Time transfer by using SONET connections between SP and Mikes

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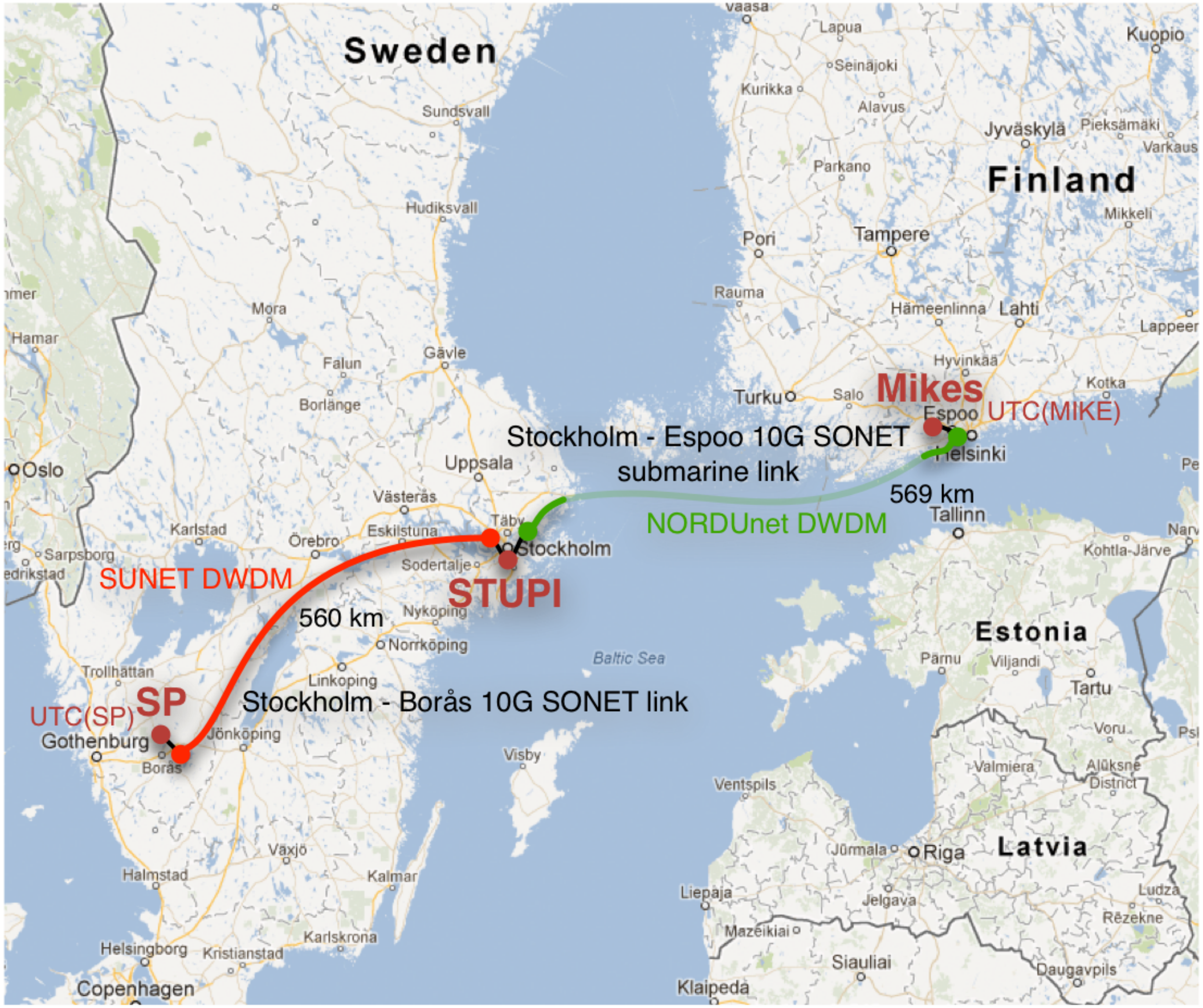
Background and acknowledgements

- A joint experiment between:
  - SP, Technical Reserch Institute of Sweden
  - Mikes, Centre for metrology and accrediation, Finland
  - STUPI, Sweden
- Funet, NORDUnet and SUNET are carriers for SONET links and provide last-mile connections
- Passive SONET frame detection and listening equipment have been developed by SP
- Setup info, figures and results in this presentation are based on a paper released at PTTI 2011 conference:
  - [1] ”**Time Transfer between UTC(SP) and UTC(MIKE) Using Frame Detection in Fiber-Optical Communication Networks**”, S-C Ebenhag et al.
- More information (”time experts”): Sven-Christian Ebenhag, SP; Mikko Merimaa, Mikes; Peter Löthberg, STUPI

