Time Transfer with Integer PPP (IPPP)

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Outline

- Time transfer
- GPS CP TT : advantages of integer ambiguity resolution
- GRG products
- Some results

Time transfer : how to compare distant clocks ?

- **Clock trip**
  - **Difficult for long distances**

- **Remote transfer : 3 basic approaches**
  - **One-way ➔ GNSS Precise Point Positioning (PPP)**
  - **Common-view**
  - **Two-way**

GPS carrier phase time transfer

- Decisive advantage of GPS carrier phase observables : lower noise

  … but some drawbacks :
  - Ambiguous
  - Sensitive to the model precision (frequency bias or drift)
  - Discontinuities at day boundaries

- Taking into account the integer nature of the ambiguities allows to overcome most of these problems

How to handle day-boundary discontinuities ?

- **processing of longer batches**
  - ↳ reports the problem to boundaries of batches
- **continuous processing**
  - ↳ heavy and some errors effects may accumulate, e.g. [Dach, 03]
- **concatenation using overlapping series,** e.g. [Bruyninx, 99] or [Larson, 00]
  - ↳ addition of a random-walk noise component, limitation of the long-term stability
- **sliding window,** e.g. [Guyennon, 07]
  - ↳ minimize rather than solve the problem
- **more sophisticated methods** [Dach, 04] **: clock handover and ambiguity stacking**
  - ↳ many internal parameters must be kept with each individual daily solution to compute a continuous clock solution (normal equations and ambiguities of the overlapping passes)

  $\Rightarrow$ not usable by external users who have access only to the daily ephemeris and clocks

Integer ambiguity advantages

- Phase clock solutions are ambiguous and need to be aligned on the code for time transfer
  - Alignment on code by 1-day batches may create boundary discontinuities due to code noise
  - For integer ambiguities solutions, such discontinuities are integer numbers of λ_c and can be easily cancelled out

Ambiguity fixing method (1/2)

- Ambiguities fixed directly on the zero-difference phase measurements
  - Clocks and all parameters are solved for simultaneously with the ambiguity fixing

- Step 1 : Wide-lane
  - Fix the widelane ambiguity (ambiguity associated to L2-L1), using the 4-observable Melbourne-Wübbena combination
  - ⇨ Fixing at pre-processing level using only the receiver measurements and a set of satellite biases (Wide-lane Satellite Biases, WSB), available on GRG ftp site (grgxxxxx.wsb, daily update)
- Step 2 : Narrow-lane
  - Use of iono-free code and phase combinations
  - Remaining ambiguity associated to an equivalent λ of 10.7 cm = Narrow-lane ambiguity
  - This ambiguity fixing is performed at zero-difference level, using the complete models and parameterization (orbits, stations coordinates, clocks...). Narrow-lane ambiguity are fixed using a bootstrap method applied on the normal equations constructed with the floating solution
  - Number of ambiguities to solve for is typically 7000, and more than 95% of the phase measurements have a fixed ambiguity at the end of the process

Ambiguity fixing method (2/2)

Zero-difference iono-free phase equation

wind-up effect

frequency 1
integer ambiguity (each pass)

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 L_2}{\gamma - 1} = D_c + \lambda_c W - \lambda_c N_1 + \frac{\lambda_2}{\gamma - 1} N_w + \Delta h$$

ionosphere free
phase combination

propagation distance
(model, including troposphere)

widelane integer
ambiguity

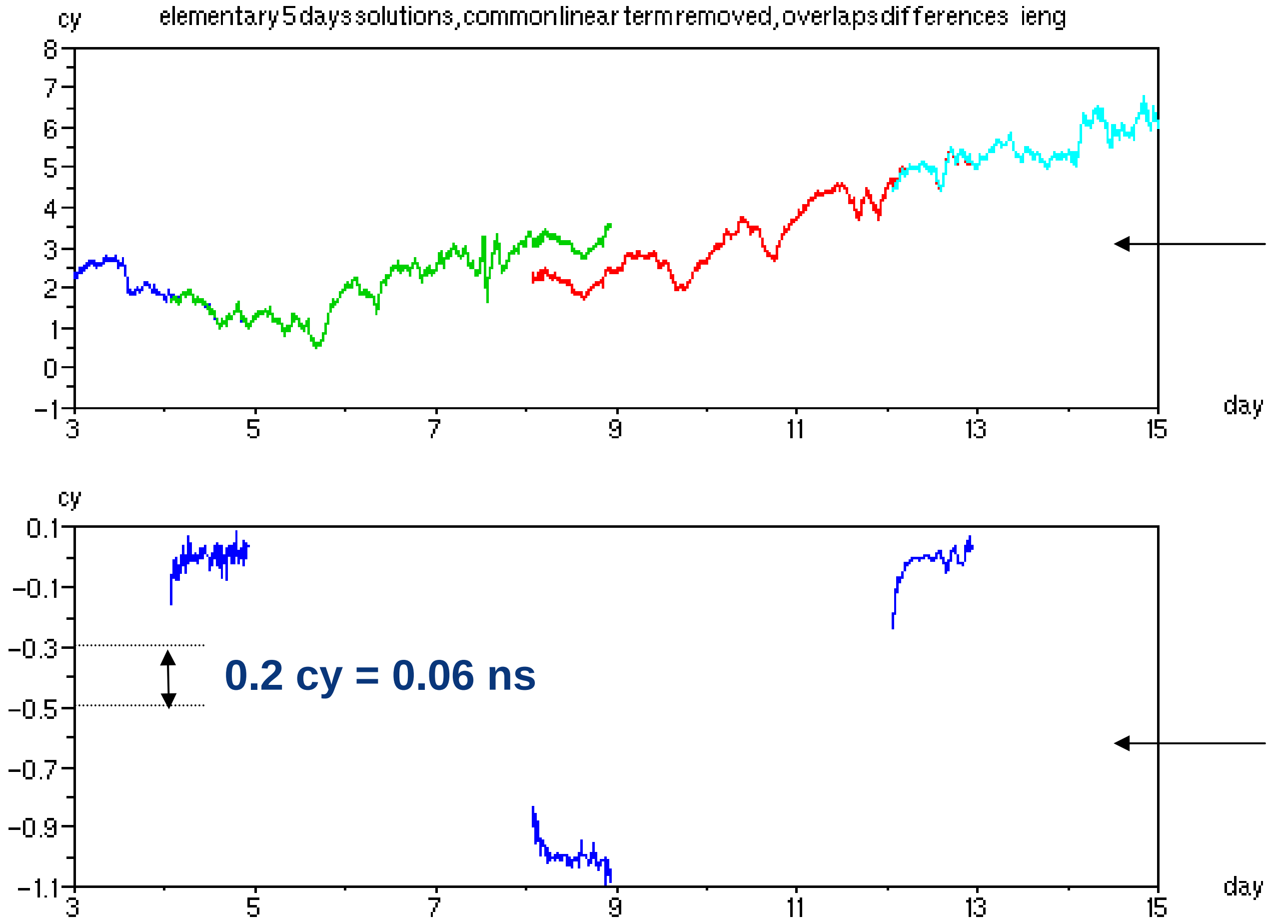
receiver/emitter clock
difference (each epoch)

