On the use of UTC to support GNSS interoperability

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GNSS system times offsets and interoperability

The issue was already discussed at several gatherings under ICG (ICG-12, Workshop June 2018, ICG-13, Workshop June 2019)

Interoperability: need to take care of the time offset between GNSS system times.

Two approaches:

- The user estimates GNSS to GNSS time offsets with additional observations
- Each GNSS computes and broadcasts the offset of its system time with respect to **a reference adopted by convention** which can be
    1. A new time scale appositely created
    2. A simple average of all GNSS times as realized by a calibrated multi-sytem receiver
    3. **A proxy of UTC e.g. the presently realized « prediction of UTC/UTC(k)» already computed and broadcast by each GNSS.**

More accurate solution except in case of poor visibility

Bureau International des Poids et Mesures

the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.

At the BIPM the Universal Coordinated Time is produced

Decision CIPM/108-41 **International Committee for Weights and Measures (CIPM)**

The CIPM decided to support the International GNSS services (IGS) and the International GNSS Committee (ICG) in exploring the capacity of GNSS providers to ensure multi-GNSS interoperability, based on Coordinated Universal Time (UTC), with the final goal of avoiding the proliferation of international reference time scales.

https://www.bipm.org/en/committees/cipm/meeting/108(II).html

Prediction of [GNSS time – « UTC reference »] can ensure interoperability?

- For timing service, each GNSS already computes and broadcast the offset of its system time with respect to a reference that is a proxy of UTC (« GNSS UTC reference »).
- The « GNSS UTC reference » is:
  - UTC(USNO) for GPS
  - UTC(SU) for GLONASS
  - (A prediction of) UTC derived from some European UTC(k) for Galileo
  - (A prediction of) UTC derived from UTC(NTSC) for Beidou
- The broadcast offset is noted [GNSS time – Brdc UTC_{GNSS}].

G2GTO can be estimated by the user with the predictions broadcast by each GNSS:

$$G2GTO = GNSST_1 - GNSST_2 = [GNSST_1 - Brdc\ UTC_{GNSS1}] - [GNSST_2 - Brdc\ UTC_{GNSS2}]$$

Which uncertainty can we expect from this approach?

G2GTO can be estimated by the user with the predictions broadcast by each GNSS:

$$G2GTO = GNSST_1 - GNSST_2 = [GNSST_1 - Brdc\ UTC_{GNSS1}] - [GNSST_2 - Brdc\ UTC_{GNSS2}]$$

Which uncertainty can we expect from this approach?

1. the UTC/UTC(k) prediction in nav messages are not based on the same UTC reference. Are the reference UTC/UTC(k) equivalent?

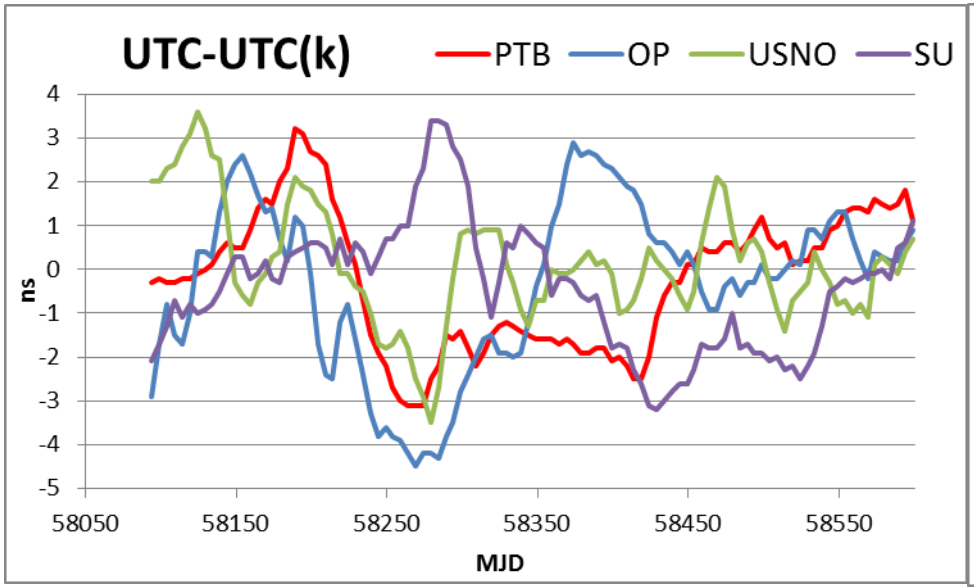
2. the broadcast offset [GNSS time – Brdc UTC_{GNSS}] is predicted by GNSS provider and there is a prediction error + calibration inconsistencies in linking GNSS times to « UTC references »

