Verification of ELT performance by Monte Carlo Simulations

Anja Schlicht, Christoph Bamann, Stefan Marz, Rebecca Abel

Technical University Munich
The ELT experiment
Optical time transfer

- One way: \( \text{tof}_{1W} = R_{\text{CoM}} + \tau_{\text{troposphere}} + \tau_{\text{Sagnac}} + \tau_{\text{Shapiro}} + \tau_{\text{attitudeDetector}} \)

- Two way: \( \text{tof}_{2W} = 2 \times (R_{\text{CoM}} + \tau_{\text{troposphere}} + \tau_{\text{Shapiro}} + \tau_{\text{attitudeReflector}}) + \tau_{\text{Reflector}} \)

- Time transfer: \( \tau = \frac{t_{\text{return}} + t_{\text{start}}}{2} - t_{\text{detector}} + \tau_{\text{corr}} = \frac{\text{tof}_{2W}}{2} + t_{\text{start}} - t_{\text{detector}} + \tau_{\text{corr}} \)
Simulation tool

**Geometric components**
- Earth orientation (IERS 2010 Conventions)
- ISS attitude simulation (3 axes, constant offsets and oscillations)
- Detector and reflector position
- Intra-reflector delay (function of incidence angle)
- Visibility constraints (minimum elevation)

**Signal delays**
- Troposphere (including cloud cover)
- Sagnac effect (processing in ITRF)
- Shapiro delay

**Relativistic effects on clocks**
- Drift of clocks w.r.t. to UTC
  - … due to special relativity (relative velocity)
  - … due to different gravitational potential

**Stochastic components**
- Background noise
- Laser Jitter
- Pulse width
- Noise of ground- and space-based clocks
- Cloud coverage (frequency and duration)
Simulation tool
Multi-reflector problem
Reflector identification

1. Simulation

Simulation: Two-way range residuals - time series (90)

2. Transformation in Timebias space

Timebias: Difference of reflectors and ISS timebias

3. Correction of Timebias

Absolute value of ELT Reflector timebias - maximum peak

4. Identification of Reflectors

Filtered two-way range residuals of all reflectors
Binominal filtering

Unfiltered data for 1e7 noise rate/s

Filtered data for $T_x = 1.6$ and $T_y = 0.5$

Filtered data for $T_x = 2.8$ and $T_y = 0.5$

Filtered data for $T_x = 1$ and $T_y = 1$
Monte-Carlo simulations

- Data simulation and processing for identical parameters
  - Passes
  - Laser system characteristics
  - Signal propagation characteristics
  - … (neglecting multiple reflectors on the ISS)

- Randomness introduced by the following sources
  - Background noise
  - Laser jitter
  - Pulse width
  - Clock noise

- Studies without systematic errors
  - Expected to converge to “true” clock offset
  - … if filtering does not fail
  - … and yields unbiased time transfer triplets
  - How does filtering perform statistically?

- Studies with systematic errors
  - Unknown attitude and orbit errors will be present
    (particularly in quick-look processing)

- Effects of cloud coverage and other constraints on performance
## Results

<table>
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<tr>
<th>Background noise rate [1/s]</th>
<th>Noise reduction</th>
<th>Time transfer $\sigma$ [ps]</th>
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</table>
Monte-Carlo simulations

Attitude error (only roll)

4 rev/orbit
\[ \sigma = 4.4 \text{ps} \]

2 rev/orbit
\[ \sigma = 2.75 \text{ps} \]

1 rev/orbit
\[ \sigma = 0.35 \text{ps} \]
Real-time TB correction

100 m along-track orbit error, 1 m radial orbit error, constant 0.5° attitude error