

Nordic Time Distribution Network Pilot

2700km High-Accuracy Low-Cost Time Service with White Rabbit

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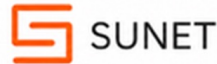
NORDUnet Conference 2026

Quantum and Time & Frequency networks

08.09.2026

NORDIC TIMING SUMMIT

@NORDUnet Community Workshop Sept.2025



A forum for Nordic timing stakeholders

National Research and Education Networks
National Metrology Institutes
& Time Service Providers



Joint agreement to:

Inspire and incubate policy and action on critical societal challenge
Identify technical and engineering solutions
Demonstrate service feasibility
Act on low hanging fruits



Regular meetings

Coordination & collaboration space, agreed meeting schedule

Content



High-Accuracy Time Distribution with White Rabbit



Challenges of White Rabbit over Long-Haul Optical Networks

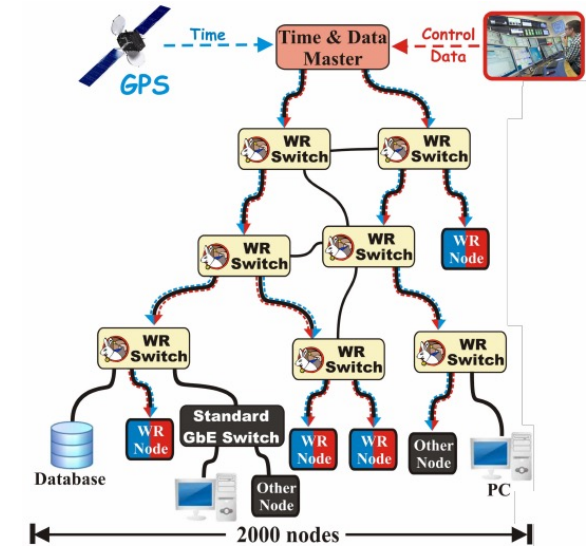


Nordic Timing Network Pilot 2026

White Rabbit Protocol for Sub-Nanosecond Time Accuracy

IEEE1588-2019 High-Accuracy Profile

- First developed at CERN in 2008, meant for Big Physics facilities, e.g. CERN, GSI, NIKHEF
- Enhancements to Precision Time Protocol (PTP IEEE1588-2008):
 - Clock syntonization over the physical layer using Synchronous Ethernet (SyncE).
 - Enhancement of timestamps precision through phase measurement
 - Calibration and compensation of hardware and transmission link asymmetries
- Initial specs metro area < 10km optical links
 - Maintaining sub-ns accuracy for ~ 14 to 20 WR nodes in a chain.
 - We need deployments of 100s of km in long-haul links.
- Open Source and commercially available
 - White Rabbit Collaboration



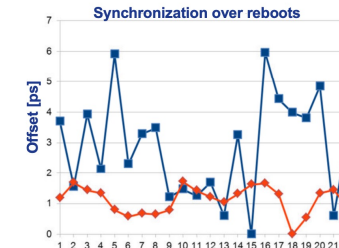
White Rabbit performance today

Time transfer performance

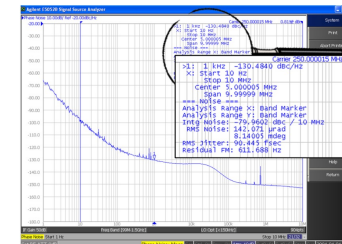
- Network-level: < 1ns accuracy
- A single link (<10km): < 20ps accuracy
- Long-distance support: ~1000km

Frequency transfer performance

- Standard: 11ps RMS
- Low jitter: 2ps RMS
- Best jitter: 100fs RMS



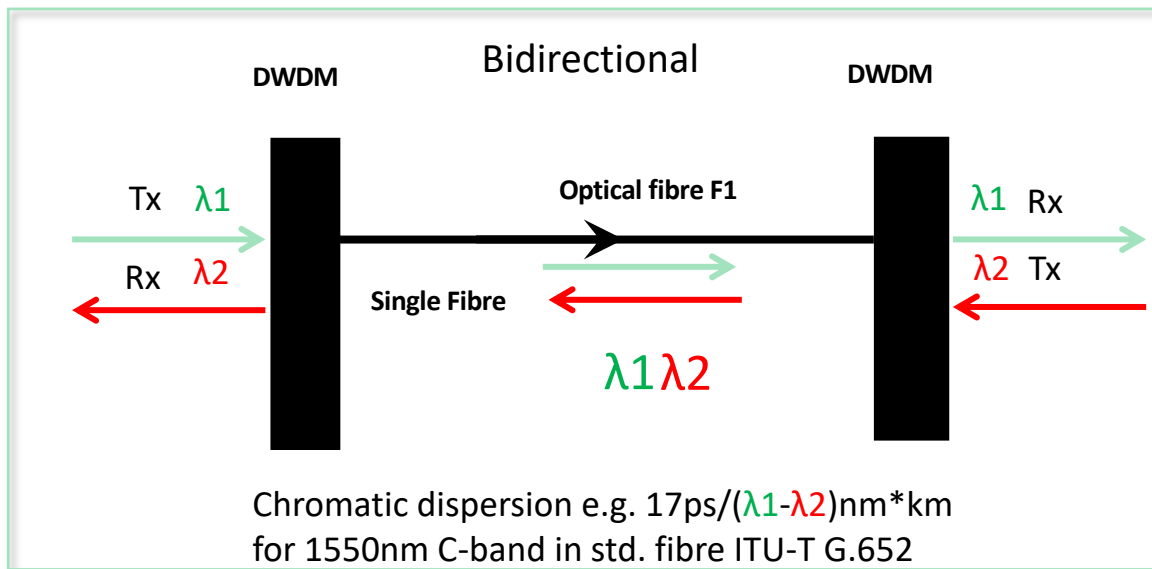
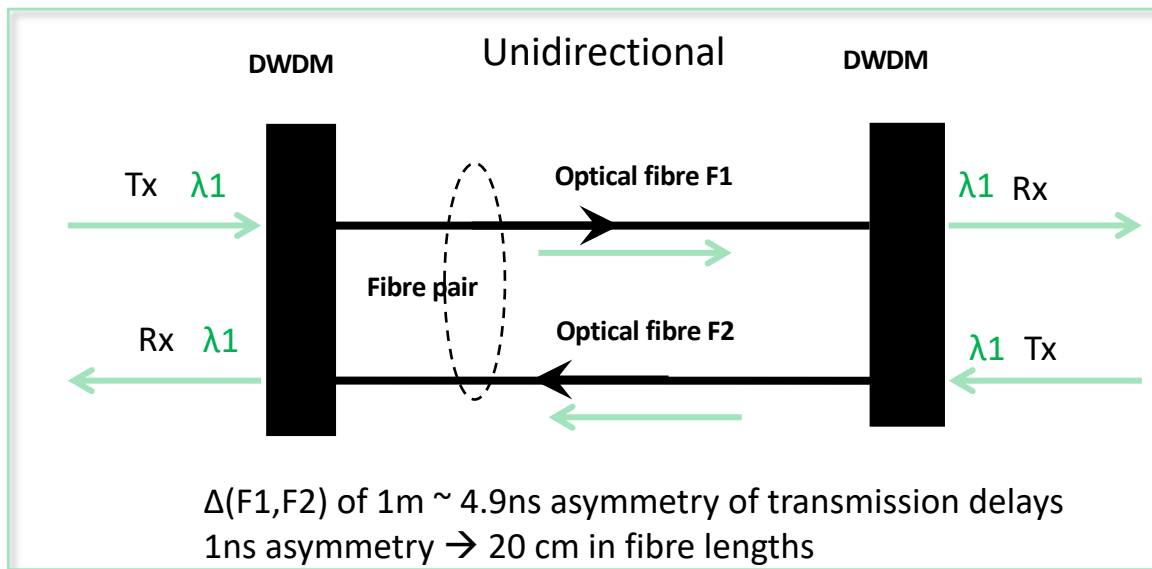
Time (1 PPS)
Clock (62.5MHz)