Participating clock laboratories

- SP and Mikes are national time laboratories which maintain UTC representations, UTC(SP) and UTC(MIKE)
  – They contribute to TAI, the international atomic time scale
- STUPI contributes to TAI via SP and maintains its own UTC representation
- All have multiple hydrogen masers and atomic clocks in dedicated clock lab facilities

Clock labs and the link topology



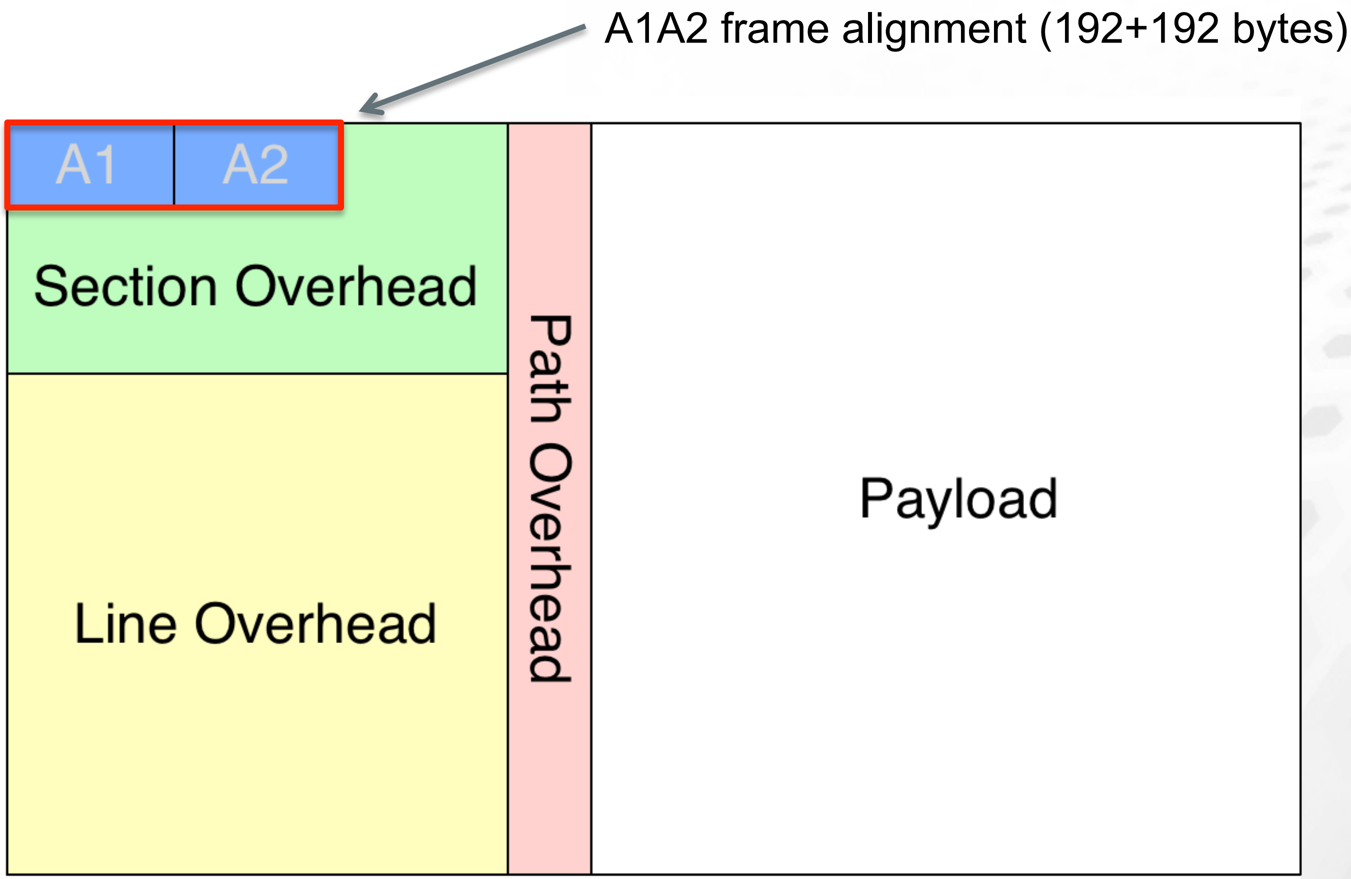
Network equipment

- 10G OC-192 SONET signal is carried over a non-modified DWDM system
  - 10G DWDM transponders for WAN links
  - Last-mile done with standard optics over dedicated single-mode dark fiber links
- Routers in both ends have normal 10G OC-192 linecards
  - SONET transmission synchronized to local router OCXO oscillator
  - Could be used to carry other unrelated traffic, but in Finland the router (Cisco 12k) does not officially support these cards ie. the backplane is too slow
- Passive SONET frame listening and detection done just before/after the router client ports