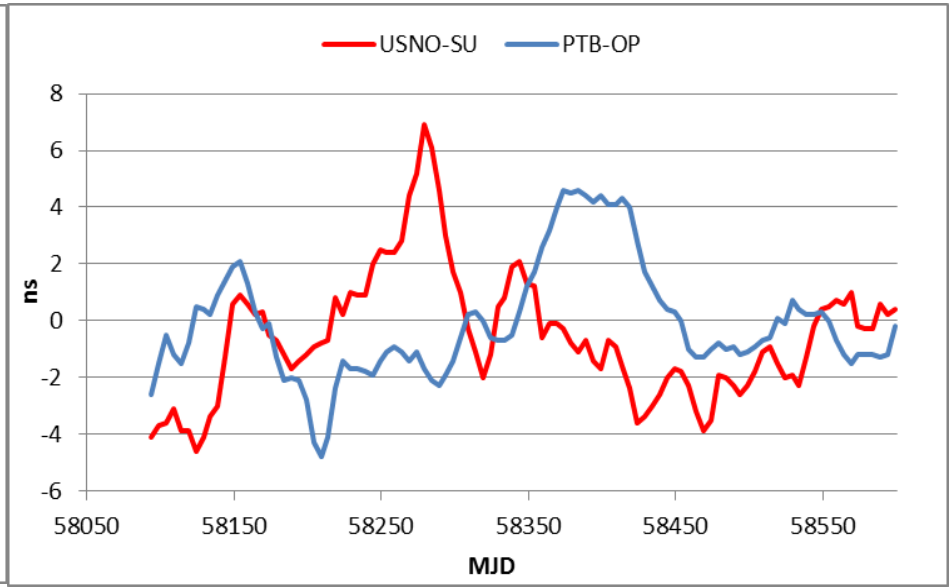
3. at user level:
   - different age/source of navigation messages
   - calibration inconsistencies between different GNSS

1: the UTC/UTC(k) prediction in nav messages are not based on the same UTC reference

Equivalence of all « UTC references »

- For many UTC participating labs, UTC(k) realizes UTC within a few ns RMS.
- E.g. OP, PTB, SU, USNO which are directly involved in referencing GNSS times have UTC(k) equivalent to UTC within 1.3 to 1.9 ns RMS (6.5 to 7.0 ns p-p) over the past 2 years.
- Several other UTC(k) achieve nearly similar performance
- Therefore, for the best laboratories, assimilating UTC(k) to UTC(l) causes errors of 2 to 2.5 ns RMS (9-11 ns p-p). Improvements are continuous