«Legacy» Dual vs. Single Fibre

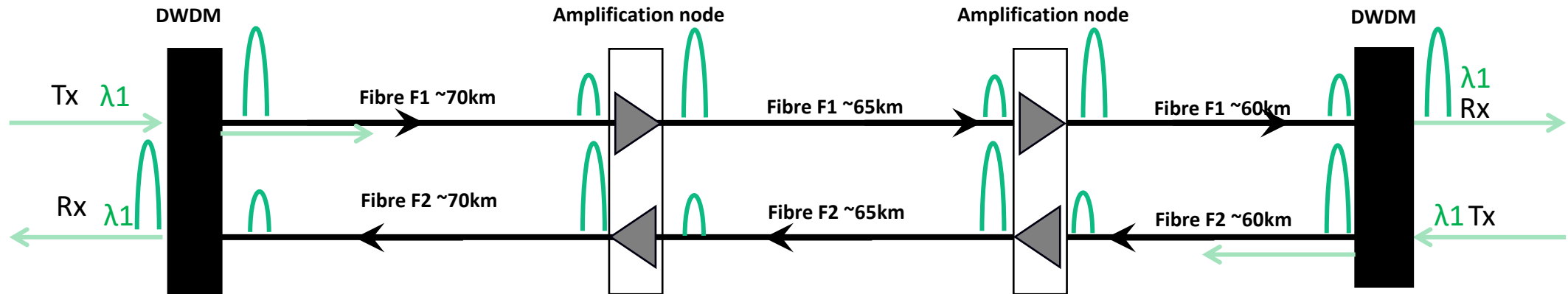
Unidirectional vs. Bidirectional deployments

- Rule of thumb: speed of light in fibre ~ 4.9 ns/m
- Unidirectional link = asymmetry from different fibers lengths in the pair
 - High-accuracy performance assurance @ns level is difficult: every “fix” of a fibre break will introduce unknown $\Delta(A,B)$ fibre length.
 - Recalibration every time!
- Bidirectional link introduces asymmetry from chromatic dispersion dependent on wavelengths and fibre type
 - Compensated with calibration “once”
 - The standard WR model (CERN)
 - 1310nm + 1490 nm bidirectional on single fibre (CWDM spectrum)

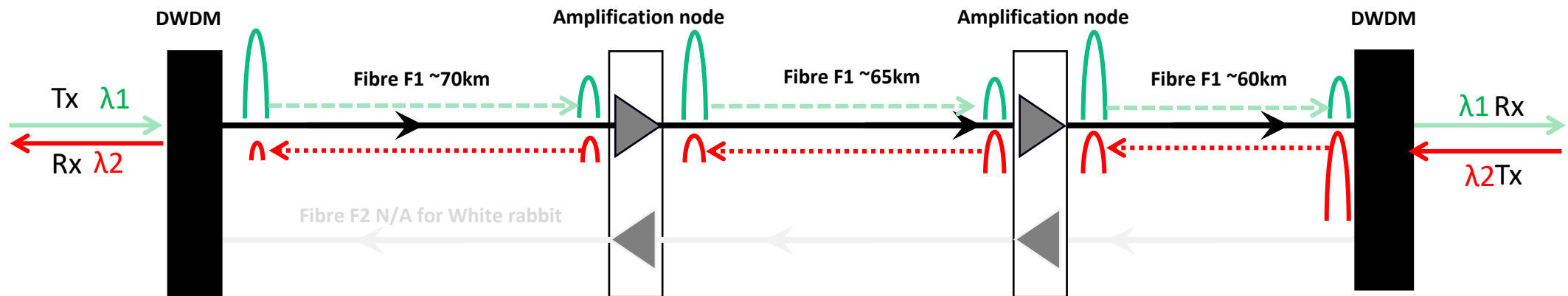


Challenge with single fibre in long-haul: signal regeneration

- Losses in fibre $\sim 0.2\text{db/km}$. Need to regenerate every e.g. 80km.
- “Legacy” optical DWDM system used for data channels is dual fibres, i.e. unidirectional signal regeneration



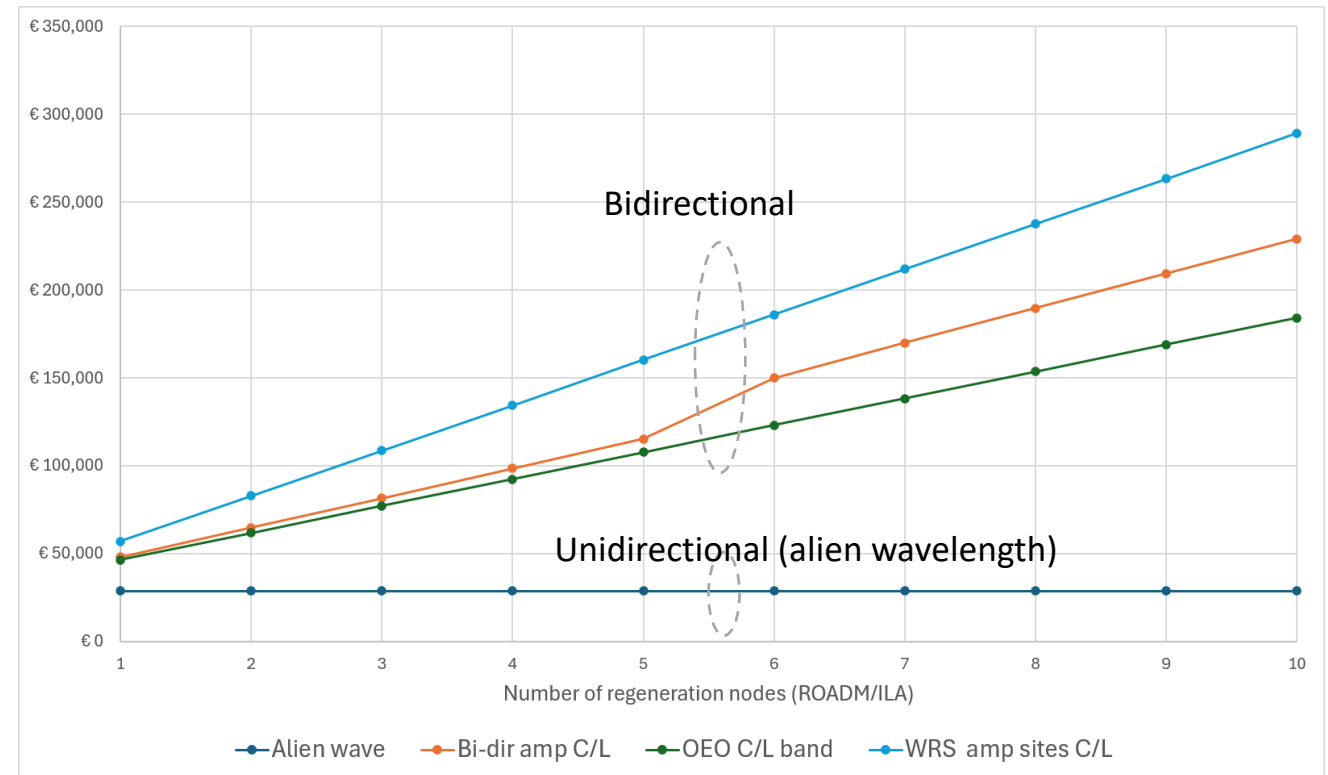
- PROBLEM for bidirectional deployment: reamplification is single direction per single fibre in current DWDM systems



