PTP and White Rabbit time distribution over optical fibre networks

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CLONETS
CLOCK NETWORK SERVICES

Overview

- Introduction to time transfer protocols NTP, PTP and White Rabbit
- The NPL*Time*® PTP service
- Testing White Rabbit over optical fibre links

Introduction to PTP and White Rabbit

PTP is a two-way time transfer protocol used to synchronize clocks throughout a computer network

- Can achieve accuracy in the sub-microsecond range
- Used to synchronise financial transactions and telecoms networks to a reference clock
- Can provide precise timing in GNSS denied environments

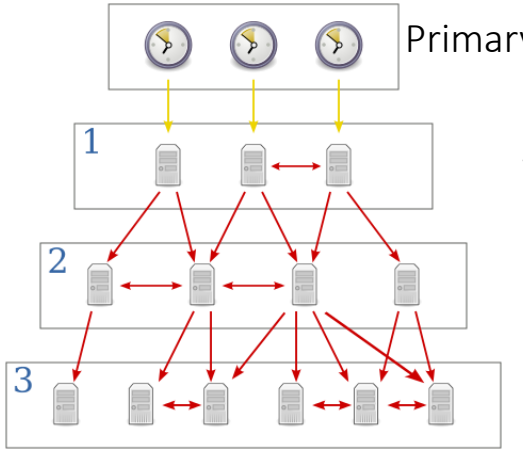
White Rabbit is an extension of PTP to achieve much higher performance

- Can achieve sub-ns accuracy
- Was developed at CERN to provide accurate time synchronisation for the particle detectors
- Originally intended to operate over 10km links, but sub-ns synchronisation has been demonstrated over 1000 km fibre links
- Used to synchronise financial transactions in Madrid (see poster from Seven Solutions) and Milan, and radio astronomy eg. SKA

Two-way time transfer over a network: NTP

- Network Time Protocol (NTP) is for clock synchronization between computer systems over packet-switched, variable-latency data networks
- Timestamps are generated in software; easy to implement and cost effective
- Either a client-server model, or peer-to-peer relationship where both peers consider the other to be a potential time source
- Errors of 100 ms or more can be caused by asymmetric routes or variable queueing time in network routers and switches
- NTP can synchronise computer clocks to within a few milliseconds (ms) of UTC

ntp1.npl.co.uk and ntp2.npl.co.uk



The blue numbers are the stratum numbers; yellow arrows show a direct reference connection, while red arrows show a network connection.

