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GNSS geodetic techniques for time and frequency transfer applications ☆

François Lahaye [a], Giancarlo Cerretto [b,*], Patrizia Tavella [b]

[a] Natural Resources Canada (NRCan), 615 Booth str., Ottawa, ON, K1A 0E9, Canada
[b] Istituto Nazionale di Ricerca Metrologica (INRIM), Strada delle Cacce 91, 10135 Torino, Italy

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Abstract

We performed an initial analysis of the pseudorange data of the GIOVE-B satellite, one of the two experimental Galileo satellites currently in operation, for time transfer.[1] For this specific aim, software was developed to process the GIOVE-B raw pseudoranges and broadcast navigation messages collected by the Galileo Experimental Sensor Stations (GESS) tracking network, yielding station clock phase errors with respect to the Experimental Galileo System Time (EGST). The software also allows processing the Global Positioning System (GPS) P1 and P2 pseudorange data with broadcast navigation message collected at the same stations to obtain the station clock phase errors with respect to the GPS system time (GPST). Differencing these solutions between stations provides two independent means of GNSS time transfer. We compared these time transfer results with Precise Point Positioning (PPP) method applied to GPS data in combined carrier-phase and pseudorange mode as well as in pseudorange-only mode to show their relative merits. The PPP solutions in combined carrier-phase and pseudorange mode showed the least instability of the methods tested herein at all scales, at few parts in 10^{15} at 1 day for the stations processed, following a tau$^{-1/2}$ interval dependency. Conversely, the PPP solutions in pseudorange-only mode are an order of magnitude worst (few parts in 10^{14} at 1 day for the stations processed) following a tau^{-1} power-law, but slightly better than the single-satellite raw GPS time transfer solutions obtained using the developed software, since the PPP least-squares solution effectively averages the pseudorange noise. The pseudorange noise levels estimated from PPP pseudorange residuals and from clock solution comparisons are largely consistent, providing a validation of our software operation. The raw GIOVE-B time transfer, as implemented in this work, proves to be slightly better than single-satellite raw GPS satellite time transfer, at least in the medium term. However, one of the processed stations shows a combined GPS P1 and P2 pseudorange noise level at 2 m, a factor 2 worst than usually seen for geodetic receivers, so the GPS time transfer results may not be at their best for the cases processed. Over the short term, the GPS single-satellite time transfer instability outperforms the GIOVE-B by an order of magnitude at 1 s interval, which would be due to the different characteristics of the tracking loop filters for GPS P1 and P2 on one hand and the GIOVE-B signals on the other. Even at this preliminary stage and using an experimental satellite system, results show that the GIOVE-B (and hence Galileo) signals offer interesting perspectives for high precision time transfer between metrological laboratories.

Keywords: GNSS; GPS; Galileo; GIOVE; Time transfer; Time scales

1. Introduction

Today, an increasing number of users need high-quality Global Navigation Satellite System (GNSS) products, such as precise satellite orbit and clock estimates, accurate receiver coordinates or tropospheric delays for their applications (e.g., GNSS augmentation services, atmospheric and space weather services, etc.). Timing applications are

* Corresponding author.
E-mail addresses: Francois.Lahaye@nrcan-rncan.gc.ca (F. Lahaye), g.cerretto@inrim.it (G. Cerretto).
[1] The time transfer technique specified herein does not refer to the definition of Galileo Common View as set up by the European Space Agency, the Royal Observatory of Belgium and Timing Expert, nor the Common View GPS standard practice for BIPM.

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no exception to this trend. The timing community was one of the early adopters of GNSS for the purpose of time transfer, using the United States Global Positioning System (GPS) early in its development stage. With the re-energized Russian GNSS GLONASS program and the development of the European GNSS Galileo, the future of GNSS time transfer seems bright.