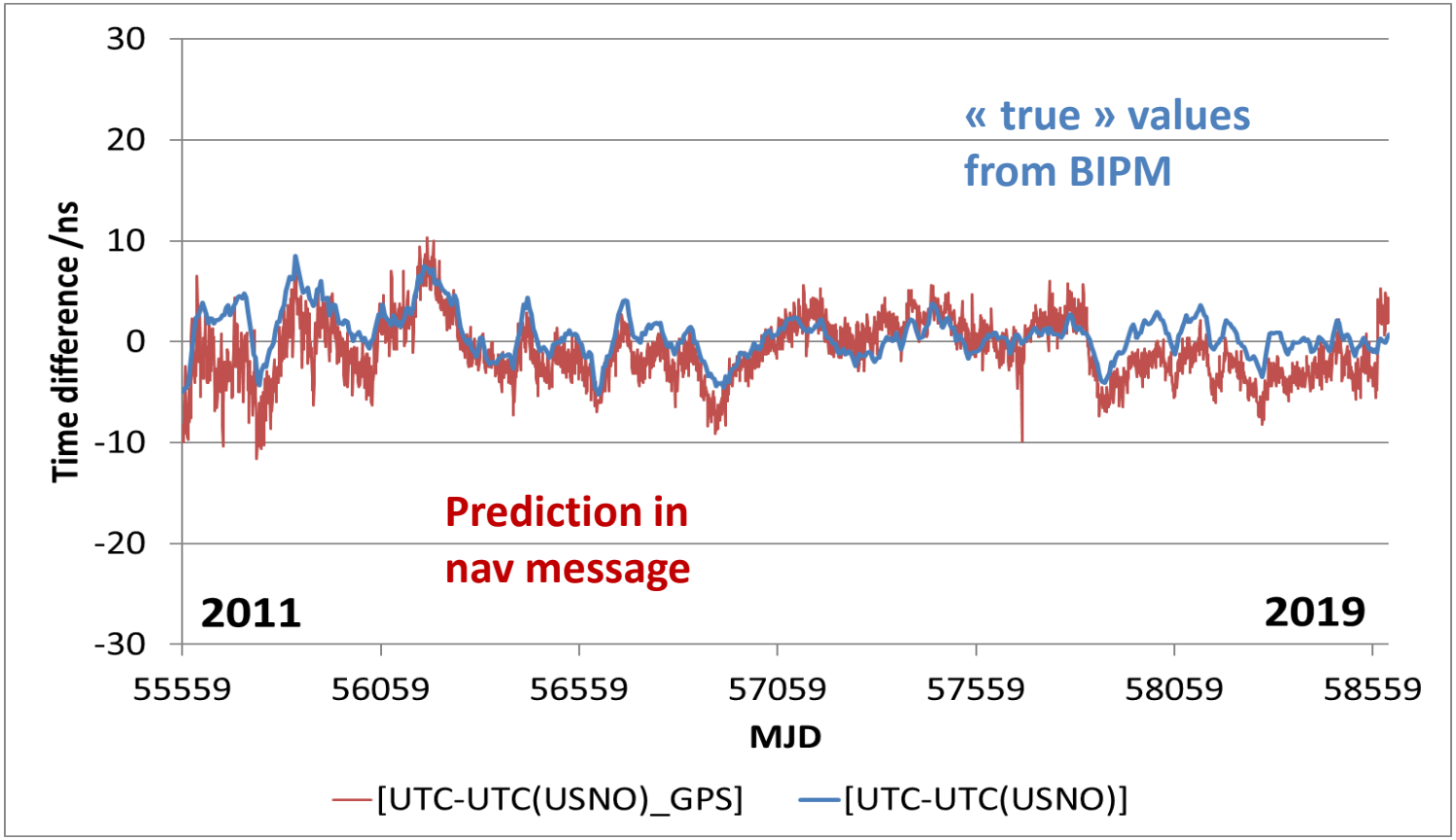




2. the broadcast offset [GNSS time – Brdc UTC_{GNSS}] is predicted by GNSS provider and there is a prediction error + calibration inconsistencies in linking GNSS times to « UTC references »