Floating solutions : direct identification of floating ambiguities
(equivalent wavelength of the N_1, N_2 integer problem is too small)

Integer solution : 1st step = separate integer N_w identification
2nd step = iono-free phase solution with integer N_1 (λ_c = 10.7 cm)

Day-boundary discontinuities

■ **Receiver clock differences are defined up to an overall unknown number of cycles**



IENG station
4 batches of 5 days each

5 days clocks results

Batch differences on overlap

Troposphere signature
residuals on overlapping arc

GRG products

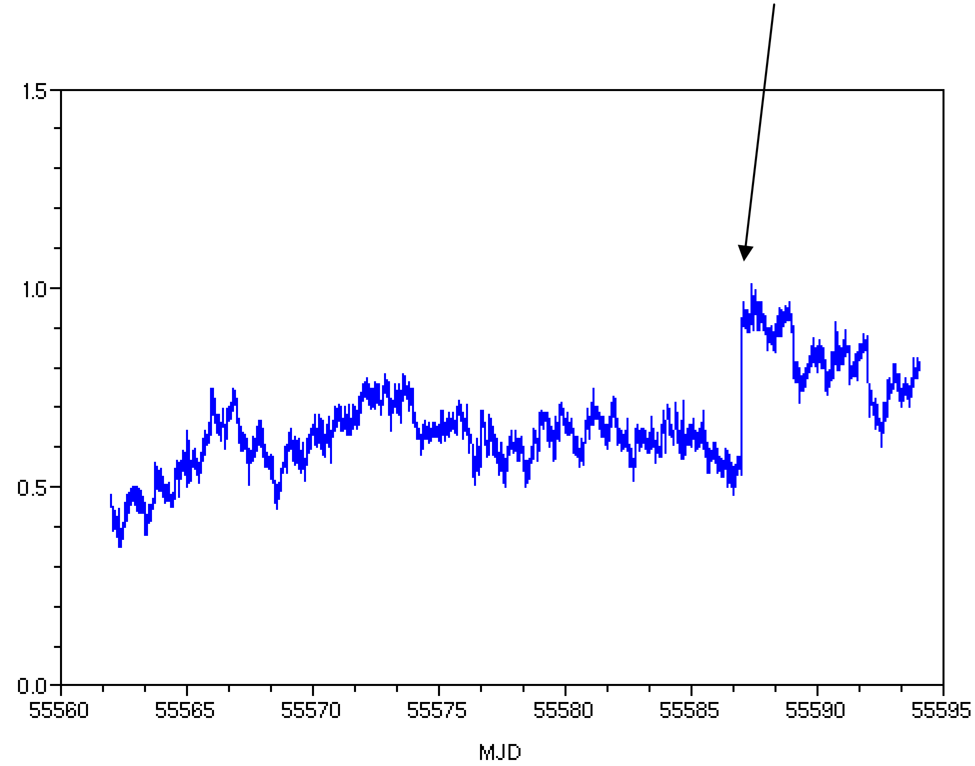
- GRG = new IGS Analysis Center since May 2010, CNES-CLS joint effort
- GRG products :
  - based upon processing of a global network of GPS stations
  - integer ambiguity resolution applied (identification of wide-lane satellite biases : WSB, called grgxxxxx.wsb)
  - This allows to perform IPPP (PPP with integer ambiguity resolution) that provides continuous receiver clock solutions between two successive batches
- See : www.igsac-cnes.cls.fr

Results on KRIS/NICT

Differences between GPSPPP (floating PPP) and IPPP (in ns)

std = 0.08 ns
(computed before the discontinuity)

Batch-boundary discontinuity in GPSPPP



Conclusions

- GRG products allows IPPP that provide continuous GPS CP TT, for instance with GINS software package

- IPPP results compared to TWSTFT and GPSPPP
  - Agreement with GPSPPP : STDEV = 0.08 ns

    GPSPPP batch-boundary discontinuities overlooked

    (these discontinuities have a median value of ~ 0.2 ns)
  - Agreement with TWSTFT : STDEV = 0.3 ns

- Long term consistencies and code/phase biases to be further investigated

- Extension to other GNSS in progress