Optical Time Transfer (OTT): Application in Telecommunication Networks and PoC Results

Helmut Imlau et. al., June, 14th 2016

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Optical Time Transfer

Agenda

Partners and participants ............................................................................................................................................

1. Hierarchical network synchronization and supervision .................................................................

2. Sync network supervision methods: GNSS Common View ............................................................

3. Optical Time Transfer (OTT) .................................................................

4. OTT Proof-of-Concept (PoC): Purpose and setup ........................................................................

5. PoC Results by DT and PTB: Time Error, MTIE and TDEV ...................................................

6. Summary, outlook ........................................................................................................................................
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Partners, participants

Participants:

Schnatz H., Bauch A., Piester D.
Physikalisch-Technische
Bundesanstalt
(PTB)
Braunschweig, Germany
Harald.Schnatz@ptb.de

Śliwczynski Ł., Krehlik P.
AGH University of Science and
Technology Department
of Electronics
Krakow, Poland
sliwczyn@agh.edu.pl

Imlau H., Ender H.,
Barasi, M., Habighorst, U.
Deutsche Telekom Technik GmbH
Fixed and Mobile Engineering
Bremen, Germany
Helmut.Imlau@telekom.de

Tasks:

- National Metrology Institute,
realization and dissemination of UTC(PTB) and
German legal time
- Clock and time transfer development
- OTT ‘ELSTAB’ development
(Electronically STABilized fiber optic time
and frequency distribution system [1])
- Network operation including
synchronization network
- Obtains traceability to UTC via
its UTC(DTAG) time scale
- UTC(PTB) provision
- System installation
- System supervision
- System repair
- Link calibration
- Fiber link and remote access planning and
provisioning
- Telecommunication domain and GNSS
Common view measurements

1The measurement data evaluation was supported by Lee Cosart of Microsemi with Time Monitor software

For OTT PoC:

- UTC(PTB) provision
- T&F domain measurements

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1. Hierarchical network synchronization solutions by ITU-T & more

Network operation needs a synchronization supply solution

- (1) Ethernet Physical Layer Synchronization (SyncE acc. to G.826x series) in combination with
- (2) Precision Time Protocol (PTP) with Full Timing Support from the network (PTP-FTS) or A-PTS
  acc. to ITU-T (G.827x series) can disseminate the required time quality.

A hierarchical synchronization network consists of several levels

- A separate layer is recommended for synchronization network supervision (in yellow).

For 24/7 synchronization dissemination:

Based on the needed maximum time error of end-application, a hierarchical synchronization network is needed (in gray)

| Supervision level | Architectural level | max|TE| | No. of Locations | Methods, Systems |
|-------------------|---------------------|-----|----|-----------------|-----------------|
| GNSS based Common View | Optical Time Transfer | \(\pm 1\) ns \(\pm 10\) ns ** | 3-5 | OTT |
| Network core level | | \(\pm 30\) ns | 10/20 | e/cnPRTC* |
| Aggregation level | | \(\pm 100\) ns | 1.000 | T-BC, PRTC |
| Base station level | | \(\pm 1.1\) \(\mu\)s | n*10.000 | T-TSC |

*) For ePRTC / cnPRTC please refer [2] [3]. **) averaged values
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2. Network supervision using GNSS Common View

- UTC(k) labs *) operate GNSS dual-frequency code and carrier-phase receivers
- Generate data files according to standard format CGGTTS (ionosphere-free combination L3P) and make them publicly available, specifically for BIPM
- BIPM calculates TAI/UTC and reports UTC-UTC(k) deviation to each contributor (via “Circular T”)

BIPM = Bureau International des Poids et Mesures
CGGTTS = Common GNSS Generic Time Transfer Standard
L3P = L (1+2=3) Carrier Phase

For Telecommunication:
- Method could be used by network operators to compare primary clocks
- Expensive specific T&M receivers, calculation effort
- No physical synchronization transfer

*) k= NIST/USNO/NPL/PTB/DTAG/……. 
3. The method: OTT/ELSTAB (1/3)

The fundamental time transfer problem over optical fibers:
- Delay variation (e.g., wander in a order of 40ps/km/K due to temperature effects over the year) to be compensated (as it is done by time stamp calculation like NTP/PTP method at a lower accuracy level)

The **ELectronic STABilization (ESTAB)** solution:
- Active frequency propagation delay (electronic) stabilization of the optical link
  1. Phase detector measures the phase difference between the input and feedback signal (Round-trip including variable delay lines (blue) in both directions)
  2. Variable delay lines in forward and return path (same values for both direction)
  3. Modified delay due to phase measurements (ASIC includes phase detector & variable delay lines)
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3. The method: OTT/ELSTAB (2/3)