Cost Analysis Example (GN5-2 WP6 Incubator Project)

- [Calculator tool](#) from [GEANT GN5-2 WP6 NETDEV Incubator “Long-haul White Rabbit Time Distribution”](#)
- Alien Wavelength is a “low hanging fruit”
 - Provision a 1GbE link end to end as for data services
 - Use the same signal regeneration and systems as DWDM Telecom data channels.
 - “Only” cost are WR switches, transceivers, management network and spectrum with guardband (~100GHz)
 - It is an **interim solution** for fast rollout of time services in small scale
- Bidirectionality in transmission is essential for high performance, stability and ease of operation

Cost of long-haul WR time service with different regeneration techniques



Note that the spectrum cost is not included in the model

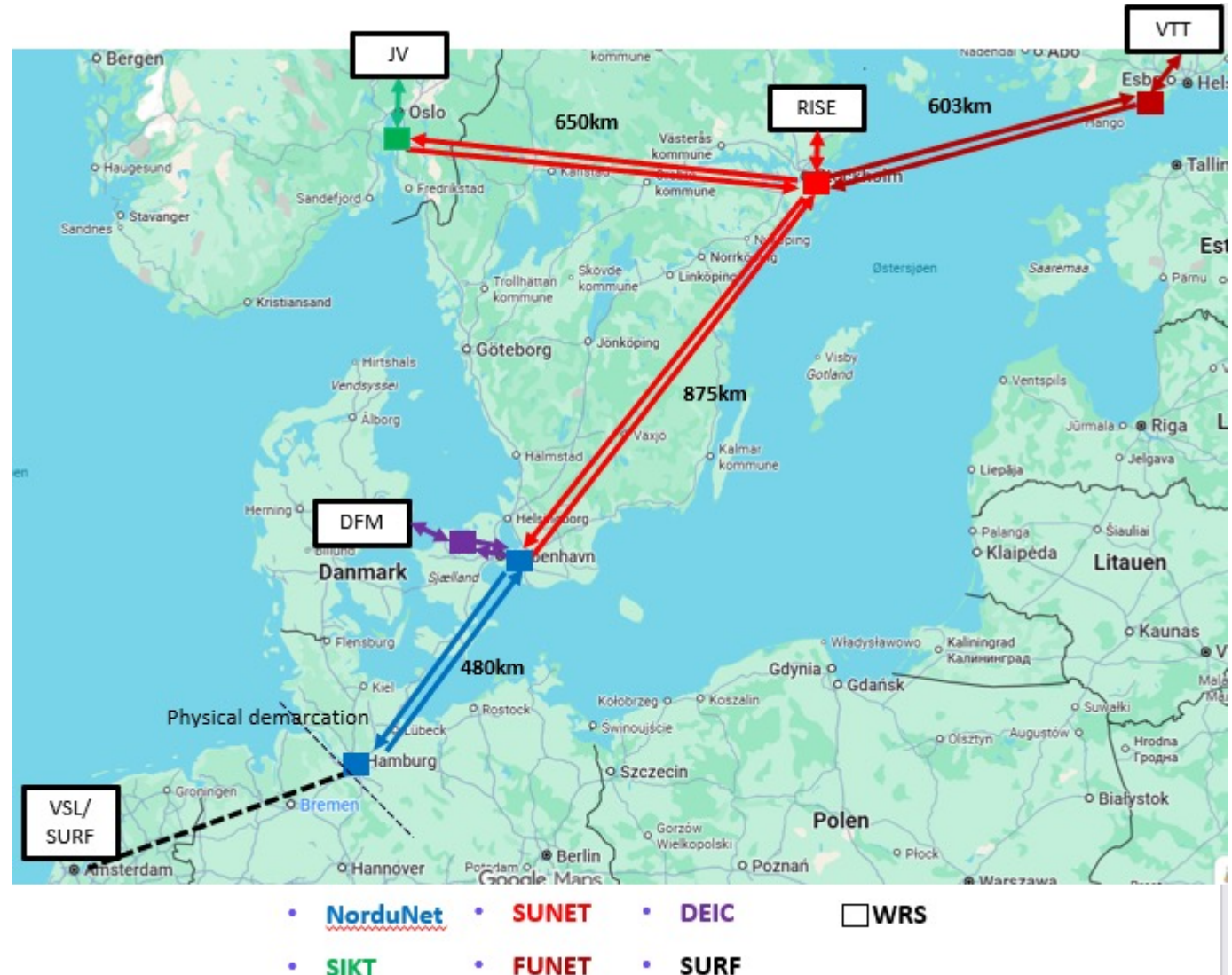
Pilot Project Interconnecting Nordic NMIs

2026 - Phase 1 Deployed and running

- 2650km unidirectional backbone interconnecting the NRENs & NorduNet
 - DWDM ITU-T Ch. 59. Edge of C-band
- ~55km bidirectional link at the edge NRENs-NMIs, from 2km to 40km with passive filters