Time Transfer Units

- Passive listening and detection done both in transmit and receive ends
  - Between DWDM transponder client and router ports, near the router end
  - 1% optical splitter in Tx, 10% optical splitter in Rx
- Listens and detects SONET frames
  - Frame length 125 µs
  - Every frame starts with well-known A1 and A2 sequences (frame alignment), both 192 bytes in OC-192
  - This A1A2 is detected
- A reference marker is generated (electrical pulse) when a full A1A2 sequence is detected

SONET OC-192 frame detection



Time Transfer Units

- SP developed hardware

Source: [1]

Source: [1]

2U TTU hardware, more details:

[2] K. Jaldehag, S. C. Ebenhag, C. Rieck, and P. O. Hedekvist,
”Time Transfer Using Frame Detection in Fiber-Optical Communication Networks: New Hardware,”
in Proc. of the 2011 Joint Conference of the IEEE International Frequency Control Symposium
& European Frequency and Time Forum, San Fransico, California, USA, pp. 300 – 303, 2011.

A low cost initiative

- Starting point: no budget
- Step 1: reuse old NREN hardware
  - Old SUNET Cisco 12k was available with prototype OC-192 linecards fitted in (provided by Peter)
- Step 2: reuse old NREN uplink connectivity
  - Funet had just switched its NORDUnet links to Ethernet, so old STM-64/OC-192 waves were “available”
  - NORDUnet agreed to provide a 10G wave free-of-charge for testing period (which still continues…)
- Step 3: reuse existing last-mile fiber in Finland which was rented for other use (an NTP service cold spare)
- Step 4: TTU (and the router) was loaned and carried to Mikes, researchers made the installations and spliced the fibers needed
- Result: a 10G international wave, without any traffic, just to listen some frame alignment bytes in empty frames