Example: UTC(USNO) disseminated by GPS

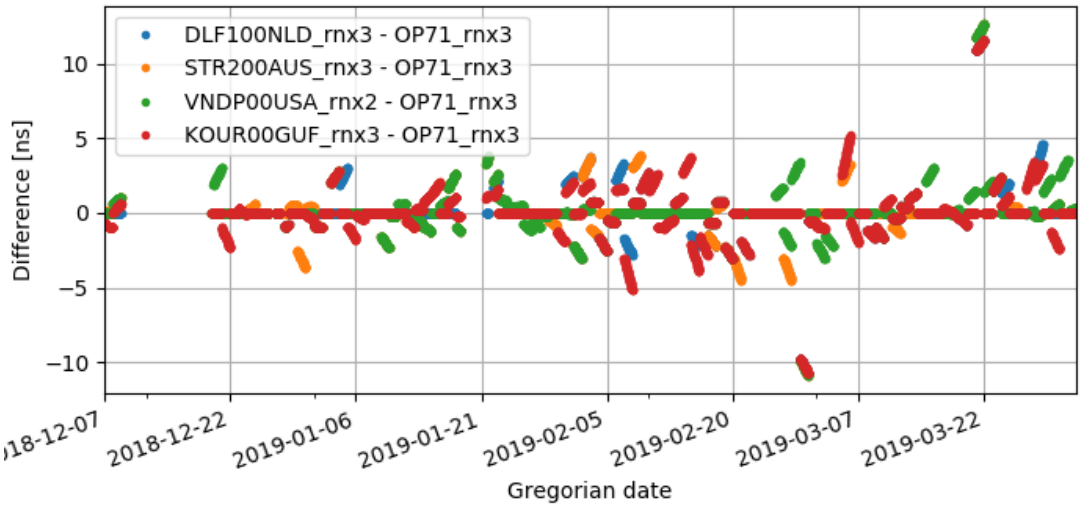
Prediction error
RMS = 1.5-2 ns



3. at user level:
   different age/source of navigation messages
   calibration inconsistencies between different GNSS

- The computation of [$GNSST_1$ – Brdc UTC_{GNSS}] is decribed in GNSS ICD.
- Typically a linear model : A0 + A1 x (t – t0) where the parameters A0, A1, t0 are found in the Rinex Nav navigation message.
- However there is no « Issue of data » to identify which are the most recent values of A0, A1, t0 and different values can be available
  - This is a problem for the real time user and also for us to study in deferred time
  - Use of different A0, A1, t0 as received by different Rx or by IGS (or other) sources causes differences of order 1.5 ns RMS + some possible outliers.

4 different receivers
get different A0, A1, t0
of order 1.5 ns RMS



Prediction of [GNSS time – « UTC reference »] can ensure interoperability?

- Each GNSS already computes and broadcast the offset of its system time with respect to a reference that is a proxy of UTC (« UTC reference »). No need of changes by GNSS providers

1. It is already possible to ensure that those « UTC references » are equivalent at the level of 2-2.5 ns RMS. Improvement is continuous

2. the broadcast offset [GNSS time – Brdc UTC_{GNSS}] is predicted by GNSS provider and there is a prediction error of about 1.5-2 ns + calibration inconsistencies in linking GNSS times to « UTC references »

3. at user level:
   - different age/source of navigation messages can give 1.5 ns uncertainty
   - calibration inconsistencies between different GNSS

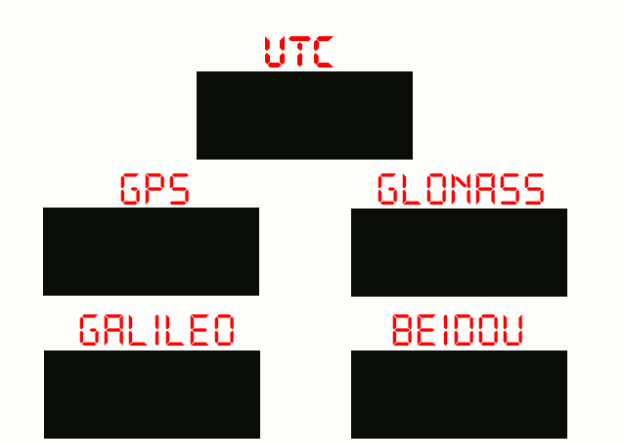
- Total uncertainty on G2GTO may be of order 3.5 ns + calibration biases.