Round trip time

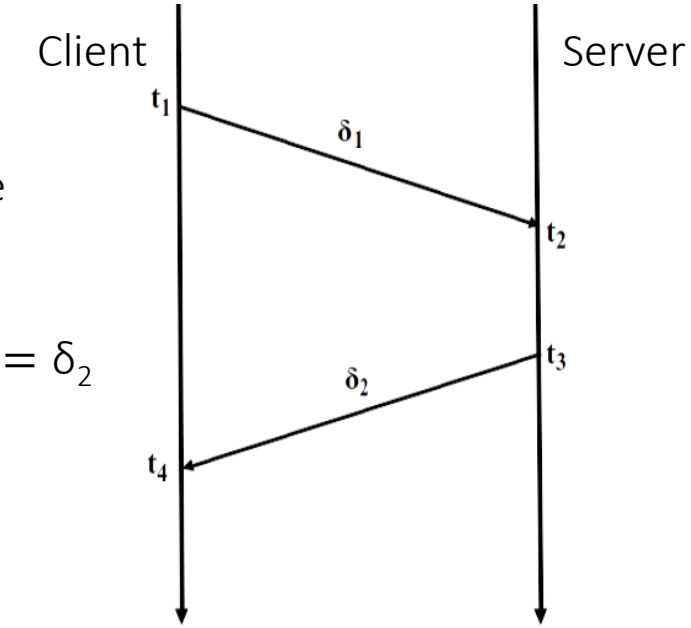
$RTT = \delta_1 + \delta_2$

Assume $\delta = \delta_1 = \delta_2$

$\delta = \frac{RTT}{2}$

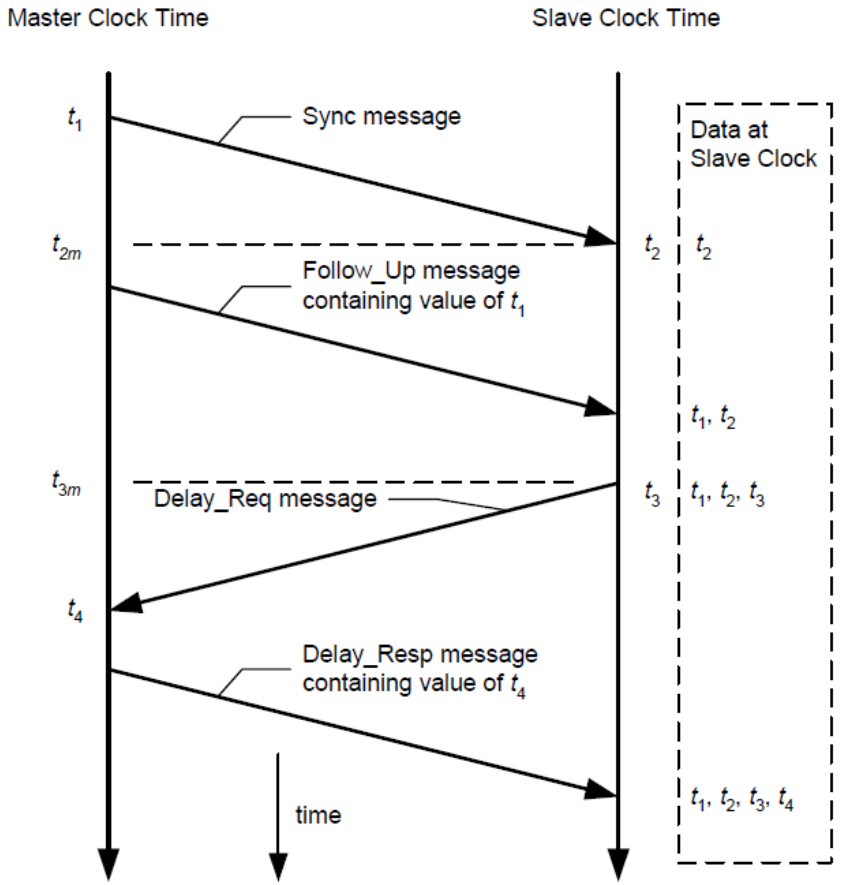
Clock Offset

$T = t_2 - t_1 - \delta$



PTP

- Precision Time Protocol or the IEEE 1588-2008 v2 current Standard (Revised standard coming soon: IEEE 1588-2019 v2.1)
- Packet-based protocol for message exchange over the Internet
- Master-slave hierarchy for clock distribution
- Hardware timestamps are implemented by PTP hardware devices to remove the slow and unpredictable software response times
- PTP compatible switches and routers: transparent clocks or boundary clocks remove the queueing time
- Asymmetry can cause time offsets as network delays are assumed to be the same in both directions: Calibration is required
- Master-slave synchronisation to within 100ns, typical accuracy is 1µs to a UTC reference



$\delta ms = t_2 - t_1 \quad \delta sm = t_4 - t_3$

$$\text{Slave offset from master} = \delta ms - \frac{\delta ms + \delta sm}{2}$$

White Rabbit

White Rabbit (WR) is an Ethernet-based network with low latency, deterministic packet delivery

- Synchronous Ethernet
- Digital phase measurements
- Precisely evaluates the master-slave delays from the round trip time

Measurement of the link asymmetry

- WR can be implemented over a single fibre in a bi-directional two-wavelength configuration: asymmetry due to difference in wavelength propagation
- Dual fibre operation with a single wavelength: fibre asymmetry leads to a time offset

WR is an Open Source collaboration

- Resources can be found at

https://www.ohwr.org/projects/white-rabbit

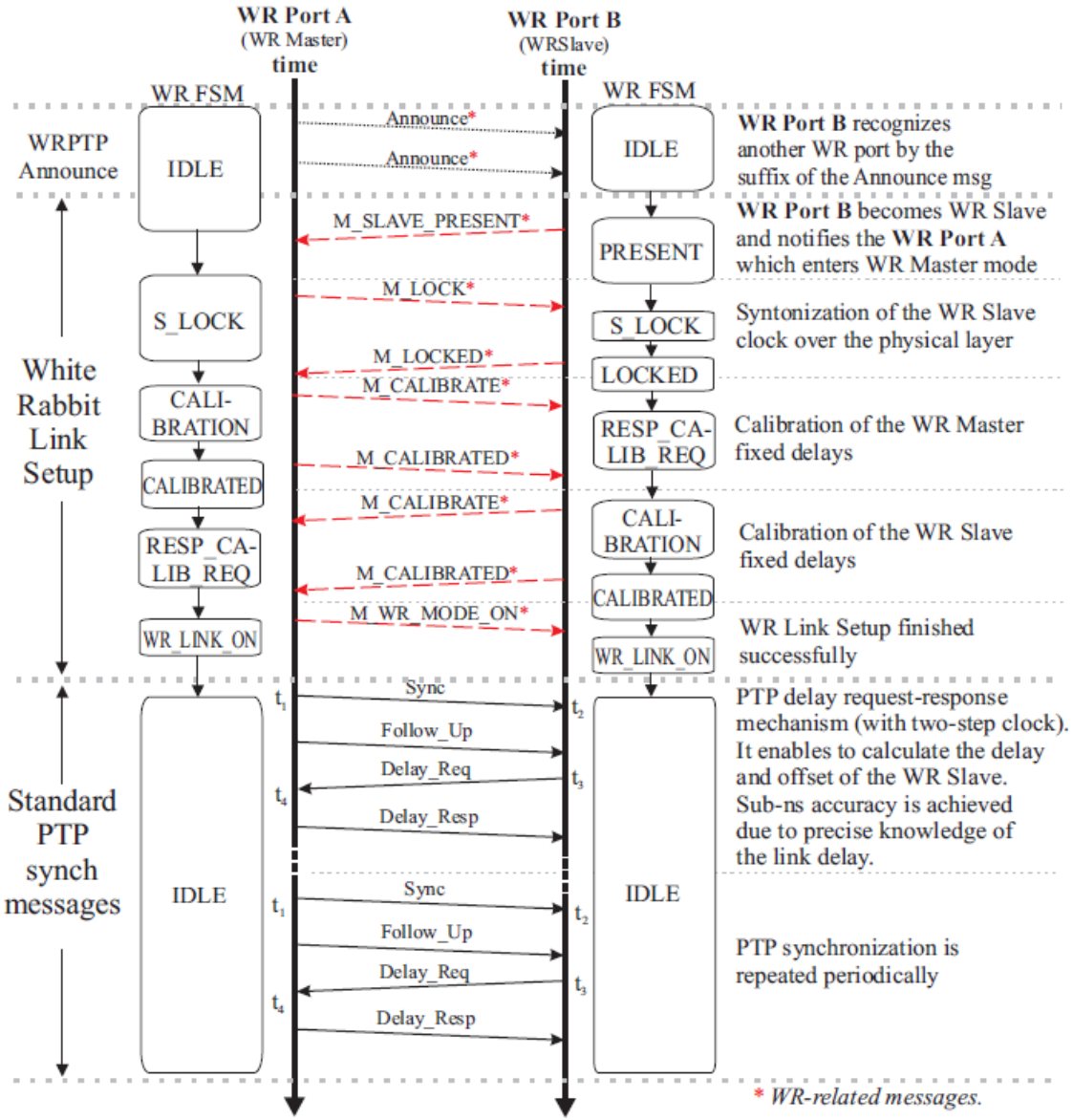


Figure: https://www.ohwr.org/project/white-rabbit/uploads/cfc34350adcbf5156f968fac0b9301b5/ISPCS2011_WR.pdf