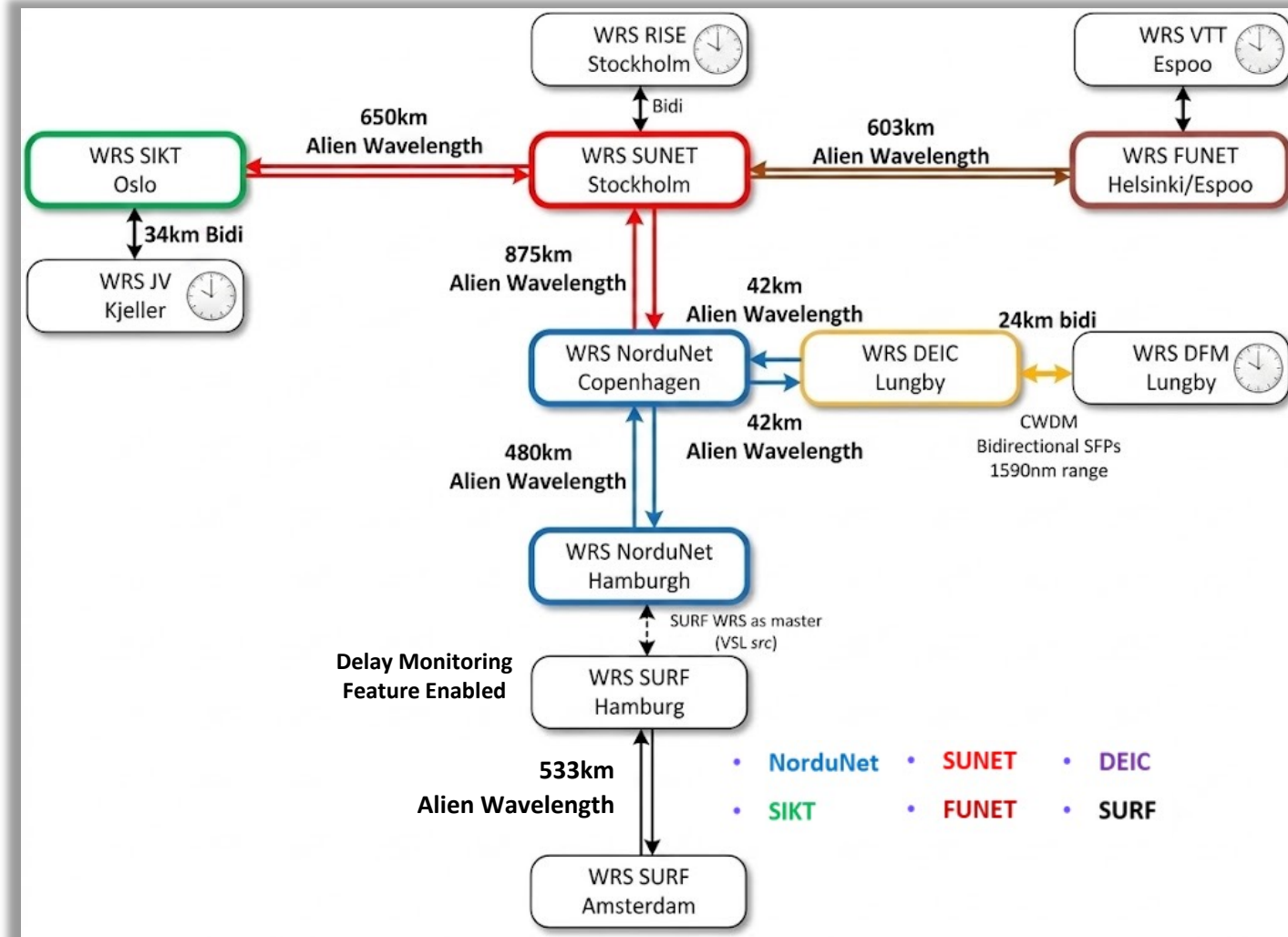
2027 - Phase 2 (TBD)

- Bidirectional link (e.g. Stockholm-Oslo) in parallel
- Calibration
- EISCAT inter-site use case (EISCAT)

