Remote optical and fountain clock comparison using broadband TWSTFT and GPS PPP

Highlight Talk
International Timescales with Optical Clocks

Franziska Riedel
ITOC consortium
Motivation

Optical clocks:
orders of magnitude more accurate and stable

Demonstration of steering local timescales
with optical clocks

Grebing et al., arXiv:1511.03888

Performance of links contributing to UTC?
Motivation

Optical fibers:
Not yet available for simultaneous comparisons on international/intercontinental scale

Currently used techniques:
GPS and TWSTFT

TWSTFT currently with 2.5 / 1 Mchip/s modulation bandwidth
Effect of higher chiprate

Main TWSTFT target in ITOC: Instability of $10^{-16}$ @ 1 day
But with lower statistical uncertainty ...

... corrections must be taken into account

Effects caused by satellite motion:

Variation of path length:
leads to non-reciprocity of uplink/downlink path

Daily variation of the Sagnac effect

See poster by S. Shemar this afternoon
ITOCTWSTFT campaigns

20 Mchip/s TWSTFT:
Lease of a full Ku-band transponder (36 MHz) on SES ASTRA 3B for two campaigns

1) 24.-31. October 2014: Link test

Equipment and performance test
ITOC TWSTFT campaigns

20 Mchip/s TWSTFT:
Lease of a full Ku-band transponder (36 MHz) on SES ASTRA 3B for two campaigns

2) 4.-29. June 2015: Optical clock comparison
Yb$^+$ (E3), Sr lattice + 2 Cs fountains

Yb lattice + Cs fountain
Overall uptime up to 90%

Yb lattice from INRIM not analysed yet
In addition: TWCP measurement during first weeks, carried out by NICT:

M. Fujieda et al., Metrologia 51 (2014) 1–10
Clock comparison campaign: link performance

Broadband TWSTFT links, selected intervals

![Graph showing modified Allan deviation vs. time for various links and institutions.](image-url)
Clock comparison campaign: link performance

PTB-NPL link, broadband TWSTFT, GPS PPP and (GPS-bbTW) double difference
Clock comparison: data analysis

Maser vs. Clock #1:
Dominated by white frequency noise

\[ y_1(t) = y_{\text{clock1}}(t) - y_{\text{Maser1}}(t) \]

Maser vs. Clock #2:
Dominated by white frequency noise

\[ y_2(t) = y_{\text{clock2}}(t) - y_{\text{Maser2}}(t) \]

Calculation of \( \tilde{y}_{\text{clock1/clock2}} \approx \tilde{y}_{\text{clock1}} - \tilde{y}_{\text{clock2}} \) with respective uncertainty
Clock comparison: data analysis

Maser vs. Clock #1:
Dominated by white frequency noise

Link data:
Dominated by white phase noise & technical disturbances

Maser vs. Clock #2:
Dominated by white frequency noise

\[ y_1(t) = y_{\text{clock1}}(t) - y_{\text{Maser1}}(t) \]

\[ y_2(t) = y_{\text{clock2}}(t) - y_{\text{Maser2}}(t) \]

Calculation of \( \bar{y}_{\text{clock1/clock2}} \approx \bar{y}_{\text{clock1}} - \bar{y}_{\text{clock2}} \) with respective uncertainty:

- Pre-average over 1-day-intervals to minimize white noise and suppress diurnals
- Use different weighting functions to eliminate white phase and frequency noise, respectively
- Choose intervals with negligible gaps
- Use local Yb/Sr measurement to fill gaps in clock data
- Take serial correlations into account for the determination of the statistical uncertainties
Clock comparison results

- Sr - Sr fiberlink (Lisdat et al., arXiv:1511.07735)
- Sr - Sr broadband TW
- Yb⁺ - Yb⁺ broadband TW
- Sr - Sr GPS PPP
- Yb⁺ - Yb⁺ GPS PPP

NPL

10⁻¹⁵

Sr-Sr & Yb⁺-Yb⁺

Confidential

LNE-SYRTE

PTB
Clock comparison results

- $Yb^+_{PTB} - Sr_{NPL/LNE}$ broadband TW/
- $Yb^+_{NPL} - Sr_{LNE}$ broadband TW
- $Yb^+_{NPL} - Sr_{PTB}$ broadband TW
- $Yb^+_{PTB} - Sr_{NPL/LNE}$ GPS PPP/
- $Yb^+_{NPL} - Sr_{LNE}$ GPS PPP
- $Yb^+_{NPL} - Sr_{PTB}$ GPS PPP

Confidential

NPL

$10^{-15}$

$Yb^+ - Sr$

LNE-SYRTE

PTB
Comparison between GPS PPP and IPPP: instability of double difference with fiber link between AOS/GUM

Petit et al., Metrologia 52 (2015) 301–309
Clock compare results via IPPP

Confidential

- Sr - Sr GPS IPPP
- Yb⁺ - Yb⁺ GPS IPPP
- Yb⁺₀PTB - Sr₀NPL/LNE GPS IPPP/
- Yb⁺₀NPL - Sr₀LNE GPS IPPP
- Yb⁺₀NPL - Sr₀PTB GPS IPPP
Summary

- Comparison of several optical clocks of NPL, LNE-SYRTE, INRIM and PTB over 26 days long period via broadband TWSTFT and GPS
- Instability of satellite links in low $10^{-16}$ range
- Statistical uncertainties for broadband TW and GPS PPP in low $10^{-16}$, for GPS IPPP < $1 \times 10^{-16}$

Outlook

- Increasing the modulation bandwidth of TWSTFT yields a respective improvement of TW performance
- However, technique more suited for dedicated campaigns than for operational use
- GPS IPPP as a promising alternative, TWCP still to be compared with other link techniques