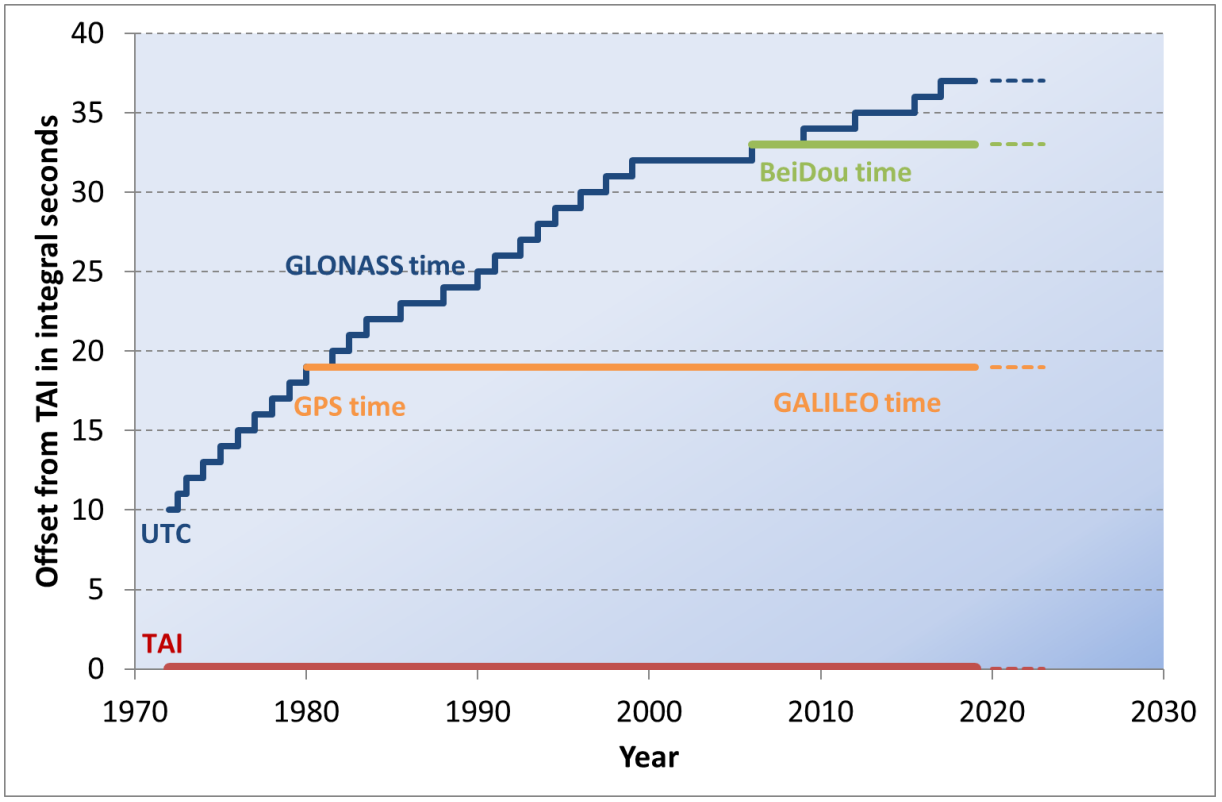
Can G2GTO uncertainty at the level of 3-10 ns satisfy the user in extreme condition of poor visibility?

GST-GPS TIME OFFSET ACCURACY < 20ns (95%) from Galileo OS SDD 2019

Interoperability needs to consider leap seconds

GNSSs prefer not to apply leap seconds (except GLONASS), different labelling of seconds needs to be taken into account





The BIPM is supporting ICG, IGS, and GNSS providers in fulfilling their services and *exploring the capacity to ensure multi-GNSS interoperability, based on Coordinated Universal Time (UTC)*