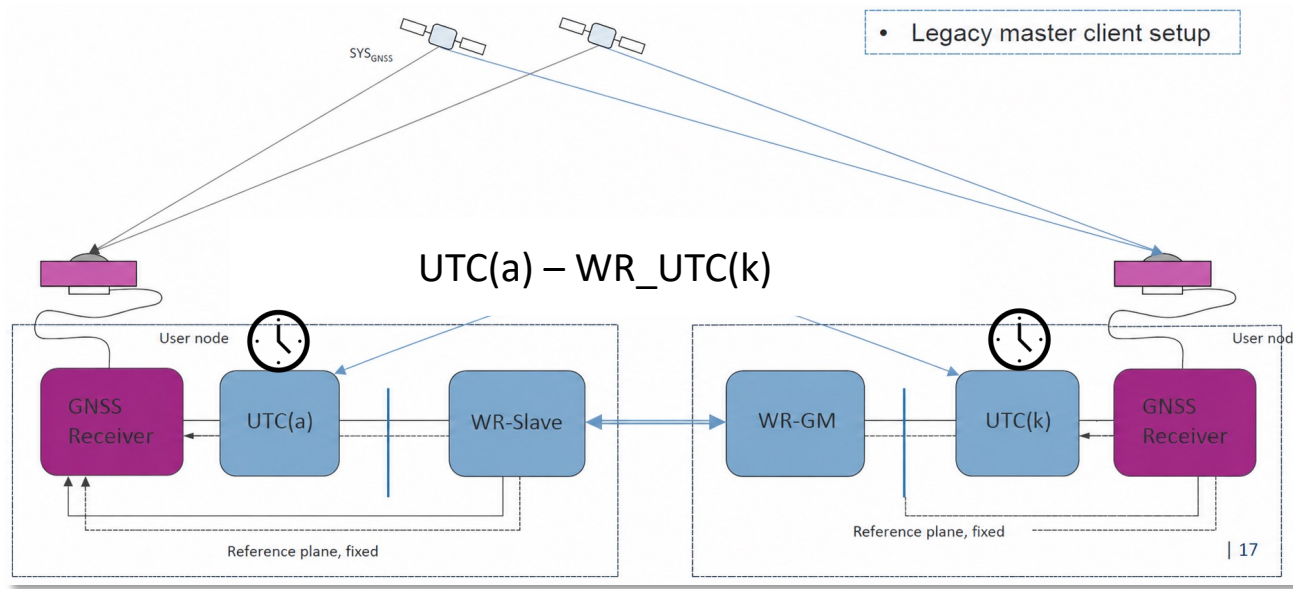


White Rabbit Network Topology 2700km ++

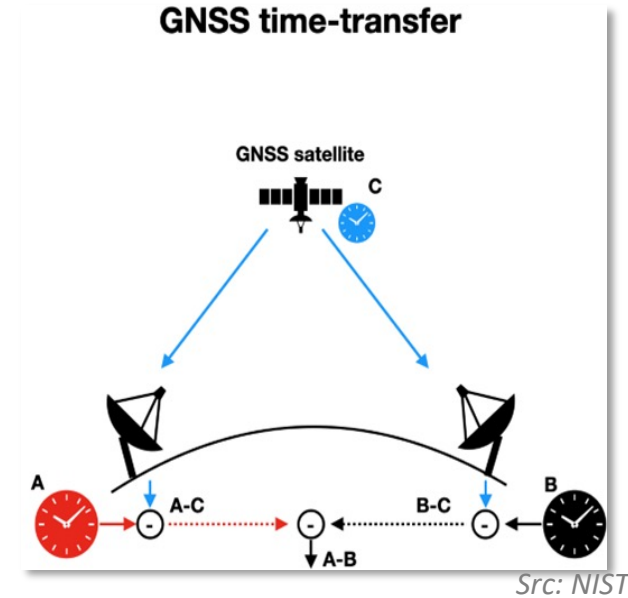
- 12 White Rabbit Switches (WRS) low-jitter Open Hardware
- Alien Wavelengths (dual fibre) between the NRENs (DWDM Channel 59) as a 1G data channel:
 - SUNET Oslo-Stockholm 13 optical nodes / 12 fibre links (dual fibre strands)
 - A big part is over-the-air fibres on power lines
 - FUNET Espoo – Stockholm 9 optical nodes (both subsea + underground fibres) and SUNET 3 nodes interconnect in Stockholm.
 - SUNET Stockholm-Copenhagen 15 optical nodes / 14 fibre links
 - NorduNet Copenhagen – Hamburg 7 optical nodes
- Bidirectional links channels between WRSs of NRENs and NMIs. Either standard 1310nm/1490nm or DWDM Ch.59/Ch.60



1st Use Case – NMIs comparing UTC(k) to WR delivered UTC(RISE)



Credit: Carsten Rieck, RISE

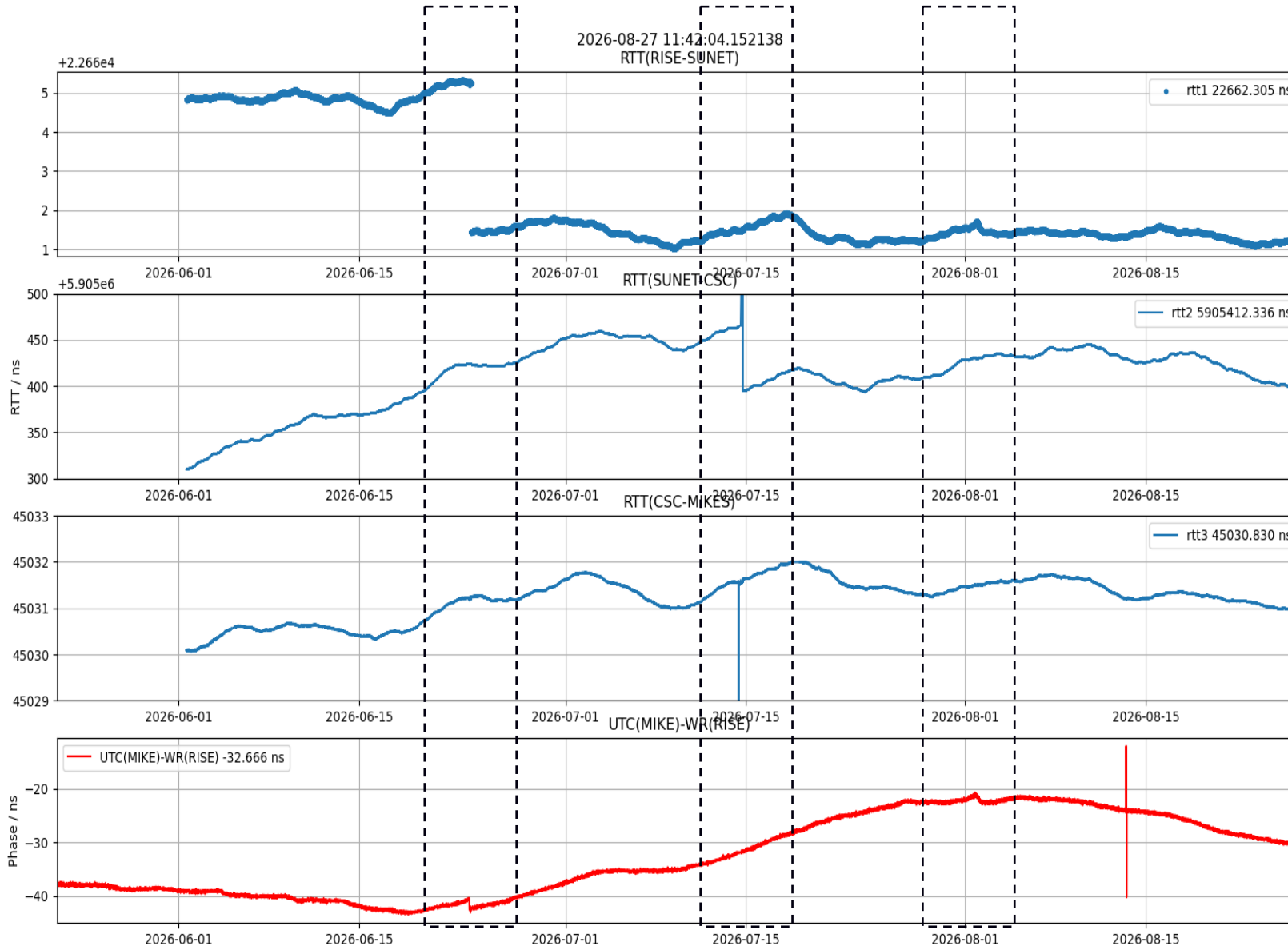


Additional sources for comparison of UTC(SP/RISE), UTC(MIKE), UTC(JV), UTC(DFM):

- BIPM Circular-T – monthly offline comparison of the timescales difference to UTC, usually in range of ns(s)
- Satellite-based comparisons e.g.: TWSTFT, GNSS Common View and GNSS-PPP FUGRO Atomichron service

Example of GNSS Common View for comparing remote clocks A and B through common GNSS satellite clock C.

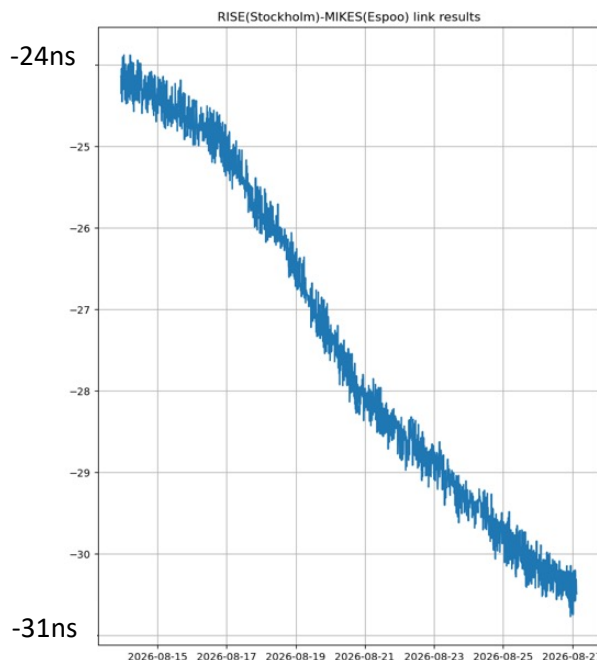
Finland: Results Measured from VTT UTC(MIKES) - WR(RISE)