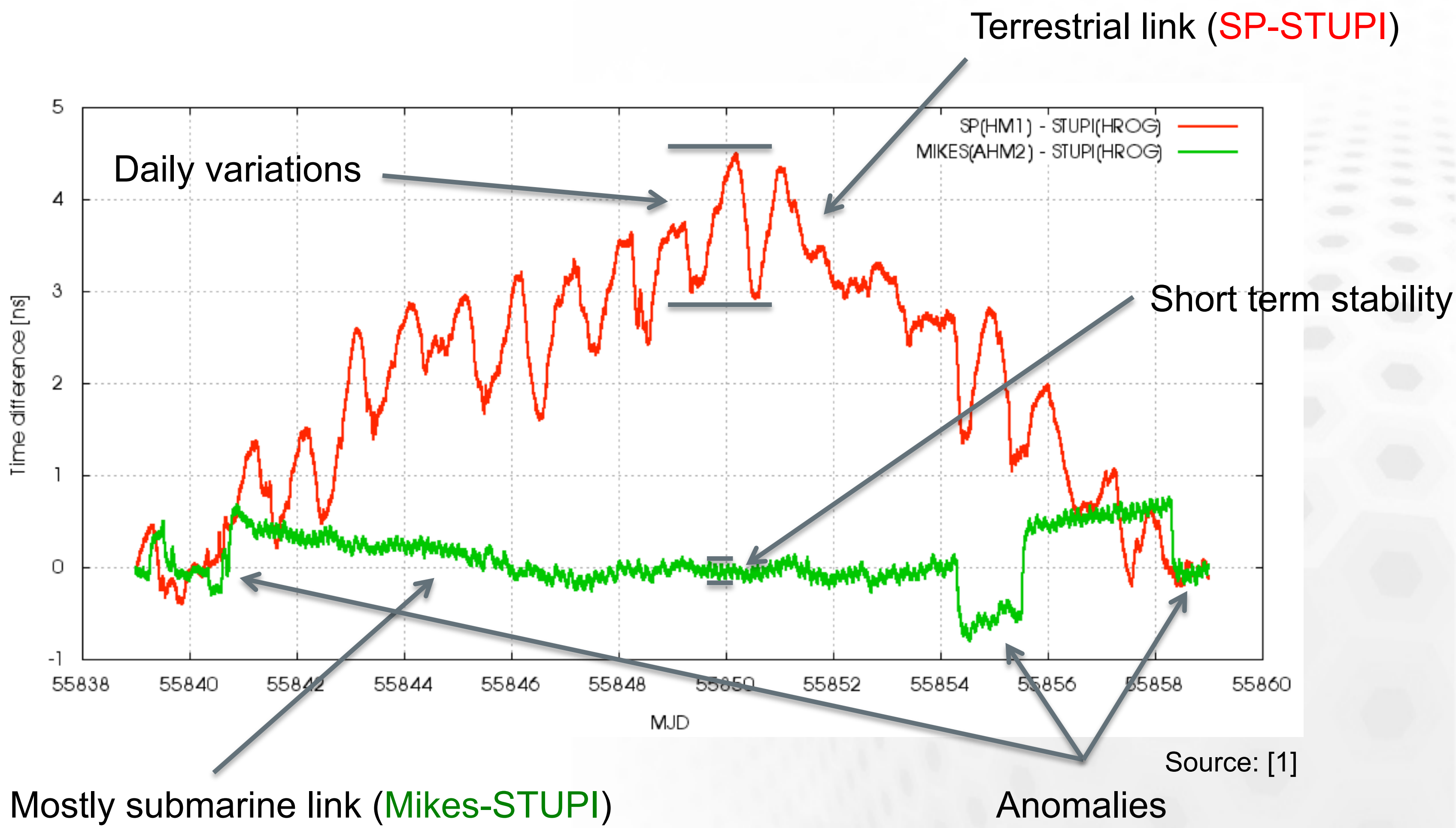
Measurements

- Measurements were done for two spans
  - SP(HM1) – STUPI(HROG)
  - MIKES(AHM2) – STUPI(HROG)
- Third result was calculated from these
  - UTC(MIKE) – UTC(SP) =

    {[UTC(MIKE) – MIKES(AHM2)] + [MIKES(AHM2) – STUPI(HROG]} –
    {[UTC(SP) – SP(HM1)] + [SP(HM1) – STUPI(HROG)]}
- and from local measurements with short term noise < 50 ps
  - [UTC(MIKE) – MIKES(AHM2)]
  - [UTC(SP) – SP(HM1)]
- Measurements were done between July and October 2011

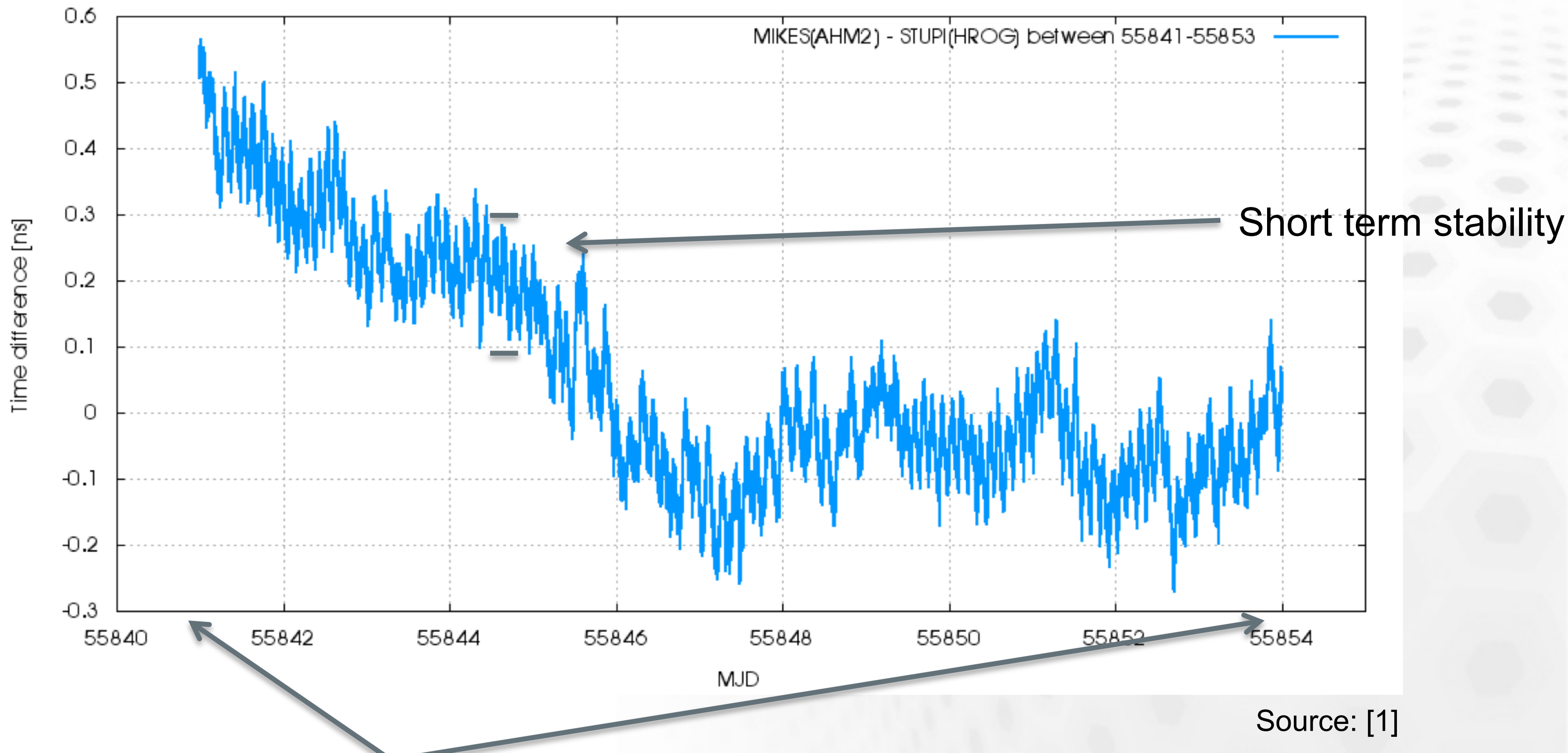
SP(HM1) = active hydrogen maser
MIKES(AHM2) = active hydrogen maser
STUPI(HROG) = steered time scale referenced to hydrogen maser, not steered during the measurements

