Use of Precise point positioning
for TAI links

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Link comparisons using geodetic GPS

- An already long history at the BIPM
  - Mostly using P3
  - Petit and Jiang (PTTI’2004, ATF2004)
  - Long-term stability (months) found to be similar for both techniques (< 1 ns)

- Several approaches
  - Network computation using phase + code (IGS analysis centers)
  - Network computation using phase only (R. Dach) for frequency comparisons
  - Precise point positioning

- PPP already in common use
  - Comparisons between different PPP results and IGS clock products in Bruyninx et al. (PTTI’2004)
  - Comparisons between PPP and TW e.g. in Orgiazzi et al. (FCS-PTTI’2005)
  - Multi-technique (PPP, Phase-only, Phase+code, IGS, TW) in Jiang et al (EFTF’2006)
PPP for TAI links

- PPP makes sense for TAI time links
  - It is the natural follower of All-in-view with P3

- BIPM thus started to gain experience with Precise Point Positioning analyses using IGS products.

- Multi-technique comparisons: to quantify the performance of the techniques that presently seem to be the best available for TAI links:
  - Precise Point Positioning (PPP) with dual-frequency geodetic GPS receivers
  - Two Way time transfer:
    - Ku band
    - X band
PPP Software presently used at the BIPM

- GPSPPP software version 2655 (January 2006).
- Developed by NRCan (Kouba and Héroux, GPS Solutions, 2001)

- Features:
  - Uses GPS satellites ephemerides and clocks from the IGS to produce (Station clock – IGS time reference)
  - Uses directly IGS products (e.g. phase center offsets…)
  - Uses up-to-date models for station displacements (tides etc…)
  - Allows to solve for station coordinates, tropospheric delays.
  
  - Continuous processing of “unlimited” number of days is possible
    => Adapted to monthly TAI computation.

- Several other packages are available
GPSPPP Settings (Nominal)

- IGS Final SP3 orbits and 5-min SV clocks (RINEX format) – fixed
- SV IGS antenna offset values applied
- Antenna PCV values used: from standard IGS file igs_01.pcv
- Ocean loading coefficients from Chalmers Centre for Astrophysics and Space Science: [http://www.oso.chalmers.se/~loading/](http://www.oso.chalmers.se/~loading/)

- *A priori* data weights: 1 m pseudorange, 1 cm phase
- Elevation cut-off: 10°

- Observation sampling & output clocks every 5 minutes
- Tropo delay estimated as 3mm/√hr random walk
- Station coordinates estimated on each 1-month batches
Link comparisons

We consider time laboratories with TW and (geodetic receivers + IGS)

• PPP to IGS: Just for checking
  GPSPPP (NRC software) to Atomium (new ORB software)

2. PPP to TW(Ku): Several links in Europe-USA, e.g.
   – USNO-PTB
   – OP-PTB

• Links in Asia-Pacific + link to Europa, e.g.
   – NICT-PTB
   – NICT-TL

3. Comparison of three independent techniques for USNO-PTB
   – TW (Ku) typically 12 or 24 points per day
   – TW (X) typically 24 points per day
   – PPP computed every 5 minutes (288 points per day)

• Three-corner hat computation possible: estimation of the stability of each technique from the three differences.
PPP – IGS

(just to check)
PPP-IGS: RMS = 290 ps

100 ps typical time stability
PPP-IGS: RMS = 160 ps

100 ps typical time stability
Different PPP softwares: GPSPPP - Atomium

(just to check)
PPP-Atomium: RMS = 330 ps

200 ps typical time stability
PPP-Atomium: RMS = 0.4 ns

200 ps typical time stability
TW(Ku) - PPP
TW(Ku)-PPP: RMS = 0.42 ns
Peak to peak: 2 ns

No clear diurnal signature
TW(Ku)-PPP: Change of calibration of TW link end March 2006

3 ns
TW(Ku)-PPP: RMS = 0.51 ns
Peak to peak = 2 ns

Mod. Allan Dev. Tau0=10481s, Scale D-15

Time Dev., Scale D-10 seconds
TW(Ku)-PPP: RMS = 0.80 ns
Peak to peak: 4 ns
Clear diurnal signature
TW(Ku)-PPP: RMS = 0.80 ns
Peak to peak: 4 ns
Three-corner hat
TW(X) - TW(Ku) - PPP
USNO-PTB 02/2006-05/2006

TW(X)-PPP: RMS = 0.97 ns

1 ns
TW(X)-TW(Ku): RMS = 0.61 ns
Peak to peak = 3 ns
Modified Allan deviation from 3-cornered hat

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Mod Sy(Tau)

Tau / d

TW(X)  PPP  TW(Ku)
Time deviation from 3-cornered hat

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![Graph showing time deviation from 3-cornered hat for different time scales](image-url)
Conclusions (1): Comparisons results

- PPP clock results generally agree with IGS Final results within ~100-200 ps: The most prominent features are the day-boundary discontinuities.

- PPP-TW(Ku)
  - Over 4 months, RMS of differences between 0.4 ns and 1 ns
  - Diurnal signatures and long-term trends sometimes visible, difficult to attribute

- PPP-TW(Ku)-TW(X) 3-corner comparisons show that
  - PPP generally more stable until 10-day averaging
  - TW(Ku) sometimes noisier than others
  - All techniques stable to 100-300 ps up to 10-day averaging
  - Long-term trend (2 ns over 4 months), possibly in GPS

- These conclusions from one example only!
Conclusions (2): Use of PPP for TAI

• The PPP package used so far is reliable. Other PPP packages are available.
• Some run-time problems eliminated by data editing (currently on a daily basis). Some refinement may be necessary.
• PPP results are satisfactory.

• The routine use of PPP for TAI links looks OK.
• Some changes needed in data transmission / handling:
  – Rinex data necessary.
  – Calibration information should be handled separately or added to Rinex format.

• Manpower needed, specially for the development and tests phase.
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