Introduction to the NPL*Time*® service

NPL*Time*® takes advantage of the UK national timescale UTC(NPL) to disseminate a time signal via fibre optic link to customers in the City of London and beyond

IEEE 1588 v2 (PTP) is used to provide end users with resilient and certified timing and synchronisation of systems to a high level of accuracy

Time signal is independent of GPS with caesium clock holdover in the City

The service is monitored by NPL and guaranteed to within ± 1µs of UTC(NPL)

Now being delivered as a fully commercial service to banks and stock exchanges in partnership with distributors:

Compliant with new EU regulations for the finance sector MiFID II RTS-25

EU Finance Sector regulation: MiFID II

EU legislation called Markets in Financial Instruments Directive, or MiFID II, came into effect on 3rd January 2018. It includes requirements on business clock synchronisation to UTC and timestamping granularity.

RTS-25: Clock Synchronization of Trade data

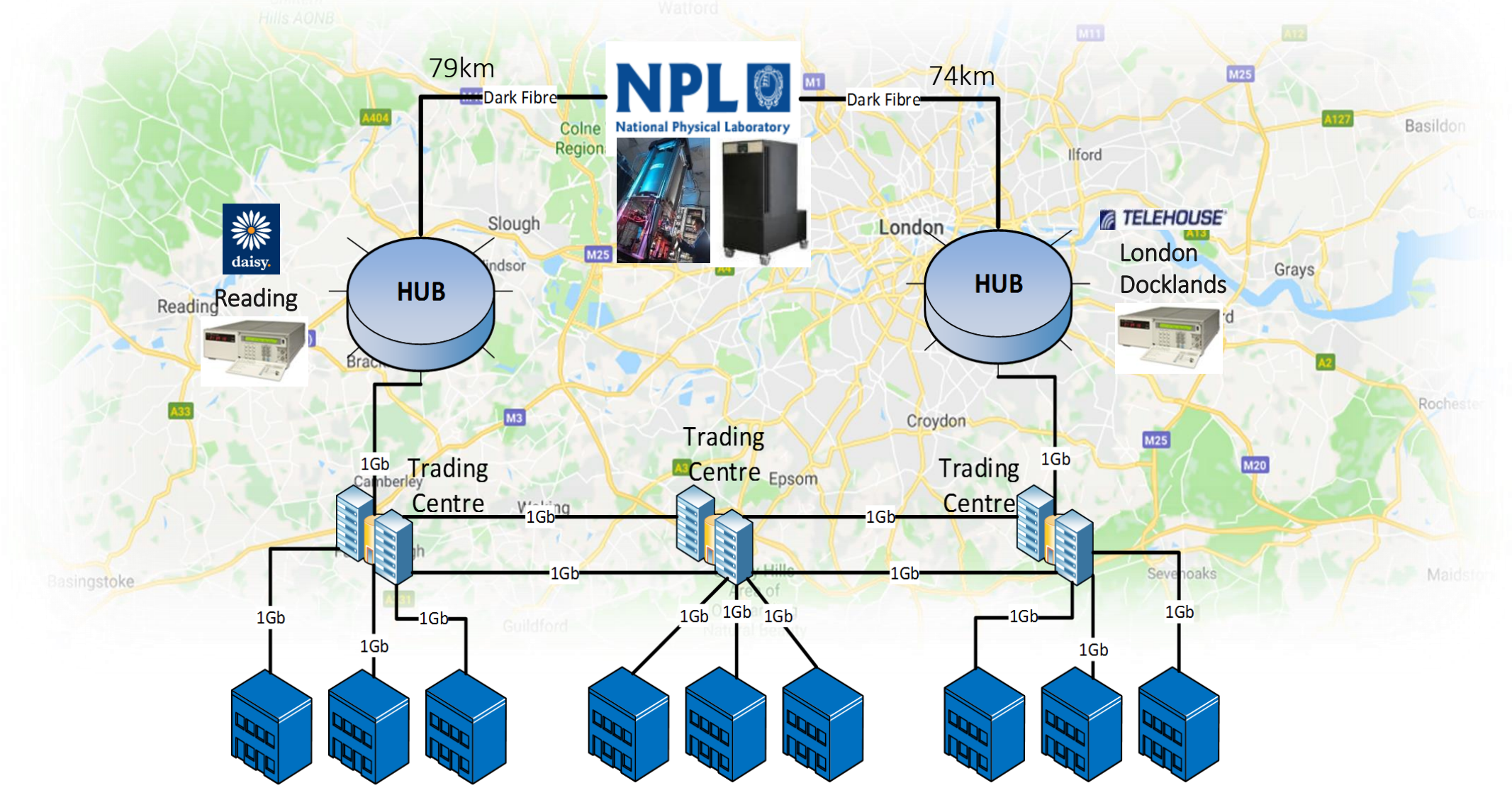
Operators of trading venues and their participants shall establish a system of traceability to UTC.

- Demonstrate traceability to UTC by documenting the system design, functioning and specifications
- Identify the exact point at which a timestamp is applied
- Traceability compliance reviews conducted at least once a year

Type of Trading	Granularity of Timestamp	Max. Divergence to UTC
Voice trading	1 s	± 1 s
All other trading	1 ms	± 1 ms
High frequency trading	1 µs	± 100 µs

The aim is to prevent trading irregularities and provide a consolidated audit trail

Current NPL*Time*® distribution over optical fibre



NPL*Time*® distribution overseas

Fibre paths set up by distributor NexGen to facilities outside the UK for NPLTime service delivery