Clock difference SP-STUPI and Mikes-STUPI



Source: [1]

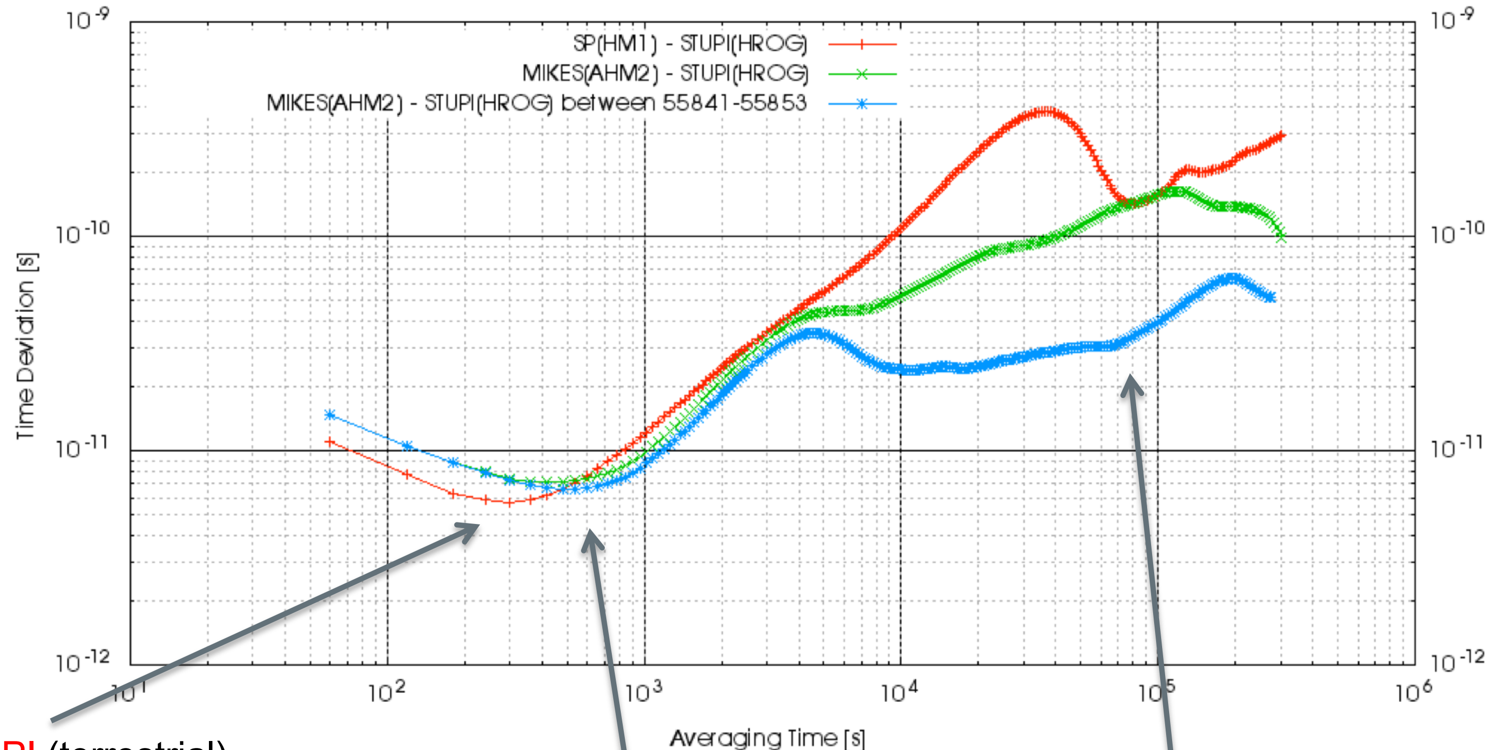
Clock difference MIKES-STUPI "best results"



