Performance of Real-Time PPP for UTC(k) Time Transfer

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***Summary*—We compare time transfer UTC(ORB) – UTC(JV) between real-time PPP (Precise Point Positioning) and post-processed PPP used by BIPM in the computation of TAI. We find close to identical stabilities and sub-ns variation in differenced time-transfer estimates. Moreover, the stability of real-time PPP clock bias estimates are an order of magnitude improved over stand-alone receiver operation for observation intervals up to 10 000 s.**

Keywords*— *GNSS time transfer; precise point positioning; real-time; low latency

I. Introduction

Time transfer based on Precise Point Positioning (PPP) enables the comparison of atomic clocks at different locations with a precision of 0.1 ns. PPP is used by the BIPM for time transfer as part of the computation of TAI [1]. BIPM uses IGS final GNSS clock and ephemeris products and publishes UTC(k) time transfer results in deferred time with a latency of up to 45 days. The availability of real-time IGS products and low latency GNSS observations was explored in [2] using the Atomium PPP software to demonstrate near real-time time transfer between UTC(k) labs. Real-time IGS products and RTKLIB PPP software was used in [3] to discipline a local crystal oscillator to follow a remote UTC(k) time scale. Near real-time time transfer has also been investigated using RTKLIB software with real-time IGS and rapid IGU products [4]. Here we show that real-time clock bias estimates using Fugro PPP software and Fugro real-time corrections provide time transfer between UTC(PTB), UTC(ORB) and UTC(JV) in real time with a stability that is close to identical with that of time transfer computed by BIPM in deferred time.

II. Methods

A. Real time PPP

PPP solutions are computed in real-time from continuous streams of observation data using Fugro PPP software and Fugro real-time clock- and ephemeris products. Real-time PPP time transfer UTC(PTB) – UTC(ORB) are based on GPS observations from station 'ptbb' 'brux' (Septentrio PolaRx5TR) connected to UTC(ORB) and station 'jv03' (Septentrio PolaRx5TR) connected to UTC(JV). Low-latency PPP clock bias estimates are computed every second. Fugro demonstrated the technology in 2020 [5] and recently launched a real-time PPP timing service [6].

B. Post-processed PPP

BIPM computes monthly batches of UTC(k) time transfer data from submitted 30s rinex observation files using NRCan PPP software and IGS clock- and ephemeris products [1]. Time transfer between UTC(PTB), UTC(ORB) and UTC(JV) is computed by differencing simultaneous PPP clock bias estimates for PTB (station 'ptbb'), ORB (station 'brux') and JV (station 'jv02') retrieved from the BIPM repository at https://webtai.bipm.org/ftp/pub/tai/data/time_transfer/ppp/.

C. Stand-alone clock bias

The stand-alone clock bias estimates for jv03 is based on multi-constellation and multi-frequency (GPS, Galileo, Beidou and Glonass) PVT solution in 3D mode. Analyzed bias data are relative to GPS system time.

III. Results

Comparisons between real-time and post-processed PPP time transfer for UTC(PTB) – UTC(ORB) and UTC(PTB) – UTC(JV) are shown in figure 1. Station timing calibration values have not yet been fully implemented in the real-time PPP processing pipeline. Fixed offsets have been added to the real-time PPP clock bias differences to align with BIPM post-processed results.

The difference between real-time and post-processed PPP estimates of UTC(PTB) – UTC(ORB) are within 0.1 ns over the 6 day timespan analyzed.

For time-transfer UTC(PTB) – UTC(JV), the difference between real-time and post-processed estimates are within 0.2 ns. In this case the comparison is made using observations from different receivers jv02 and jv03, both connected to UTC(JV), but using separate antennas and cables. Receivers and cables are in different thermal environments.

The stability of real-time and post-processed PPP time transfer UTC(PTB) – UTC(ORB) and UTC(PTB) – UTC(JV) are close to identical (figure 2). Note that UTC(JV) is generated

