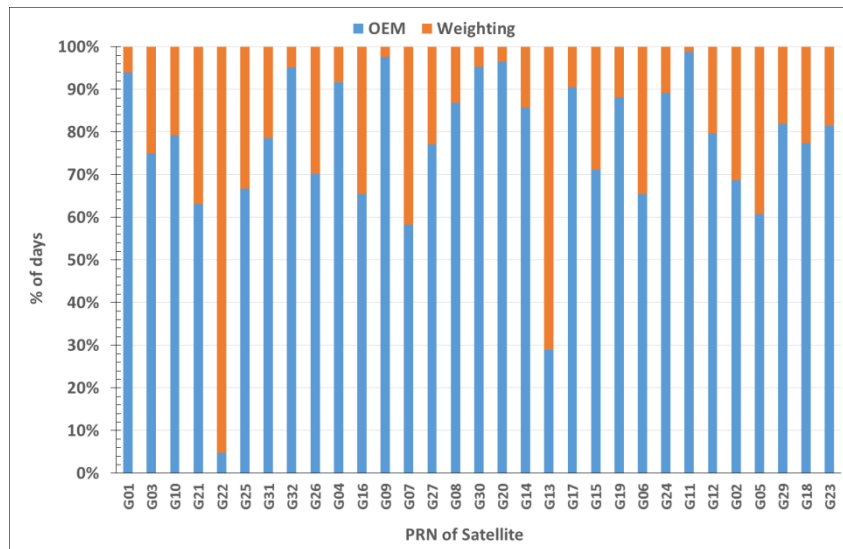


Fig. 1.

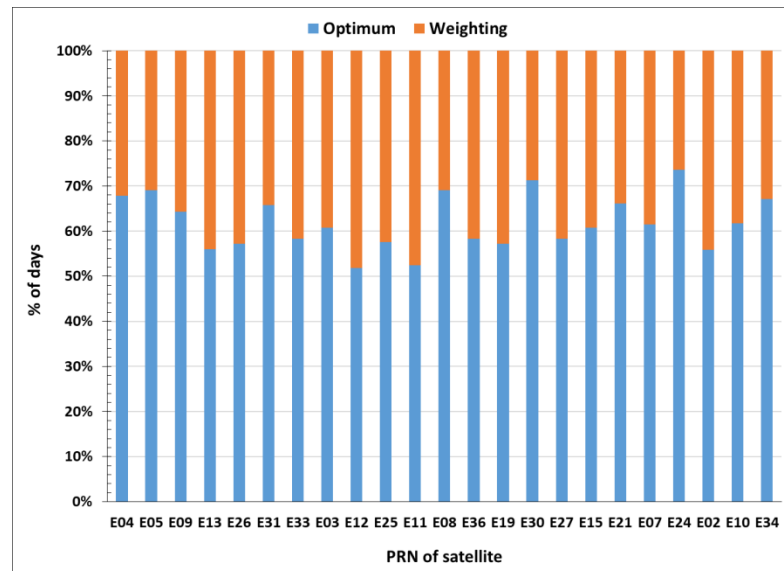


Fig. 2.

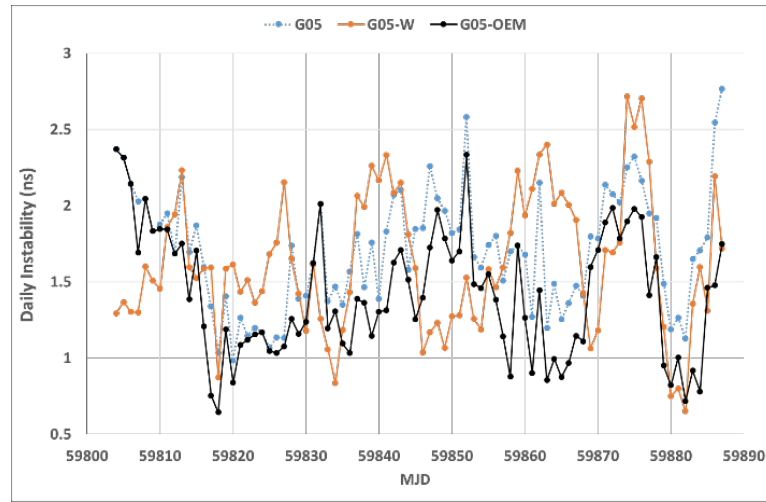


Fig. 3.