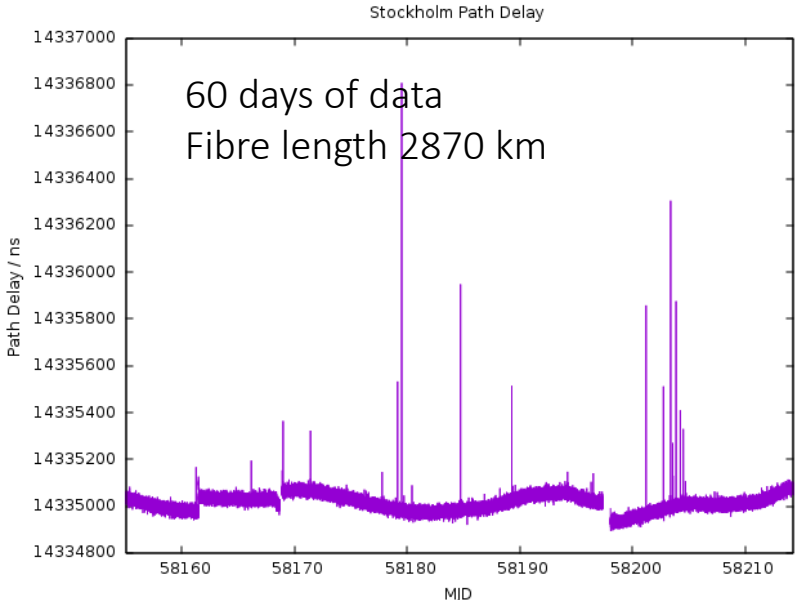
Standard duplex fibre pairs: configured as 10 Gb/s Ethernet waves (LAN PHY) using DWDM equipment

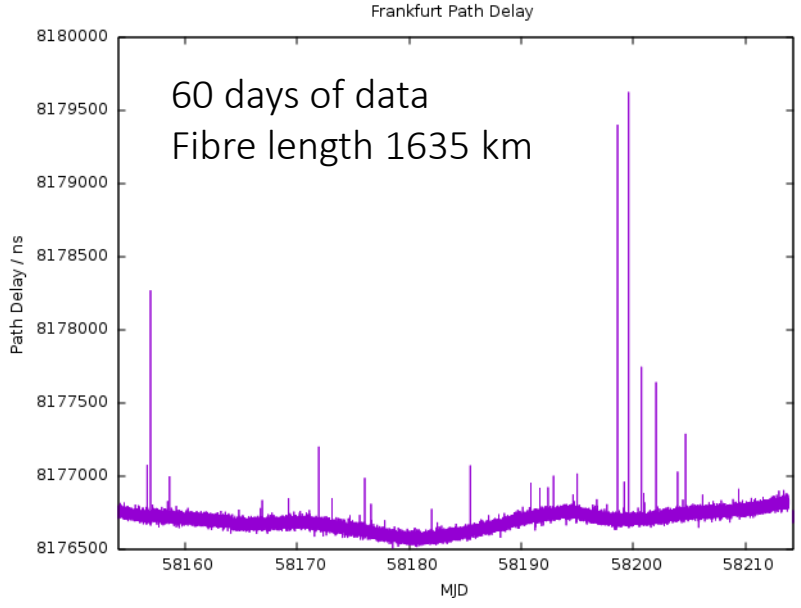
Transport technology is OTN (OTU2)

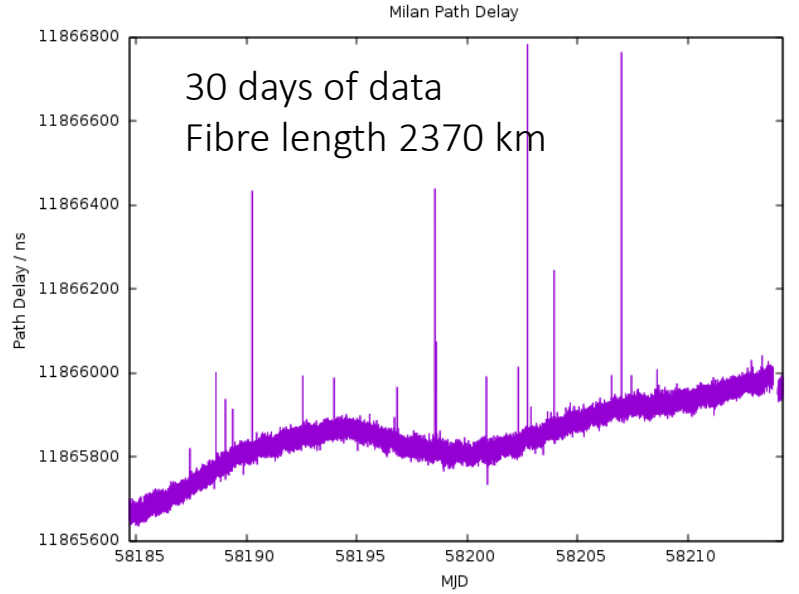
Equipment is either Ciena Long Haul or Transmode Metro

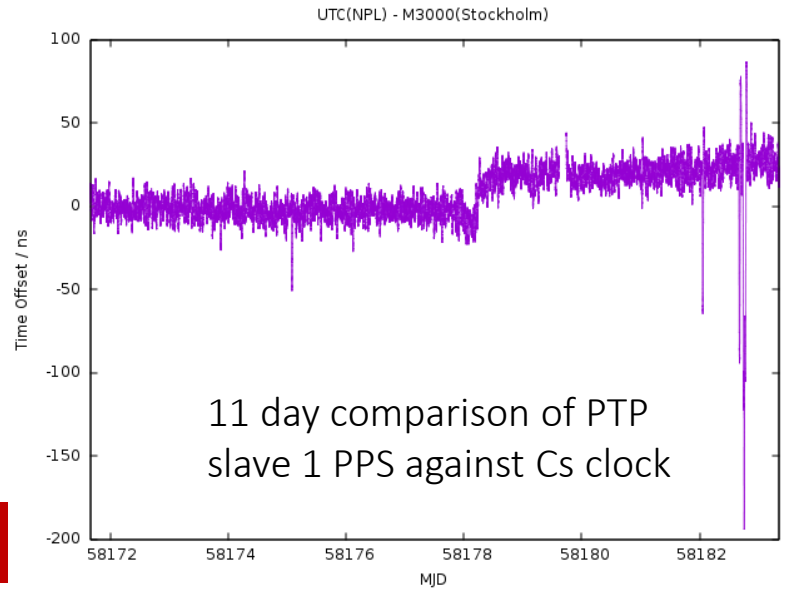
Results from PTP distribution over long-distance OTN links indicate no significant degradation in performance