- 2026-06-23
RISE-SUNET RTT jump
 - Asymmetric delay change!?
 - Seen in WR(RISE)-UTC(MIKE) time interval also
- 2026-07-14 SUNET-FUNET
large RTT change (fiber repair)?
 - Seems symmetric
 - No detectable jump in WR(RISE)-UTC(MIKE)
- 2026-08-13 glitch in UTC(MIKE)
measurement system, not related to NTS
WR-links
- Todo: GNSS-PPP comparison

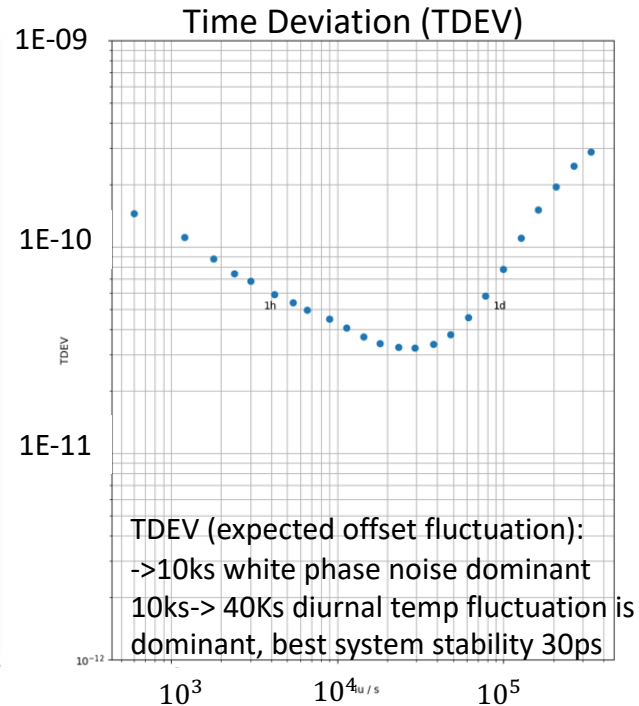
WR Time Link Stability at VTT

VTT phase comparison, 10-min data, Aug 2026 — first assessment



12 days phase diff measurements
WR(RISE)-UTC(MIKES).