Assumptions:

- Same delay fluctuations (wander) effects in both directions due to same fiber and more or less similar wave length (Only chromatic dispersion and Sagnac effect to be compensated)
- Same values of variable delay compensation in both directions

The stabilization solution:

- DLL (Delay Locked Loop) with variable delay modules keeps round trip delay constant

\[
\Delta t_{DF} + \Delta t_{L\rightarrow R} + \Delta t_{R\rightarrow L} + \Delta t_{DB} = \text{const}
\]

\[
\Delta t_{DF} + \Delta t_{L\rightarrow R} + \Delta t_{R\rightarrow L} + \Delta t_{DB} = 0
\]

\[
\Delta t_{DF} + \Delta t_{L\rightarrow R} = 0
\]
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3. The method (4/4)

Extension for 1PPS transfer

At A:
- Every second, specific phase modulation is applied on frequency signal at ‘PPS embedder’
- ‘De-embedder’ extracts the 1PPS
- Round-trip delay measured between 1PPS ref out and 1PPS return out

At B:
- 1PPS out calculation with ½ round trip delay
  + corrections due to chromatic dispersion, + Sagnac effect  1ns/100 km east-west correction
- currently manually performed, may be implemented into the OTT ELSTAB system
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4. Proof-of-Concept: Purpose and setup

- Feasibility of OTT over an existing fiber network to transfer frequency and phase/time synchronization over around 450 km.
- Use of optical mono-mode fiber cables laid between 2000 (14%) and 2015 (2%).
- Use optical fiber type: ITU-T G.652 acc. to valid specification at installation year.

Diagram:

- Local Module
  - 10 MHz
  - 1 PPS
  - 77 km

- Remote Module
  - 10 MHz
  - 1 PPS
  - 77 km

- Tap Module
  - 10 MHz
  - 1 PPS

Connections:

- Braunschweig to Peine: 77 km
- Peine to Hannover: 53 km
- Hannover to Nienburg: 48 km
- Nienburg to Bremen: 46 km

Note: 7 bidirectional amplifier.
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5. Measurements and evaluation by DT

Time Transfer Braunschweig-Bremen-Braunschweig ≈ 450 km

- blue: 1PPS CV (L3P data)
- brown: 1PPS counter measurement
- green: 10 MHz counter measurement

UTC(PTB)

PT02 L3P data

GTR-51 L3P data

blue: L3P-DT09 minus L3P-PT02 (1 hour average values)

brown: 1PPS result (Braunschweig / 53230)

Time Error

(fixed constant time error is not considered)

malfunction occur with laser wavelength stabilization

LIFE IS FOR SHARING.
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5. Measurement and evaluation by DT
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5. PTB view

Measurement setup

10 MHz:
- K&K frequency counter, direct mode
- with frequency difference multiplication by 128 in order to increase the measurement resolution (DMTD = dual mixer time difference method), for stability assessment

1 PPS:
- Evaluations performed using low-noise counters: Stanford Research SR-620, PikTime T4100U

Measurement results:
- TDEV(@ $\tau = 1$ s) $\approx 6$ ps
- TDEV(@ $\tau = 10^4$ s) $\approx 1$ ps

Conclusions for metrological application:
- After initial calibration: time transfer uncertainty in the loop BS-Bremen-BS $< 0.1$ ns.
- Method suited for UTC(k) comparisons
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Summary

Metrology view:

- Perfect to compare different UTC(k) time scales, like UTC(PTB) ⇔ UTC(DTAG)

Telecommunication network operator view:

- Outstanding performance, well below 1 ns
- Only for a few links at highest accuracy level due to need for dedicated optical fiber, need for manual calibration

Areas for improvements:
- fault, performance and security management via Element Management System (EMS) with North-Bound Interface (NBI) needed
- output squelching in case of problems needed

Currently, a scientific method rather than a telecommunication ‘carrier grade solution’, perfect for ‘supervision’ layer, less perfect for 24/7 ‘production’ layer.
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Outlook

Currently, OTT

- can be used for time dissemination and/or to measure primary clocks remotely
- allows better primary clock comparison than GNSS CV as used for TAI/UTC
- performs well for telecommunication synchronization supervision (< 1 ns) over existing (including older) fibers
- requires specific operational attendance

In future, OTT

- may be developed as ‘carrier grade solution’
- may be sufficient for synchronization network ‘production layer’ (if needed)
Thank you very much
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Thank you very much!

References:

[1] P. Krehlik; L. Sliwczynski; L. Buczek; J. Kolodziej; M. Lipinski,
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„Towards sub-nanosecond synchronization of a telecom network by fiber optic distribution of UTC(k)”

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Latest draft for September 2016 plenary meeting