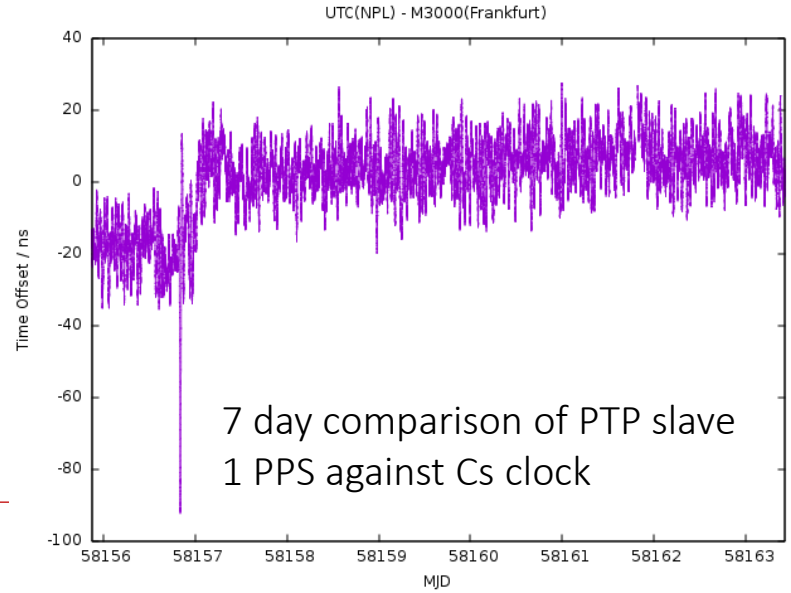
PTP path delay and Cs clock comparisons

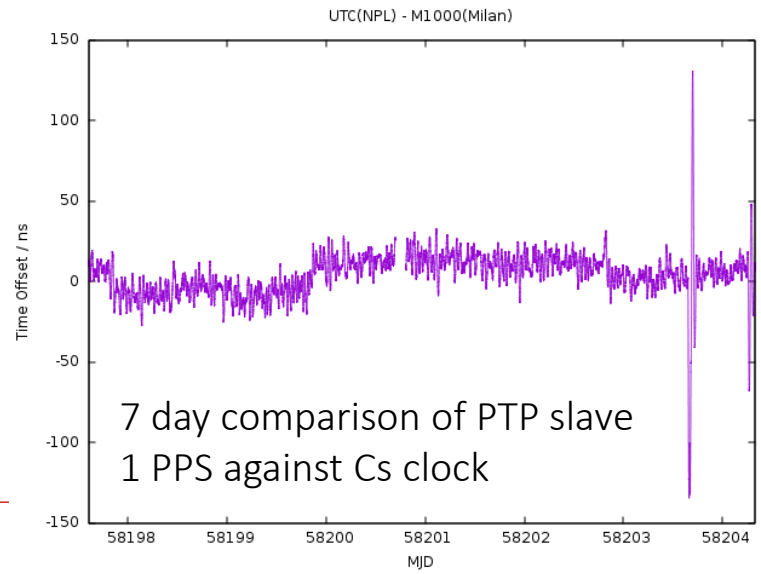






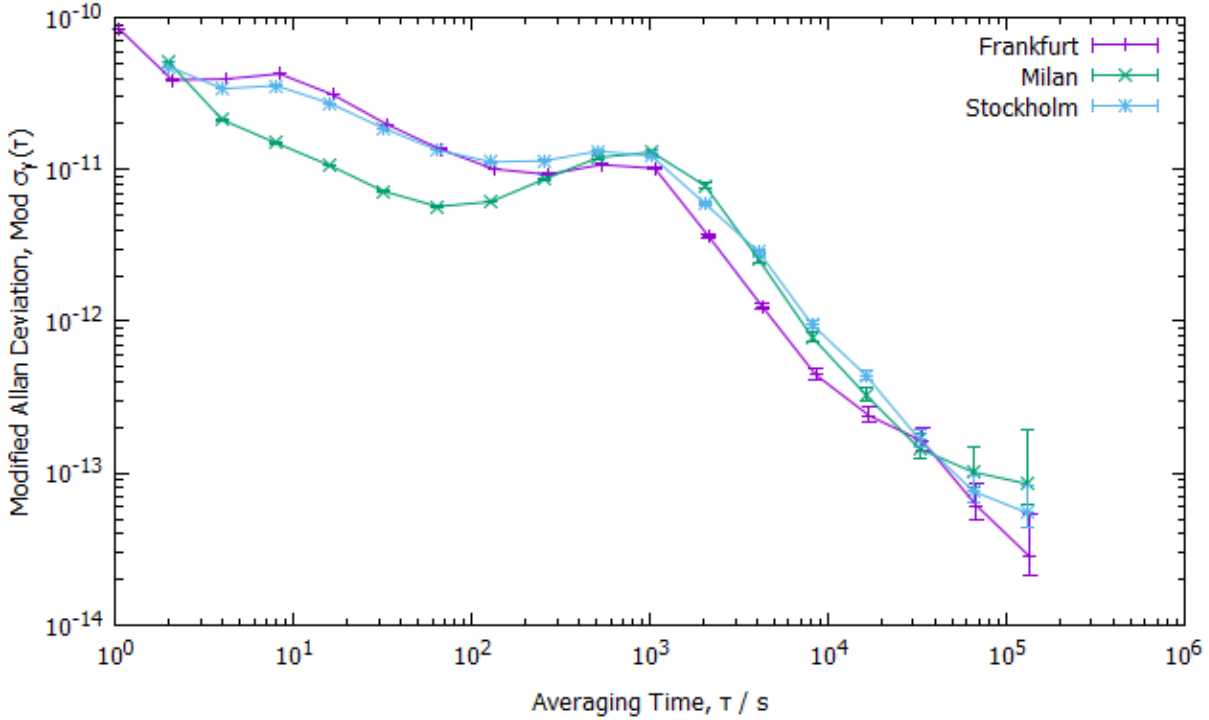






PTP stability over long-distance fibre links

MDEV



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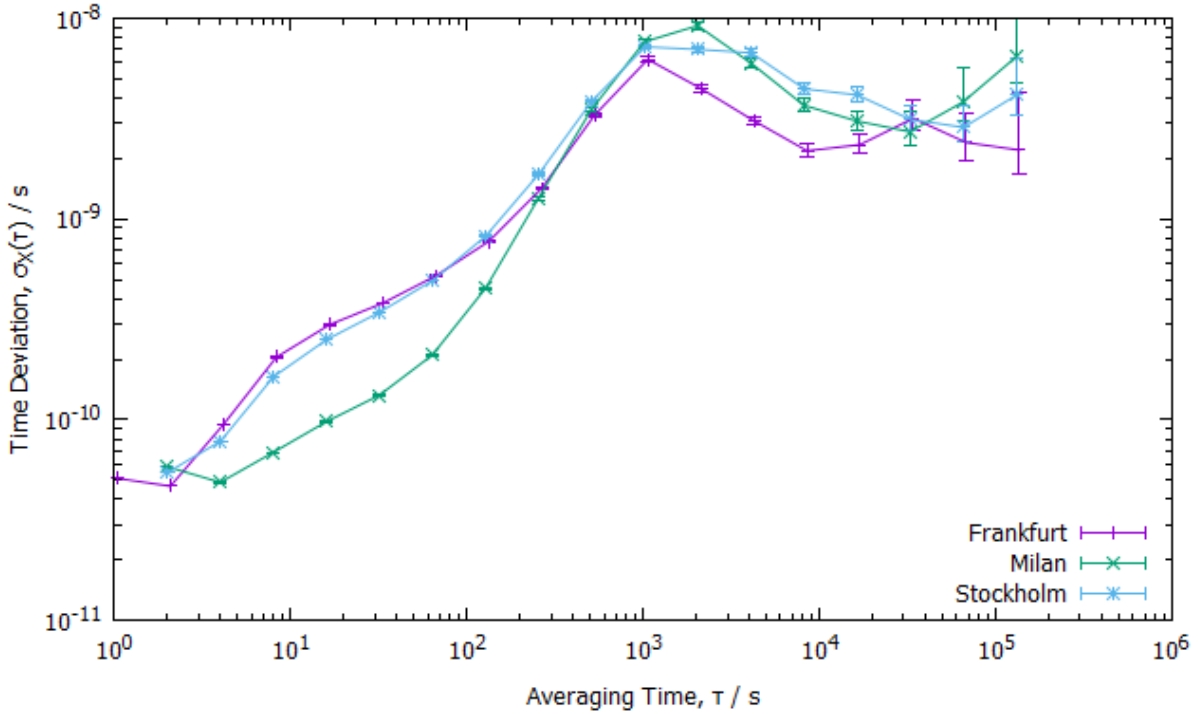


Future Applications for NPL*Time*®

- Finance sector:

Expansion of the service to customers at new locations, dependent on availability of suitable fibre links