Source: [1]

Period of MIKES-STUPI measurement between MJD 55841 - 55853

Time stability



SP-STUPI (terrestrial)
5-6 ps at 300 s

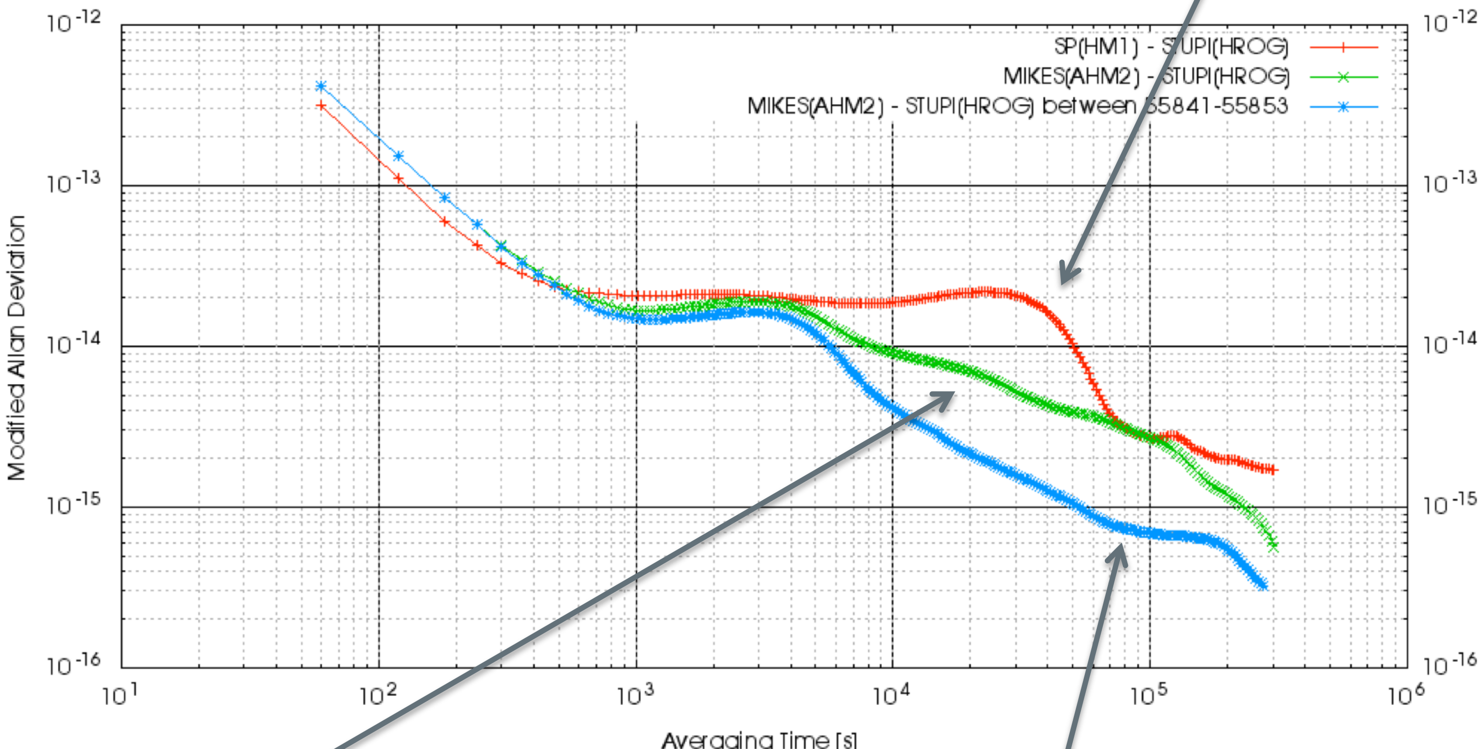
Mikes-STUPI (submarine)
6-7 ps at 600 s

Source: [1]

Mikes-STUPI "best results" (submarine)
30 ps at one day (80400 s)