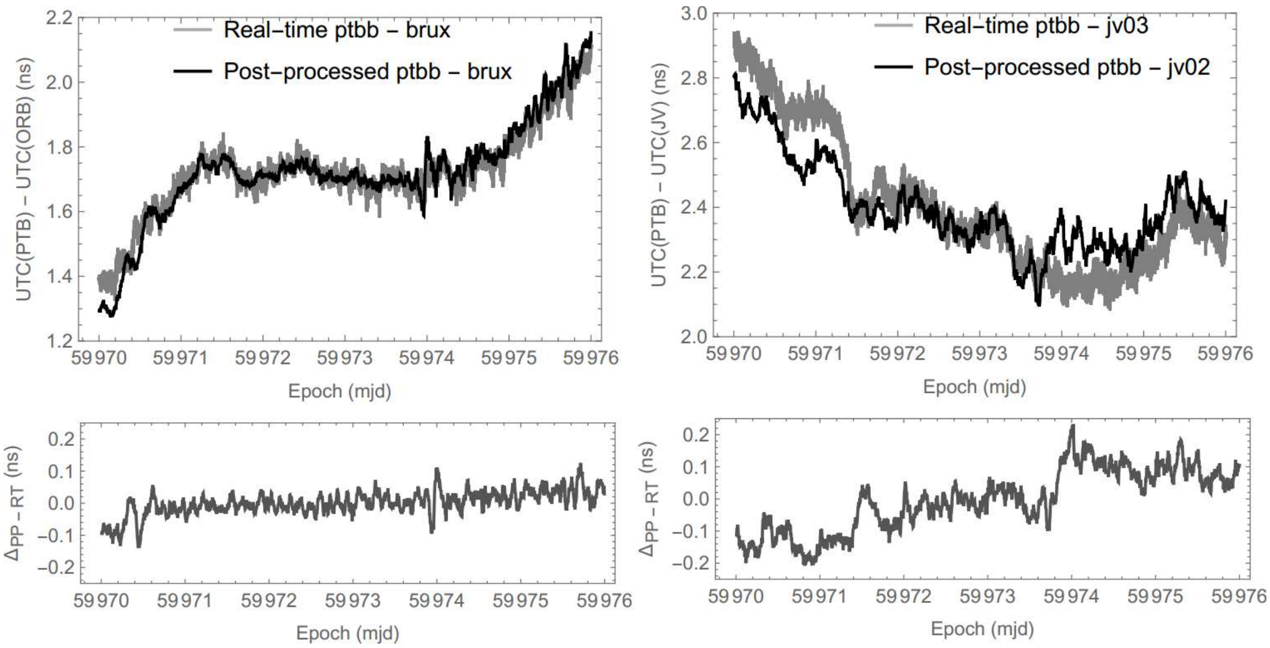

Fig. 1. Comparison of real-time PPP, post-processed PPP and GPS common view time transfer UTC(PTB) - UTC(ORB) (left panels) and UTC(PTB) – UTC(JV) (right panels). Post-processed PPP data are computed by BIPM. A fixed value have been added to real-time PPP clock bias differences for alignment with post-processed values. Real-time values (top panels) are plotted using the full 1 s resolution bias estimates. Differences post-processed PPP – real-time PPP (bottom panels) are computed using real-time values decimated to 300 s epochs after applying a 300 s wide moving average filter.

from a passive H-maser. The estimated stability for observation intervals beyond a few 1000 s may therefore be limited by the reference clocks involved and not by the performance of real-time and post-processed PPP. Archived real-time PPP data used in figure 1 have been decimated to 300 s intervals by averaging 1 s decimated bias estimates.

Figure 3 compares the conventional stand-alone receiver clock bias estimate against the real-time PPP clock bias for receiver jv03 referenced to UTC(JV). The stability of real-time PPP clock bias estimates against the Fugro PPP time scale are more than an order of magnitude improved over stand-alone multi-GNSS operation using broadcast satellite clock- and orbit data.

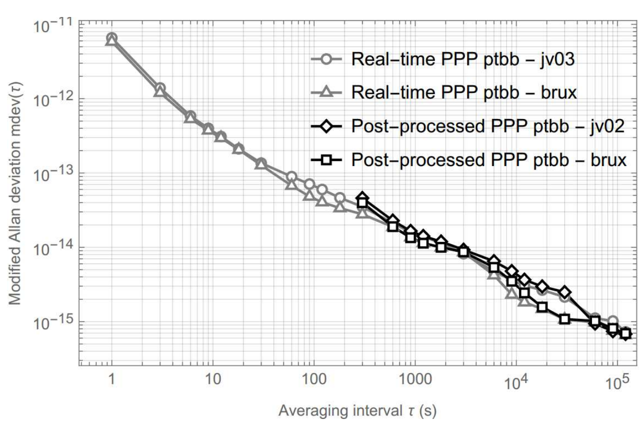

Fig. 2. Stability of real-time and post-processed time transfer UTC(ORB) – UTC(JV) and clock bias estimates for receiver jv03 referenced to UTC(JV).

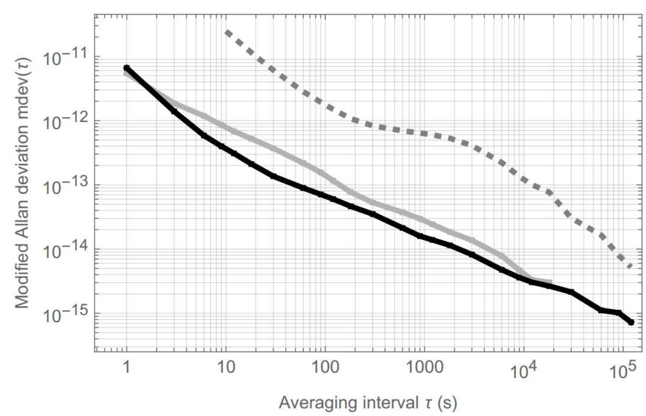

Fig. 3. Stability of real-time clock bias estimates for receiver jv03 referenced to UTC(JV). Stand-alone multi-GNSS clock bias estimate UTC(JV) - GPST (dashed gray), UTC(JV) – Fugro PPP time scale (solid gray) and real-time PPP time-transfer UTC(JV) – UTC(PTB) (solid black).

IV. Conclusions

Time transfer between UTC(PTB), UTC(ORB) and UTC(JV) using real-time PPP (Fugro) and post-processed PPP (BIPM/NRCan/IGS) show close to identical stabilities and sub-ns discrepancies. Real-time PPP clock bias estimates against Fugro reference timescale have stabilities an order of magnitude better than stand-alone clock biases against GPS system time. Real-time PPP timing techniques will improve the performance of disciplined GNSS clocks compared to conventional methods using broadcast satellite data. Real-time PPP enables improved low noise low-latency time transfer methods between reference UTC(k) time scale systems. Furthermore, real-time PPP has the potential to be a cost effective and scalable method for sub-ns accuracy time dissemination. Fully realizing this potential requires improvements both in time scale generation and in GNSS receiver chain calibrations.

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