- Power grids:

Phasor Measurement Units,
Sync accuracy <1µs (error – 0.022deg (60Hz))
Disturbance monitoring <2ms to UTC
Fault location <1µs (300m uncertainty)

- Telecoms:

4G/LTE A (<150 Mbps) 1.5µs
5G (10-100 Gbps) 200ns

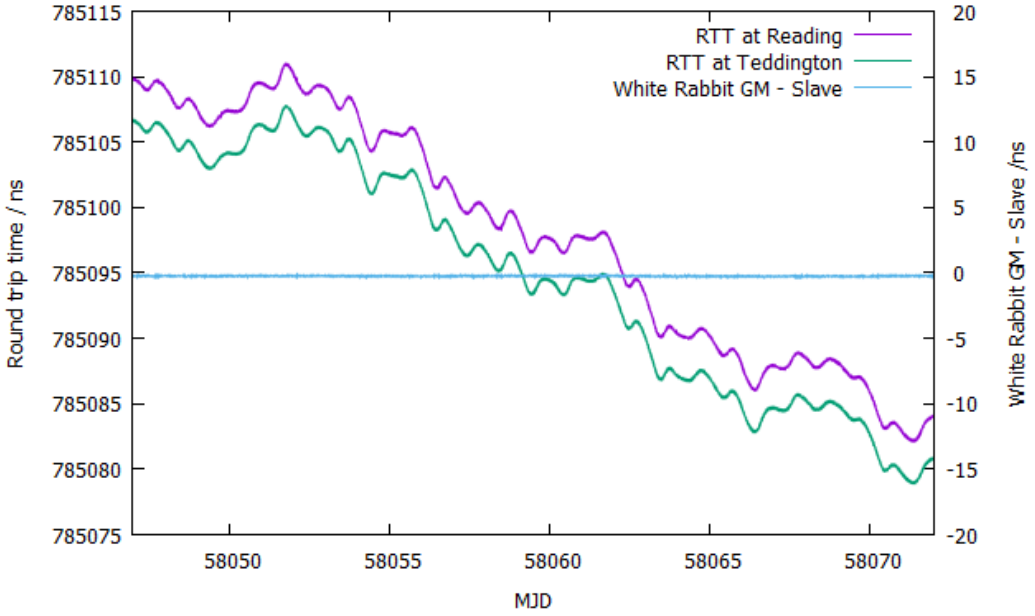
The Blackett Review: A Government Study of Critical Dependencies
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/676675/satellite-derived-time-and-position-blackett-review.pdf