- Daily variation ± 1 ns
- Downward trend due to

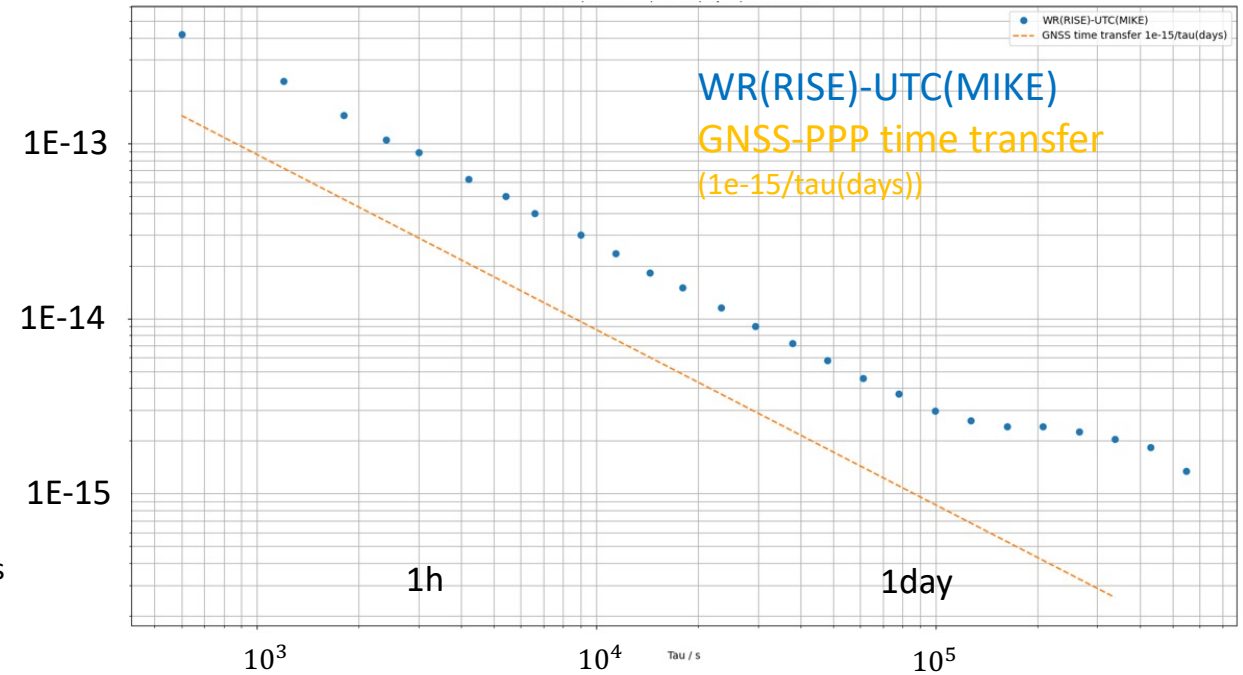


TDEV MIN

30–70 ps

1h–8h

Allan Deviation (ADEV)
Compared with typical “systematic” GNSS-PPP time-transfer



ADEV @ 1 day

3E-15

vs. **1E-15 GNSS-PPP**

Gap to GNSS-PPP

$\approx 3\times$

at every τ

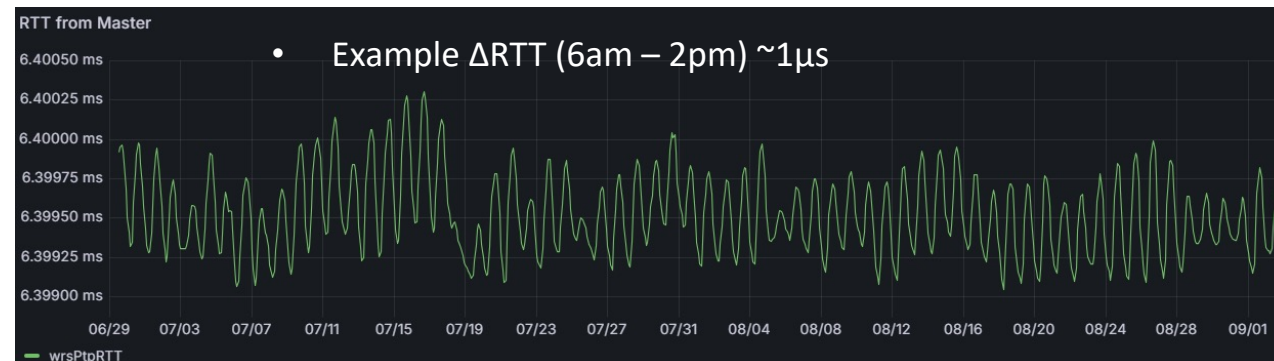
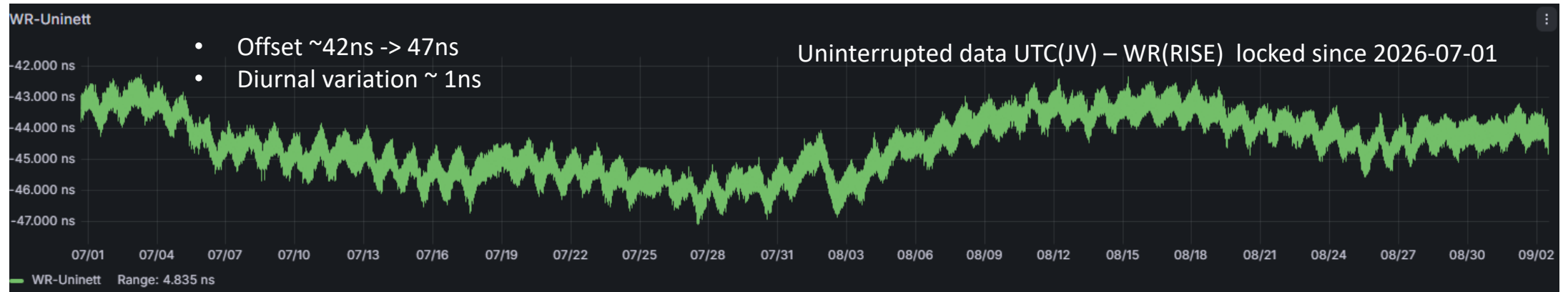
- Sub-100 ps stability at 1h–1d, but the link is $\sim 3\times$ short of GNSS-PPP at every τ — not yet a replacement.
- Need a parallel GNSS-PPP comparison of UTC(RISE) clock source and local UTC(MIKES) to separate link noise from the two atomic clocks.



Norway: results measured UTC(JV) - WR(RISE)

4 WR nodes and 686km end-to-end, SUNET alien wavelength through 12 ILA/ROADM nodes

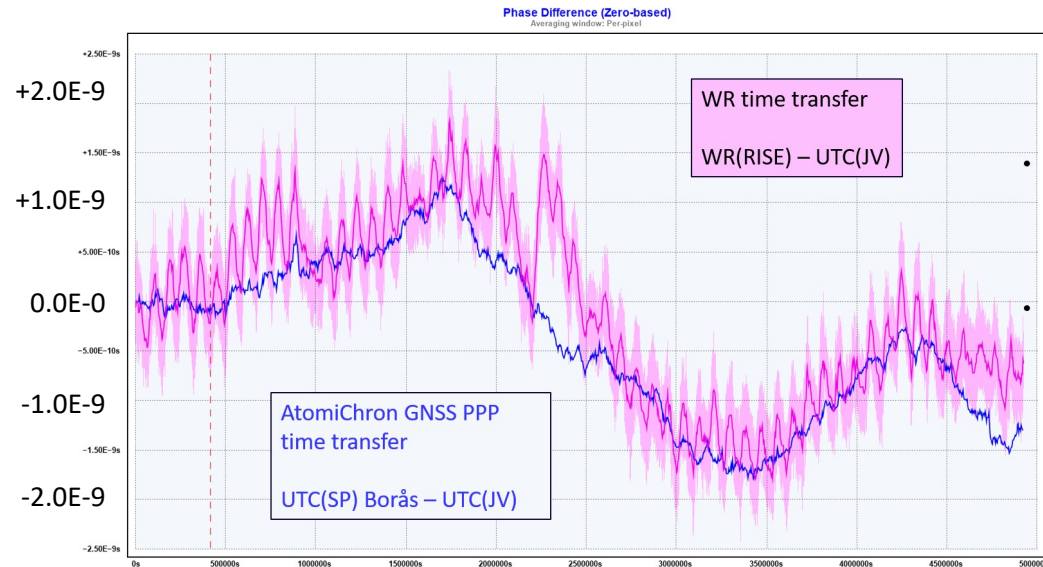
Phase offset daily variations of order ± 1 ns



Stockholm – Oslo fibre pair is mainly aerial on power lines

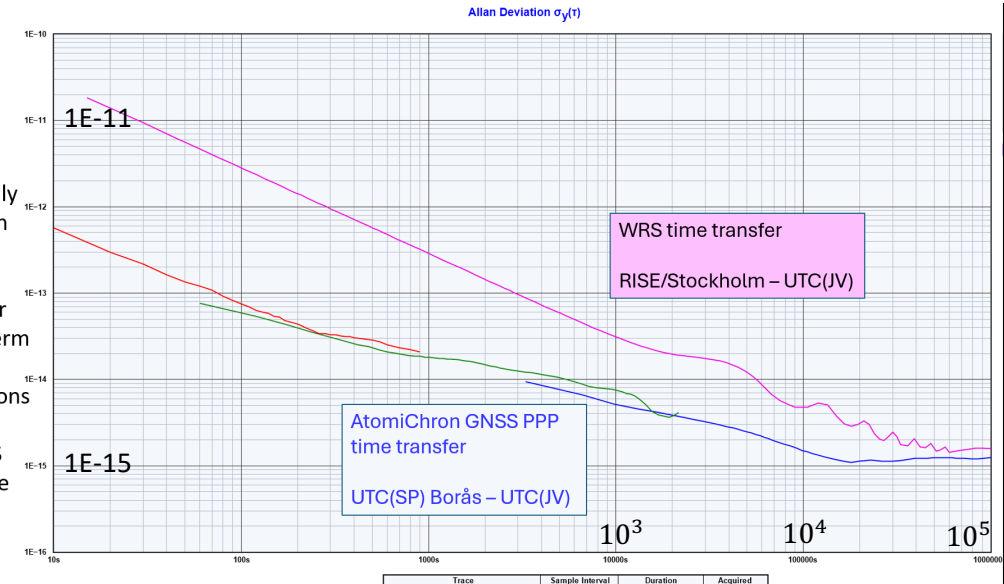
- Daily temperature fluctuations influencing RTT and offset (e.g. @1550nm $\sim 40\text{ps/km}/^\circ\text{C} \rightarrow 650\text{km} \sim 25\text{ns}/^\circ\text{C}$)
 - 2026-09-02 ΔRTT (4pm-6am) $0.437\mu\text{s}$
 - 2026-07-16 (4pm -6am) $\sim 0.868\mu\text{s}$

Comparison with GNSS-PPP real-time time transfer UTC(RISE) – UTC(JV)



Phase difference: both links show the same slow swing

- Large and slow variations primarily due to variation in UTC(JV)
- WRS time transfer has more short term (white) noise and large daily variations compared to Atomichron GNSS real time PPP time transfer.