As part of the development of Galileo, two experimental satellites have been launched since 2005, namely GIOVE A and GIOVE B, together with the deployment of a globally distributed network of Galileo Experimental Sensor Stations (GESS), supported by the European Space Agency (ESA). One GESS is installed at the Time and Frequency Laboratory of the Istituto Nazionale di Ricerca Metrologica (INRIM) and is connected to an Active Hydrogen Maser, which is acting as time reference against which all the system clocks are evaluated, by processing all the pseudorange measures generated by the GESS network within an Orbit Determination and Time Synchronization (ODTS) algorithm. These orbital and clock parameters are then used to determine predictions that are uploaded on the satellites in the form of broadcast messages to be transmitted to users.

In this frame, INRIM and Natural Resources Canada (NRCan) undertook a preliminary study to assess the data of the GIOVE-B satellite for time transfer,[2] comparing against what can be achieved using GPS satellites in a similar algorithm. Also the higher precision geodetic time transfer technique, Precise Point Positioning (Zumberge et al., 1997; Kouba and Héroux, 2001), was used as benchmark in the evaluation of raw GIOVE-B and GPS time transfer results.

After briefly reviewing the importance of GNSS for time transfer applications, the methodologies and the results related to the different methods addressed in the present work will be presented, considering them as a starting point of what could be most likely the future evolution of time transfer with Galileo.

2. GNSS time transfer

2.1. International timekeeping

The Bureau International de Poids et de Mesures (BIPM) has the important task to compute and distribute the International Atomic Time (TAI) timescale, that is obtained using data from more than 200 clocks distributed around the world (Petit, 2003). TAI is kept as close as possible to the SI second using the information coming from the Primary Frequency Standards (PFS) located in a reduced number of National Metrology Institutes (NMI). Conversely, the level of instability of the TAI time scale is controlled by properly weighting the data from the contributing atomic clocks. Due to the atomic definition of the SI second and the deceleration of Earth rotation, TAI is not suitable for public time coordination. In order to overcome to this aspect, BIPM generates another time scale – UTC – that is equivalent to TAI, but with the addition of the so called "leap seconds" as necessary to ensure that the Sun crosses the Greenwich meridian at noon UTC to within 0.9 s when averaged over a year. UTC is computed and made available every month by the BIPM through its Circular T and is the reference time scale for the worldwide time coordination, providing the basis for the legal time in different countries. UTC (as well as TAI) being a "paper" time scale, a local and physical realization of the time scale must be generated within each country for practical applications. This task is performed by time and frequency laboratories at NMI(s) and the resulting time scales are called UTC(k).

2.2. Time and frequency transfer

The computation of TAI requires time and frequency transfer techniques allowing the comparison of all the contributing clocks. The basic idea of the Time and Frequency Transfer techniques for TAI computation is to relate each atomic clock to a local realization of UTC by means of local measurements systems and "transferring" this local information using systems with global coverage. Artificial satellites are the perfect candidates to accomplish this role, in particular the Global Navigation Satellite Systems (GNSS), such as the United States Global Positioning System (GPS), the Russian GLONASS and the future European system GALILEO, to name a few.

2.3. Time and frequency transfer using GPS

Since the beginning of the 1980s, the GPS has proven to be a reliable source of positioning and time distribution for both the military and civilian users. Over the years, GPS has also proven to be versatile system for the synchronization of globally distributed atomic clocks over long distances with high precision and accuracy. For the timing community, the GPS system has quickly grown as a fundamental tool for the remote comparison of atomic clocks and time scales.

The time community began using GPS signals for time transfer at the beginning of the 1980s, when Allan and Weiss, 1980, at the National Institute of Standards and Technology (then National Bureau of Standards) proposed a system using common view observations of GPS satellites. The basic idea of this approach is to relate the single atomic clock to be compared to the "intermediate" GPS system time scale (GPST) by using dedicated receivers. The first GPS devices conceived for this purposes were the so called "single-channel/single-frequency" receivers able to track the C/A code (Coarse Acquisition code) of a single satellite at time. Due to these characteristics, it was necessary to track the GPS constellation following a schedule identifying the common view satellites between

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