Frequency stability

SP-STUPI



Mikes-STUPI

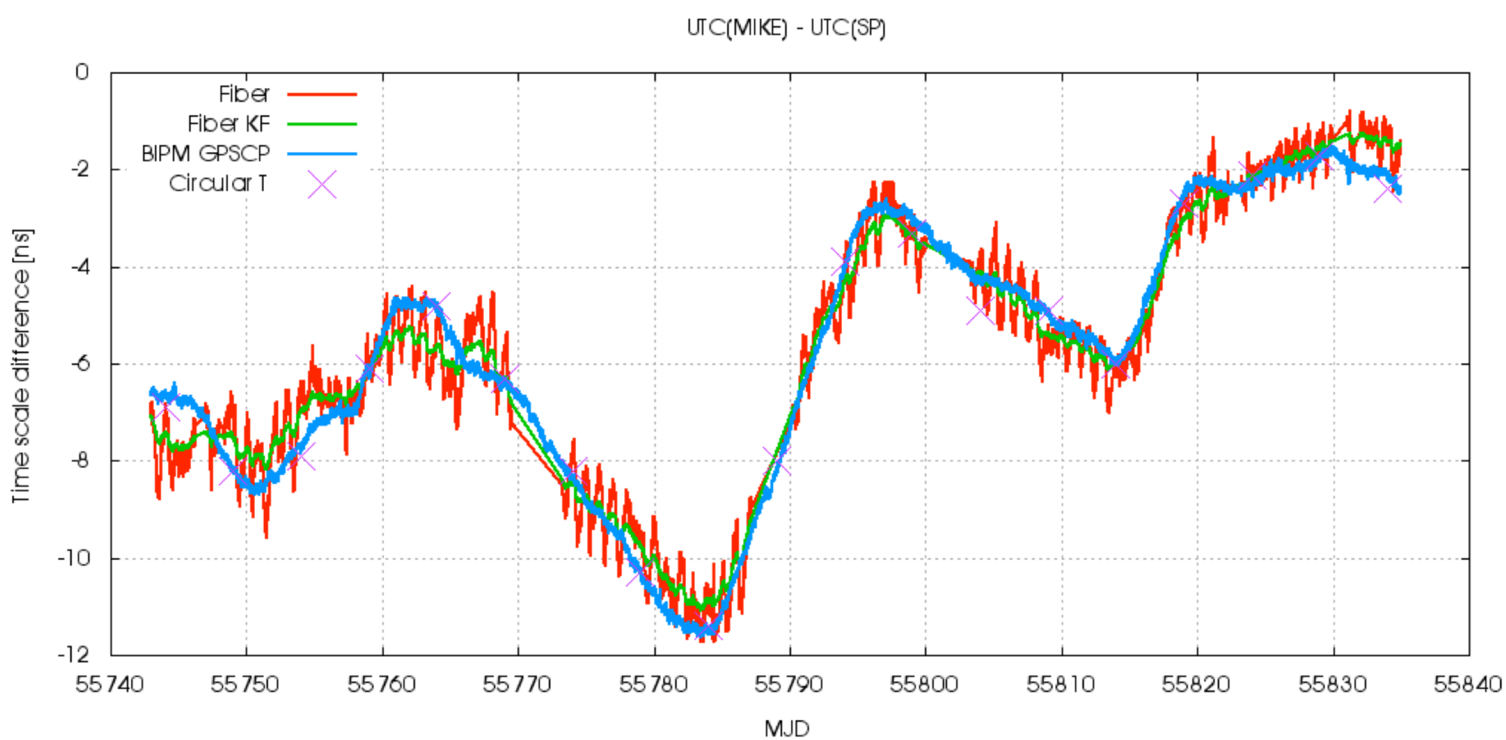
Source: [1]

Mikes-STUPI “best results”
8E^{-16} at one day (80400 s)

Time comparison SP-STUPI and Mikes-STUPI

- SP(HM1) – STUPI(HROG)
  - Time stability approaching 5-6 ps at averaging time 300s
  - Daily variations up to 2 ns
    - Temperature changes and asymmetric paths?
  - Frequency stability approaching 3E^{-15}
- MIKES(AHM2) – STUPI(HROG)
  - Time stability approaching 6-7 ps at averaging time 600s
  - No similar daily variations, but short term stability worse
    - Fiber located in seabed of the Baltic Sea
    - Short term stability affected by clock noise?
  - Anomalies up to 200 ps with a period 2 to 4 hours
  - “best results” time stability 30 ps and frequency stability 8E^{-16} over one day