ADEV: WRS converges to GNSS-PPP floor at long τ

Common slow swing
 $\pm 1.5\text{--}2$ ns

seen in both links alike $\rightarrow$ variation on UTC(JV)

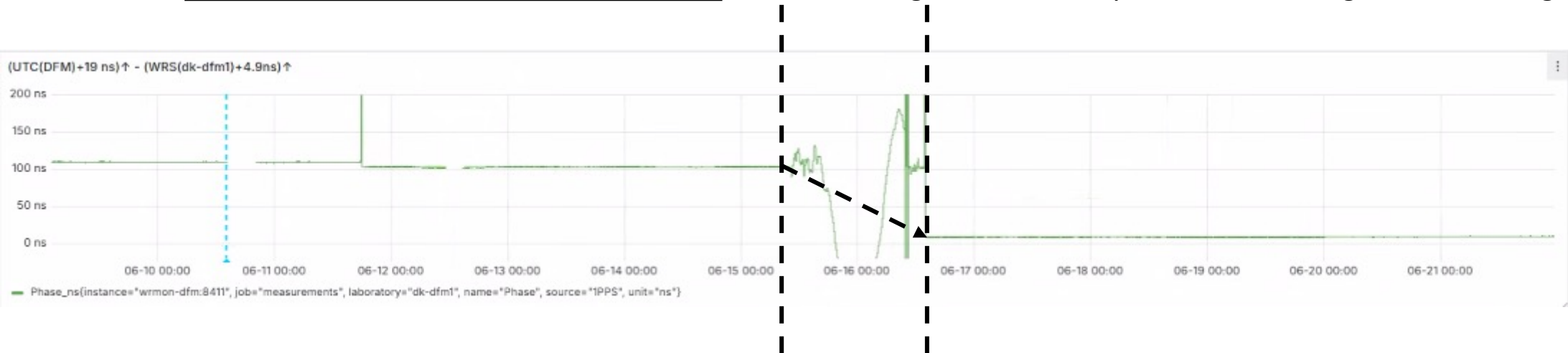
WR excess noise
10 $\times$
short τ (1h), link-specific

Long- τ floor (both)
1-2E-15
 ≈ 10 days, converge

White Rabbit time link has better performance than “standard” code-based GNSS receivers

Danmark: Results Measured from DFM UTC(DFM)-WR(RISE)

- 945km end-to-end with 15 ILA/ROADM sites Stockholm-Copenhagen; 5 white rabbit switches
- After a fibre route change Stockholm-Copenhagen the offset changed “dramatically” from ~ 97ns range to ~40ns range



Note: the management logging system had issues during the summer. The lack of data is related to that not the time network being down.

Custom field	Custom field (Final ticket report)
2026-08-19	The link between Växjö - Nybro was down due to a fiber break in a sub subprovider network.
2026-08-25	Provider performed cable rerouting between Lund - Malmö and Lund - Möarp.
2026-07-06	Provider performed an emergency fiber maintenance between Norrköping - Kimstad.
2026-06-30	The link between Norrköping - Kimstad was down due to a major fiber cut.
2026-06-11	SUNET performed rerouting of wavelenghts between Stockholm and Copenhagen/Ballerup
2026-06-16	Maintenance performed to troubleshoot fiber issues.
2026-06-12	Provide perform fiber maintenance that affected the link between Hörby - Gussa Svenstorp - Alvesta.
2026-06-03	Provider performed fiber maintenance between Norrköping - Nyköping.

“The life of a unidirectional white rabbit time link”

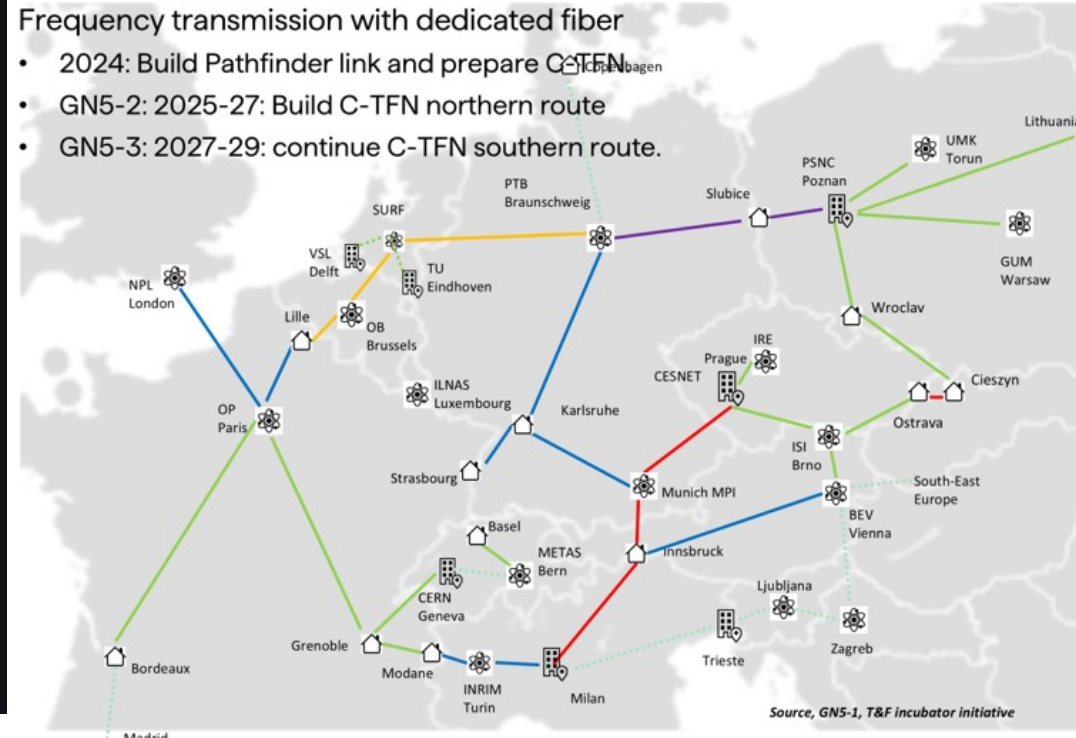
Connecting Nordics to mainland Europe C-TFN!



2025-2029 Core Time and Frequency Network

Frequency transmission with dedicated fiber

- 2024: Build Pathfinder link and prepare C-TFN
- GN5-2: 2025-27: Build C-TFN northern route
- GN5-3: 2027-29: continue C-TFN southern route.



- SURF connected to NORDUnet in Hamburg
 - White Rabbit firmware with delay monitoring feature (CERN, SURF & NTS trial finished last week)
 - SURF comparing UTC(VSL) of their network to NorduNet delivered WR(RISE).
 - Offset in the +-2ns range – result processing ongoing

Key Takeaways

1

Nordic NMI-NMI terrestrial network is live

All four of the Nordic NMIs are interconnected for the first time through White Rabbit time links , opening a path toward wider C-TFN connectivity.

2

Alien wavelengths: a fast interim fix

Great for quick, small-scale rollout — but unpredictable fibre asymmetry makes operations and calibration complex.

3

Time Laboratories: Terrestrial links must beat GNSS-PPP

They become compelling for metrology labs only once they clearly outperform GNSS-PPP — not yet the case.

4

Bidirectionality is essential

Needed for performance, stability and ease of operation — critical for sub-ns science like EISCAT 3D.

Thank you

Any questions?

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