GNSS
Time Transfer
Pascale Defraigne
Royal Observatory of Belgium
OUTLINE

• Principle

• Instrumental point of view

• Calibration issue

• Recommendations
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• Calibration issue

• Recommendations
GNSS Time Transfer

Compare two remote clocks to a same reference

Clock(1) – Clock(ref)          Clock(2) – Clock(ref)          Clock(1) – Clock(2)
rec2 rec1
GNSS Time transfer

What can be this common reference:

• GPS time
• IGS time (IGS = International GNSS Service)
• Satellite clock (in common view)
• Glonass time
• Galileo time
• ......
All in View (also PPP)
Observation modeling

Satellite clock

Satellite orbit

Atmosphere (Ionosphere + troposphere)

multipath

Receiver clock

Ground displacements
Observation equations

Pseudorange:

\[ P_{1,2}^{sat} = \| x_{sat} - x_{rec} \| - c \left[ (t_{rec} - ref) - (t_{sat} - ref) \right] + I_{1,2} + Tr + \delta_{1,2} + \epsilon_{1,2} \]

To be determined

- iono
- tropo
- Hardware delays
Satellite position

\[
P_{1,2}^{sat} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c \left[ (t_{rec} - ref) - (t_{sat} - ref) \right] + I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2}
\]

To be determined

From NAVIGATION message

Or

from precise IGS orbits
Receiver position

\[ P_{1,2}^{sat} = \| x_{sat} - x_{rec} \| - c \left[ (t_{rec} - \text{ref}) - (t_{sat} - \text{ref}) \right] + I_{1,2} + Tr + \delta_{1,2} + \varepsilon_{1,2} \]

Fixed

Or

determined in PPP, i.e. using code and carrier phase data
Satellite clock

\[ P_{1,2}^{\text{sat}} = \| \mathbf{x}_{sat} - \mathbf{x}_{rec} \| - c \left[ (t_{rec} - \text{ref}) - (t_{sat} - \text{ref}) \right] 
+ I_{1,2} + Tr + \delta_{1,2} + \epsilon_{1,2} \]

From NAVIGATION message
or
from precise IGS clock products
Ionosphère

$P_{1,2}^{sat} = \| x_{sat} - x_{rec} \| - c \left[ (t_{rec} - ref) - (t_{sat} - ref) \right]$

$+ I_{1,2} + Tr + \delta_{1,2} + \epsilon_{1,2}$

From Klobuchar model (using parameters given in the NAVIGATION message)

or

Removed using the ionosphere-free combination P3
P3 removes 99.9% of the ionosphere delays
While models like Klobuchar, only 60%.
Tropospheric delay

\[ P_{3}^{\text{sat}} = \| \mathbf{x}_{\text{sat}} - \mathbf{x}_{\text{rec}} \| - c \left[ (t_{\text{rec}} - \text{ref}) - (t_{\text{sat}} - \text{ref}) \right] + Tr + \delta_3 + \epsilon_3 \]

To be determined

**Hydrostatic part:** modeled

**Wet part:**
Must be determined from the observations but only in PPP (small : < 1 ns)
Hardware delay

\[ P_{3}^{sat} = \| x_{sat} - x_{rec} \| - c \left[ (t_{rec} - \text{ref}) - (t_{sat} - \text{ref}) \right] + Tr + \delta_3 + \varepsilon_3 \]

To be determined by calibration
GNSS code data analysis and CGGTTS Format

<table>
<thead>
<tr>
<th>Common</th>
<th>Results for $(t_{rec} - \text{REF})$ from GNSS code measurements</th>
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<td>Using satellite positions and clocks from the navigation message</td>
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Using broadcasted satellite orbits and clocks:

1. For each point: Correction for geometric distance, troposphere relativistic effect, hardware delays ionosphere (if not P3)

2. Linear fit: UTC(lab) - Tsat (value at mid-point)

3. For each point: Correction for satellite clock

4. Linear fit: UTC(lab) – TGPS (value at mid-point)
CGGTTS FILE

CGGTTS GPS/GLONASS DATA FORMAT VERSION = 02
REV DATE = 2002-07-01
RCVR = Z-XII3T
CH = 12 (GPS)
IMS = Z-XII3T
LAB = ORB
X = +4027896.26 m (GPS)
Y = +307045.98 m (GPS)
Z = +4919478.21 m (GPS)
FRAME = ITRF
COMMENTS = NO COMMENTS
INT DLY = 303.5 ns (GPS P1), 312.8 ns (GPS P2)
CAB DLY = 333.8 ns (GPS)
REF DLY = 50.6 ns
REF = HORB
CKSUM = 22

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« Geodetic » Time and Frequency Transfer

i.e. code + carrier phase data

Precise Point Positioning (PPP)

- Needs precise satellite clocks/orbits like the ones delivered by the IGS
- No advantage of using precise carrier phases if broadcast orbits and clocks are used.
Observation equations

Codes:

\[ P_{3}^{sat} = \| x_{sat} - x_{rec} \| - c [(t_{rec} - \text{ref}) - (t_{sat} - \text{ref})] \]
\[ + Tr + \delta_{3} + \varepsilon_{3} \]