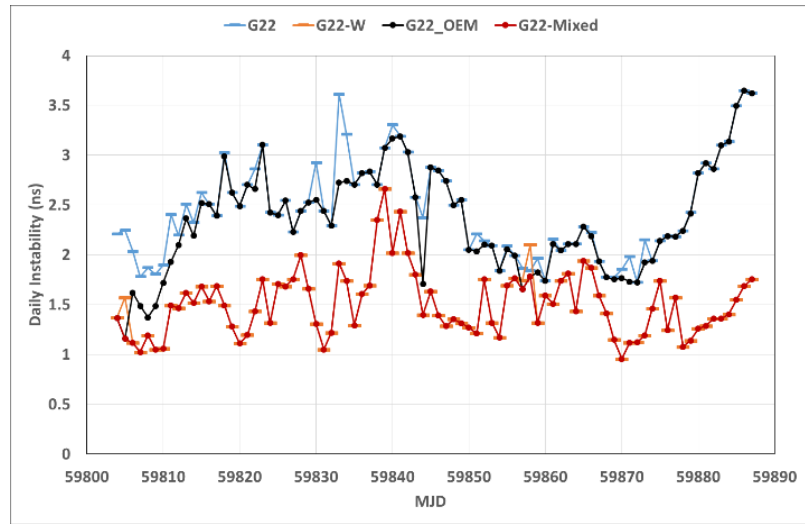


Fig. 4.

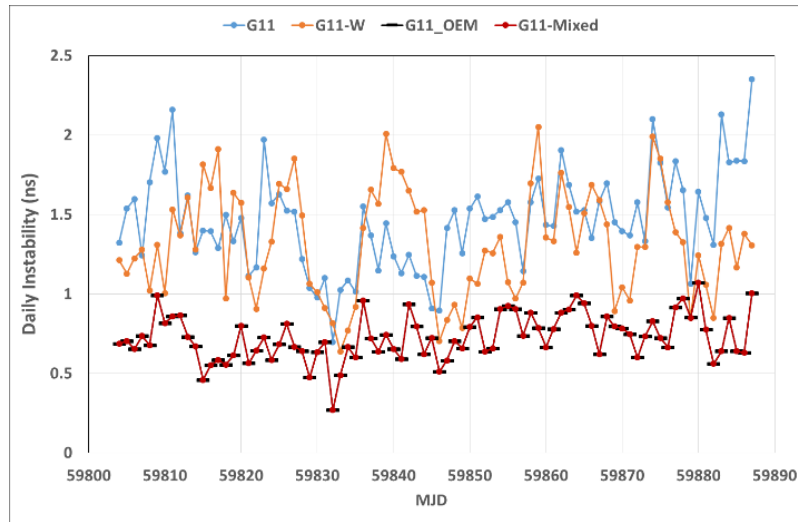


Fig. 5.

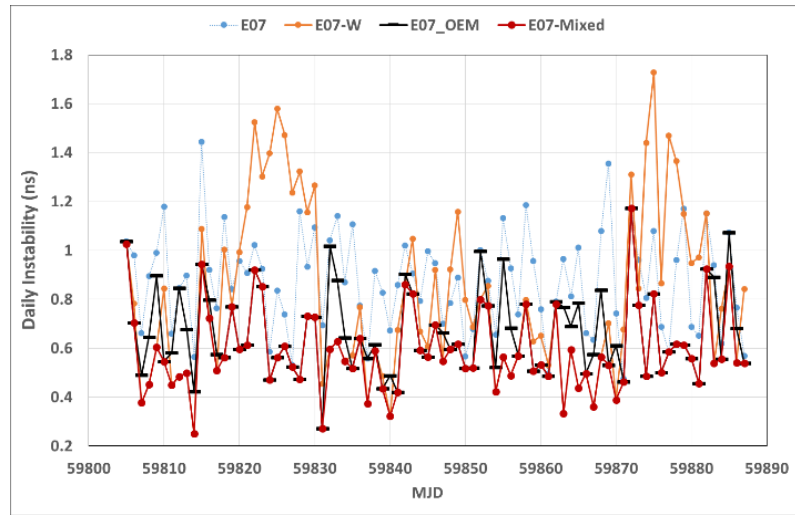


Fig. 6.

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