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Receiver clock modeling in PPP: Analysis of impact and feasibility for ground-based and LEO GPS receivers

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Processing data from Global Navigation Satellite Systems (GNSS) always requires time synchronization between satellite and receiver clocks. In Precise Point Positioning (PPP), advantage is taken from the highly precise satellite clock corrections provided by the IGS or its individual analysis centers, whereas the receiver clock synchronization error has to be solved for as part of the point positioning problem. Due to the limited stability of the receiver's internal oscillator, the offset of the receiver clock with respect to the system time has to be estimated for every observation epoch or eliminated by processing differences between simultaneous observations. If, in contrast, the internal oscillator of the receiver is replaced by a stable atomic clock the receiver clock offset can be modeled rather than estimated on an epoch-by-epoch basis. In our contribution, we will discuss the technical requirements for GNSS receiver clock modeling at the carrier phase level and analyze its impact on the precision of the PPP position estimates.

If we want to model the evolution of a receiver clock connected to a stable frequency standard, we have to ensure that variations of the delays inside the GNSS receiver hardware do not degrade the signal of the external oscillator. In order to verify this condition, we have analyzed relative receiver clock offsets for a number of GPS receivers that derive their frequency reference from a common oscillator. Based on these experimental data, we show that apart from long term drifts, the noise from variations of the hardware delays in the receiver electronics does not exceed the receiver observation noise if the receiver is operated in a temperature-stable environment and suitable antenna cables are used. Consequently, hardware delay variations in the receiver do not generally limit the applicability of clock modeling.

In order to study the impact of GNSS receiver clock modeling on kinematic and static positioning results, simulations and real data PPP solutions have been performed. We demonstrate that a piece-wise linear clock model is suitable for receivers that derive their frequency reference from a hydrogen maser. Based on simulated and real GNSS data it is shown that receiver clock modeling improves the RMS of the height component of a kinematic PPP with data from a static reference station by up to 70 %. In contrast, the coordinate improvement for static PPP solutions is almost negligible.

The proposed clock model was also successfully applied to kinematic orbit determination of the two GRACE satellites. Both of the satellites are equipped with a geodetic GPS receiver that is locked to the frequency of an Ultra Stable Oscillator (USO). Simulations and code-only solutions indicate an improvement of the satellite trajectories of approximately 55 % in the along-track and radial direction and approximately 35 % in the cross-track direction when clock modeling is applied. For PPP with real GRACE data, however, the improvements were found to be significantly smaller. This discrepancy is possibly due to remaining systematic errors and partial relaxation of the clock constraints due to the large number of float ambiguities that need to be estimated in the LEO PPP case.