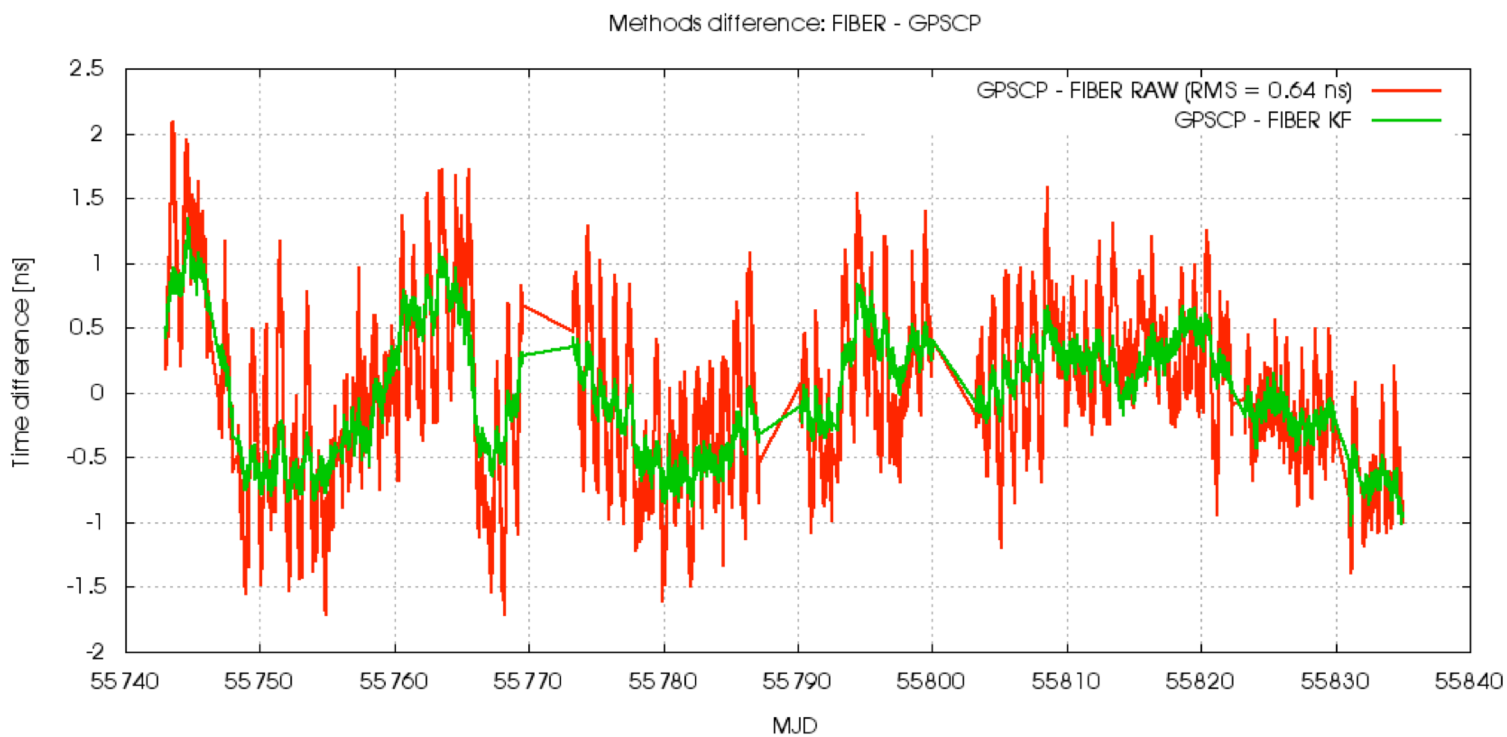
Time scale difference UTC(MIKE) – UTC(SP)



Source: [1]

MJD = Modified Julian Date
Fiber = fiber link with arbitrary offset
Fiber KF = Kalman smoothed fiber link
BIPM GPSCP = GPS carrier-phase (GPSCP) link as retrieved from BIPM
Circular T = BIPM Circular T data

Comparison to GPS time link



MJD = Modified Julian Date

Fiber = fiber link with arbitrary offset

Fiber KF = Kalman smoothed fiber link

Source: [1]

Results

- Able to achieve with TTU hardware
  - Time stability of < 6 ps over 300 seconds
  - Frequency stability < $1E^{-15}$ over one day
- Daily variations a few nanoseconds, due to
  - Temperature changes in the optical path (network equip., fibers etc.)
  - Asymmetric fiber paths (including dispersion compensation)
- RMS-agreement < 1 ns for longer term
  - Based on comparison to GPS time link over 3 months

RMS = Root Mean Square

Thanks

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