Real-Time Estimation of GPS Satellite Clocks
Based on Global NTRIP-Streams

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Agenda

- Motivation

- Overview of the real-time clock estimation system

- Assessment of clock product quality
  a) SISRE
  b) Orbit determination results
  c) Direct clock comparisons

- Conclusions and future work
Motivation

- GSOC routinely performs precise orbit determination
- Near real-time precise orbit determination (decimeter level) required for:
  - Occultation measurements (e.g. MetOp-A, TerraSar-X)
  - Altimeter missions (e.g. Sentinel-3)
- Requirements cannot be fulfilled with IGU predicted orbits/clocks
- Precise real-time GPS clock estimation established at GSOC to support current and upcoming space-missions
Motivation

- Participation in IGS Real-Time Pilot Project (www.rtigs.net/pilot)
- Kick-off in October 2007
- Key objectives:
  - Maintain real-time tracking network
  - Production and monitoring of real-time products
  - Distribute real-time products to users
- Currently product submission by 3 real-time analysis centers
  - ESA/ESOC
  - NRCan
  - DLR/GSOC
- Orbit and clock comparisons w.r.t. IGS rapid products (Sept. 2008)
- Real-time product dissemination and combination (Jan. 2009)
Overview of RETICLE system

- Real-Time Clock Estimation (RETICLE) implemented at DLR/GSOC
- Real-time data streams from global network (~25 stations)
Overview of RETICLE system (cont.)

- Data streaming via NTRIP (Networked Transport of RTCM via Internet Protocol)
- ~120 real-time tracking stations available
- Data formats:
  - RTCM 3.x
  - RTIGS
  - RTCM 2.x
- Typical transmission latency between 0.5s – 4s
Overview of RETICLE system (cont.)

- RETICLE algorithm based on Kalman filter
- Processing of ionosphere-free pseudo-ranges and carrier-phases
- Estimation parameters:
  - GPS clock offset & drift
  - station clock offset
  - tropospheric zenith delay
  - carrier-phase biases (float values)
- Station coordinates from IGS Sinex-files or PPP-fit
- Clock parameters based on most recent IGU predicted orbits
Overview of RETICLE system (cont.)

- Modeled observations include corrections for:
  - Solid earth tides
  - Polar tides
  - (Ocean loading)
  - Tropospheric delay
  - Phase center offsets and variations
  - Differential code biases (P1-C1)
  - Phase wind-up

- Output:
  - SP3 file with 30 sec epochs
  - NTRIP data-stream every 5 seconds
Overview of RETICLE system (cont.)

- NTRIP streams
- IGU orbits & clocks
- P1C1-Bias
- EOP
- Antex-File
- NANOs

Kalman-filter
- Data Pre-Processing
  - Time Update
    - Ambiguity Management
      - Clock Constraint
        - Measurement Update

Observations @ 30sec epochs
- Orbit/Clocks @ 30sec epochs
Overview of RETICLE system (cont.)

- Mean constellation clock constrained to IGU predicted mean clock
- Variation of mean RETICLE clock:
Overview of RETICLE system (cont.)
Assessment of Clock Product Quality

- Computation of Signal-In-Space Range Error (SISRE)
- Orbit / clock comparison w.r.t. reference solution

\[
SISRE^{(i)} = \sqrt{\left(e_{RE/CE}^{(i)}\right)^2 + \frac{1}{49}\left(e_C^{(i)}\right)^2 + \left(e_A^{(i)}\right)^2}
\]

radial orbit / clock error  cross-track orbit error  along-track orbit error

- Common constellation radial/clock offset removed:

\[
SISRE^{(i)} = \sqrt{\left(e_{RE/CE}^{(i)} - \bar{e}_{RE/CE}\right)^2 + \frac{1}{49}\left(e_C^{(i)}\right)^2 + \left(e_A^{(i)}\right)^2}
\]

cross-track orbit error

common constellation offset
Assessment of Clock Product Quality

Signal In Space Range Error

Day of Year 2008
Assessment of Clock Product Quality (cont.)

- Results of a precise orbit determination
- 15 days of flight-data from TerraSar-X
- 24h POD with DLR and IGU products
- POD with DLR’s GHOST software:
  - iterative least-squares fit
  - un-differenced measurements
- CODE products (30s clocks) for reference orbit generation
Assessment of Clock Product Quality (cont.)

- 3D positioning error
  - RETICLE: 2.5 cm – 6 cm
  - IGU: 16 cm – 26 cm

3D RMS Position Error
Assessment of Clock Product Quality (cont.)

- Pseudorange residuals: ~75 cm for CODE and DLR
  ~110 cm for IGU

- Carrier phase residuals:
Assessment of Clock Product Quality (cont.)

- Clock comparisons w.r.t. IGS rapid products
- Provided by ESA/ESOC (ftp://nng.esoc.esa.de/gps/products/)

- RMS clock differences:
Assessment of Clock Product Quality (cont.)

- Clock comparisons w.r.t. IGS rapid products
- Provided by ESA/ESOC (ftp://nng.esoc.esa.de/gps/products/)

- Standard deviation of clock differences:

![RT PP Clock Comparison Diagram](image-url)
Conclusions and Future Work

- RETICLE orbit and clock products fulfill requirements for LEO-POD
- Current NTRIP-network is sufficient for global precise clock estimation
- Additional stations beneficial for improving global coverage
- Refine modeling of observations (ocean loading, ...)
- Install DLR NTRIP-caster for distribution of RETICLE products
- Implementation of near real-time TerraSar-X POD