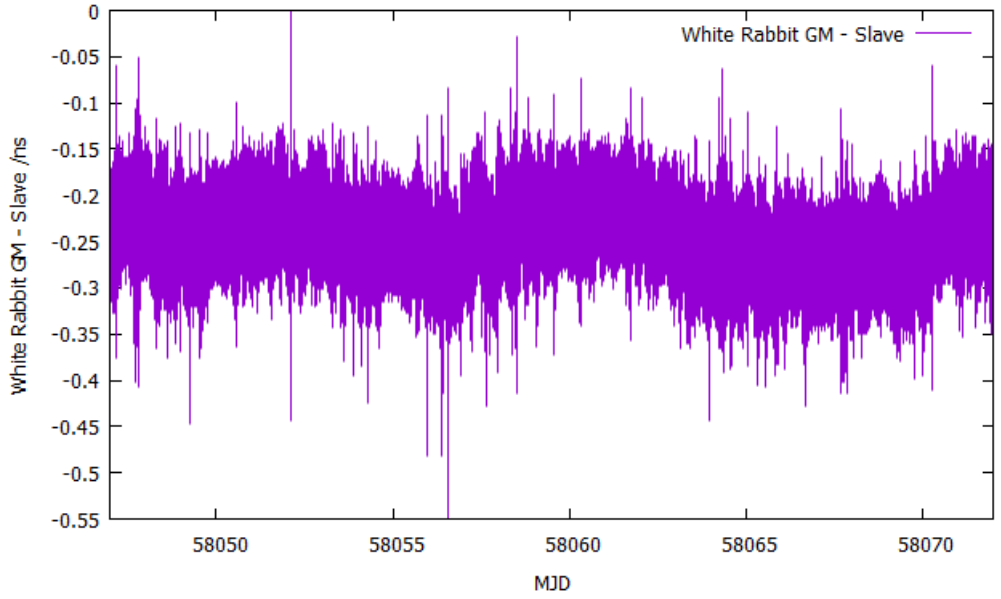
White Rabbit over fibre link NPL- Reading Nov 2017

WR over dual fibres NPL-Reading ITU ch33 and Reading-NPL ITU ch36

- Round Trip Times (RTT) monitored at each end
- Measured over 25 days, 5 ns /d
- Long term drift due to external environmental temperature decrease 14-10 deg C
- Short term oscillations due to lab temperature changes

Results from Oct-Nov 2017





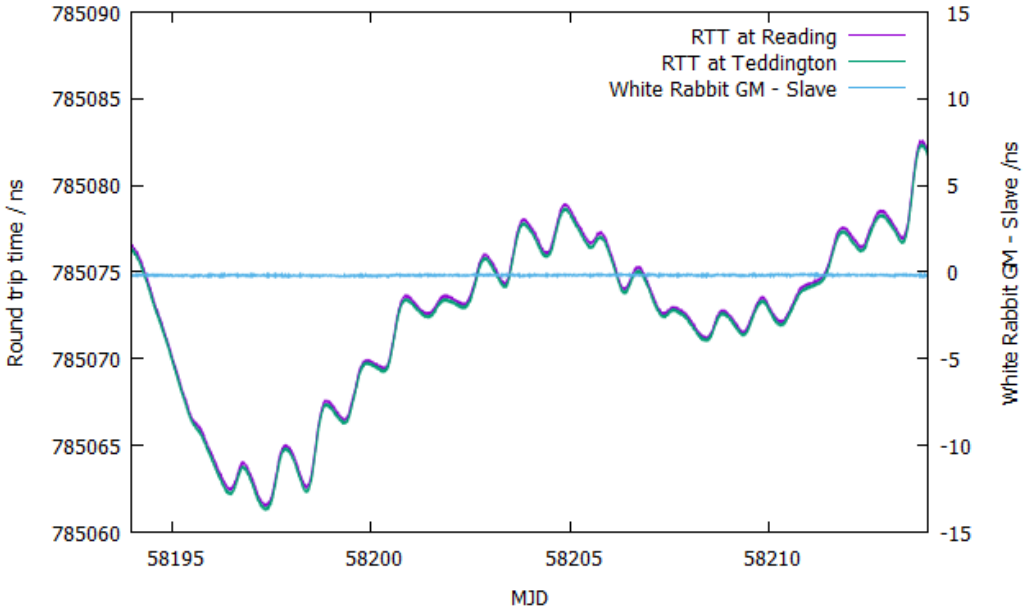
Offset between GM input and slave output 1 PPS signals, 50 ps /d

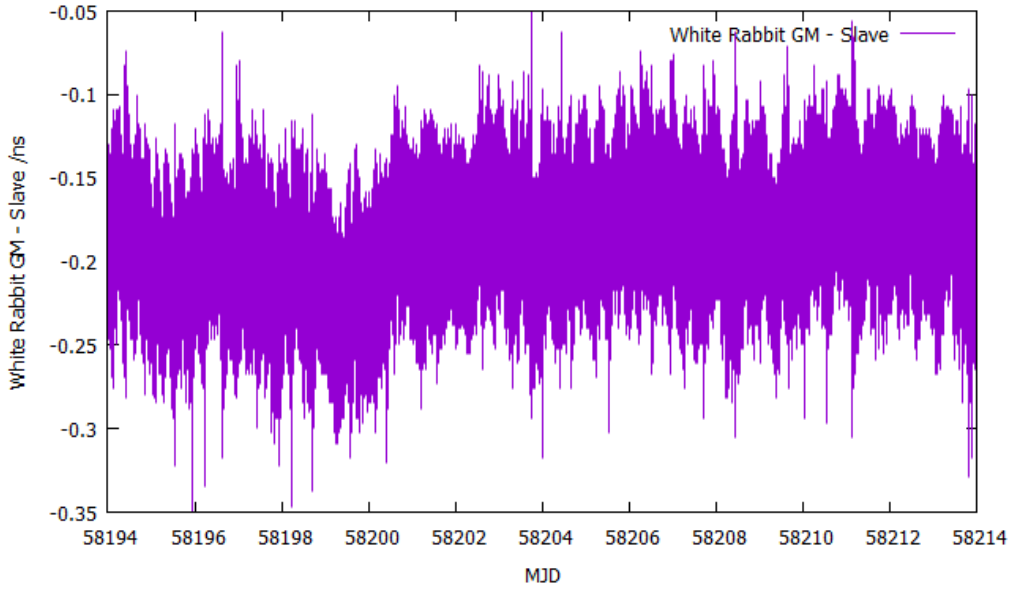
White Rabbit over fibre link NPL- Reading Mar 2018