Carrier Phases:

\[ L_{3}^{sat} = \| x_{sat} - x_{rec} \| - c [(t_{rec} - \text{ref}) - (t_{sat} - \text{ref})] \]
\[ + Tr + \lambda_{3} N_{3} + \varepsilon'_{3} \]
Working with GPS codes and phases

Called « geodetic time transfer »

**Code Wavelength:**
- P code: 29.3 m, C/A code: 293 m
- Carrier wavelength: 19 cm (L1) and 24 cm (L2)

→ Carrier phase measurements about 100 times more precise than codes measurements

**BUT** carrier phases ambiguous
→ only usable for frequency transfer, no time
→ need code data for time transfer

Carrier phase data will give the shape of the clock solution
Code data will give the numerical value of the clock solution.
ionosphere-free

P code vs carrier phase

BRUS-NPLD (2 H-masers)

P3 code results

combined code (P3) and carrier phase (L3) results

MJD
ionosphere-free
P code vs carrier phase

Advantage of Carrier Phases: for averaging times < 5 (or 10) days;
Available PPP tools

Bernese, NRCan, Atomium, Gipsy, ....

Just as an example
OUTLINE

• Principle

• Instrumental point of view

• Calibration issue

• Recommendations
GNSS set up

antenna

receiver

clock

computer

1 PPS

x Mhz
Receiver
**Time receivers (possibly Geodetic)**

**Advantage:**
- calibration procedure is easy, as long as the 1PPS is the reference for calibrations and the trigger level of the receiver is known.
- Proper operation as a time receiver is simpler, in general.
- CGGTTS files directly available

**Drawback:**
- Not all are dual-frequency (→ no P3, e.g. TTS2)
- Not all are code + carrier phase (→ no PPP)
- If RINEX data reported to UTC(k): may be affected by the TIC measurement ⇒ phase noise is larger (e.g. GTR50) or even data affected more generally (e.g. TTS3).
- If RINEX data reported to the internal reference: calibration procedure more complicate
Geodetic receivers (possibly Time) using the clock signal as internal reference

**Advantage**: No additional noise from a TIC

**Drawback**: Calibration issue: need additional measurements to get UTC(k), following the definition of the internal reference from the combination of external 1 PPS and frequency.

Not all provide the CGGTTS, but these can be created from RINEX

(Ashtech Z12T, Septentrio, Javad, Novatel)
R2CGGTTS:

Software developed at the Royal Observatory of Belgium

**Goal**: Generate CGGTTS files from RINEX files

**Input files**: RINEX obs files
    RINEX nav files
    parameter file (position, receiver and cable delays)

**Output file**: CGGTTS

Present version 5.0: allows for GPS and possibly GLONASS

Available on the BIPM ftp: tai.bipm.org, user: labotai,
    password: dataTAI, remote directory: /soft/r2cggtts
Antenna

Choose an antenna which reduces multipath
CGGTTS influenced by multipath
Influence of multipath on PPP solution: day-boundary discontinuities
Ideal setup

Reduces near-field effects
Temperature influences
Influence of temperature variations on the carrier phase measurements

Receivers:
SNR-12RM

L1: 40 ps/°C
L2: 30 PS/°C
0.5 ns/°C  cause = amplificateur

H-maser BRUSSEL - H-Maser WETTZELL

(a) Detrended single Diff. P3 Code

(b) 15 min. running average

(c) Detrended Single Diff. L3 Phase

Temperature nearby BRUS
Temperature sensitivity

**Indoor**
- **Amplifier**: 0.5 ns/°C
- **Receiver**: up to 100 ps/°C (large differences between receivers)

**Solution**: temperature stabilized with 0.1°C

**Outdoor**
- **Antenna code**: expected up to 2 ns/day
- **Carrier phase**: 0.2 to 2 ps/°C (diurnal) or to 10 ps/°C (long term)
  - example: 20 °C diurnal → max 40 ps
  - 30 °C long term → max 300 ps

**Cable**
- Choose cable with low sensitivity to temperature variations,
  - e.g. Andrew company: about 0.02ps/m/°C
  - example: 30 m, 20 °C → 3 ps
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Calibration issue

\[ \Delta t_{\text{rec}} = \Delta t_{\text{rec}} (\text{GNSS}) + (\delta_1 + \delta_2) - (\delta_3 + \delta_4) \]

- \( \delta_1 \)
- \( \delta_2 \) = receiver + antenna
- \( \delta_3 \)
- \( \delta_4 \)

Must be measured

Provided by the manufacturer
Absolute Calibration

1. Absolute calibration of one receiver
   Using GNSS signal simulator
   Precision about 1 ns (Proia et al., 2011)
Absolute Calibration

1. Absolute calibration of antenna
   Using GNSS signal simulator
   Precision about 1 ns (Proia et al., 2011)
Relative Calibration:

Relative calibration of the chain receiver + antenna

$P_1(\text{Ref})-P_1(\text{Rec})$-cable delays
$P_2(\text{Ref})-P_2(\text{Rec})$-cable delays

To be calibrated

Reference, provided by BIPM
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• Recommendations
Some recommendations

- Temperature stabilization in the laboratory
- Use dual-frequency receivers (→ P3) and also measuring the carrier phases (→ PPP)
- Choose an antenna setup which reduces multipath
- Use antenna cable with low temperature sensitivity
- Contact BIPM/RMO to conduct regular calibration