WR over dual fibres NPL-Reading ITU ch33 and Reading-NPL ITU ch36

- Round Trip Times (RTT) monitored at each end
- Measured over 20 days, 5 ns /d
- Short term oscillations due to lab temperature changes

Results from Mar-Apr 2018





Offset between GM input and slave output 1 PPS signals, 50 ps /d

WR stability over 79 km fibre link

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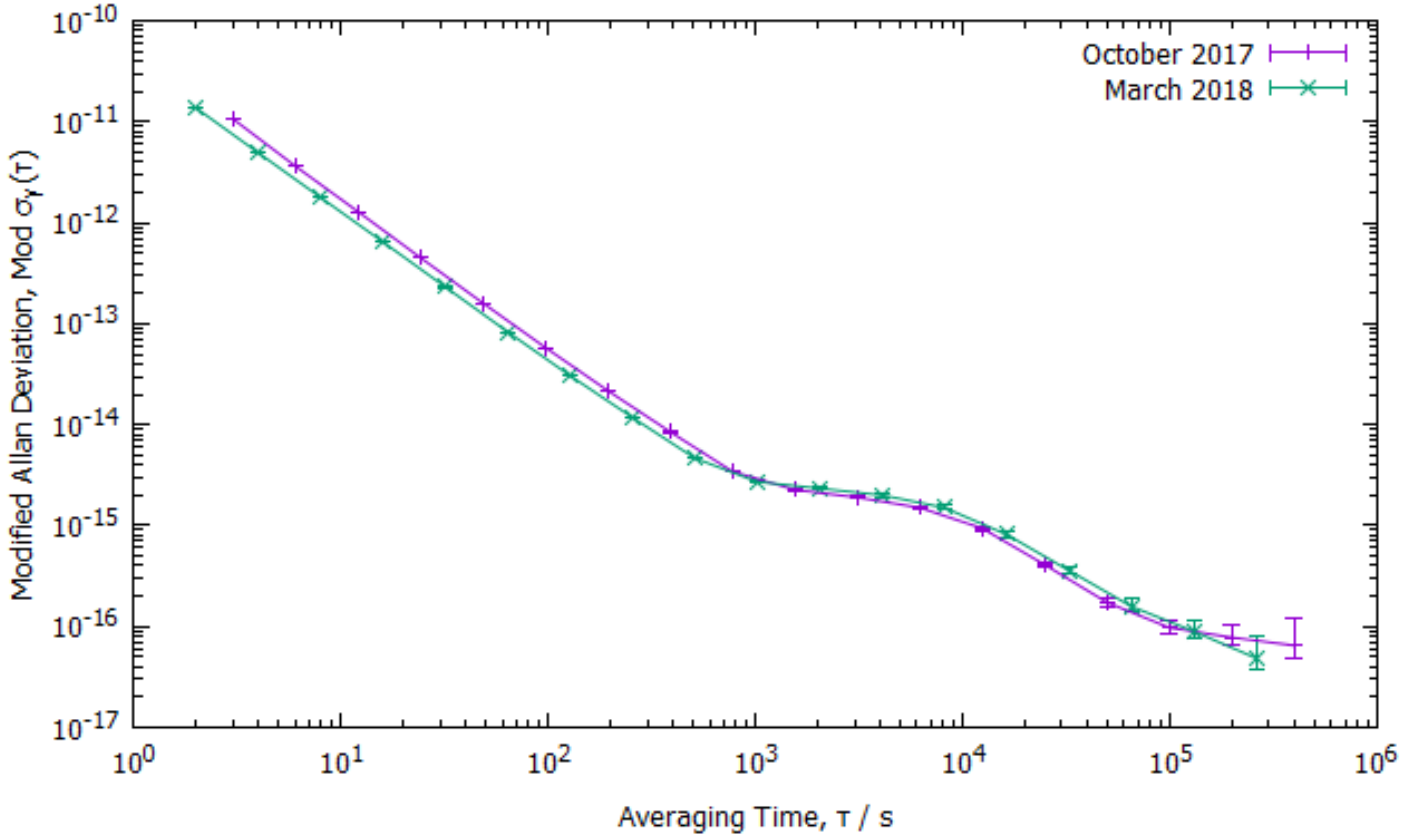

Future Plans with White Rabbit

- Implement WR on the primary NPL*Time*® fibre to Telehouse North in London

- Further research on temperature effects – compare with other studies

New European project WRITE: White Rabbit for Industrial Timing Enhancement
http://empir.npl.co.uk/write/
Project started in June 2018, duration 3 yrs

WRITE project objectives:

- Scalability – develop calibration techniques to measure asymmetry over telecoms fibre networks
- Resilience – develop holdover capabilities and improved network monitoring
- Performance – improve hardware and compatibility with existing protocols and standards
- Real field – Demonstrate UTC(k) distribution to space and telecoms industries
- Impact - Knowledge transfer and training; workshops and papers

Summary

- Introduction to time transfer with NTP, PTP and WR
- An example of PTP for the finance sector is the NPL*Time*® service, which is expanding to new locations and targeting customers in other industries
- WR in operation over the same fibre links as PTP: potential for a more precise time NPL*Time*® service in future
- Ongoing research into WR for industry with European project WRITE

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CLONETS – CLock NETwork Services

Strategy and innovation for clock services over optical-fibre networks

Proposal ID: **731107**
Topic: **INFRAINNOV-2016**
Duration: **30 months**
Start date: **1st January 2017**
Web page: **http://www.clonets.eu**

Coordinator

Participants

Third Parties