NET
NOD

Long Distance White Rabbit Distribution in a Coherent Network Within Sweden
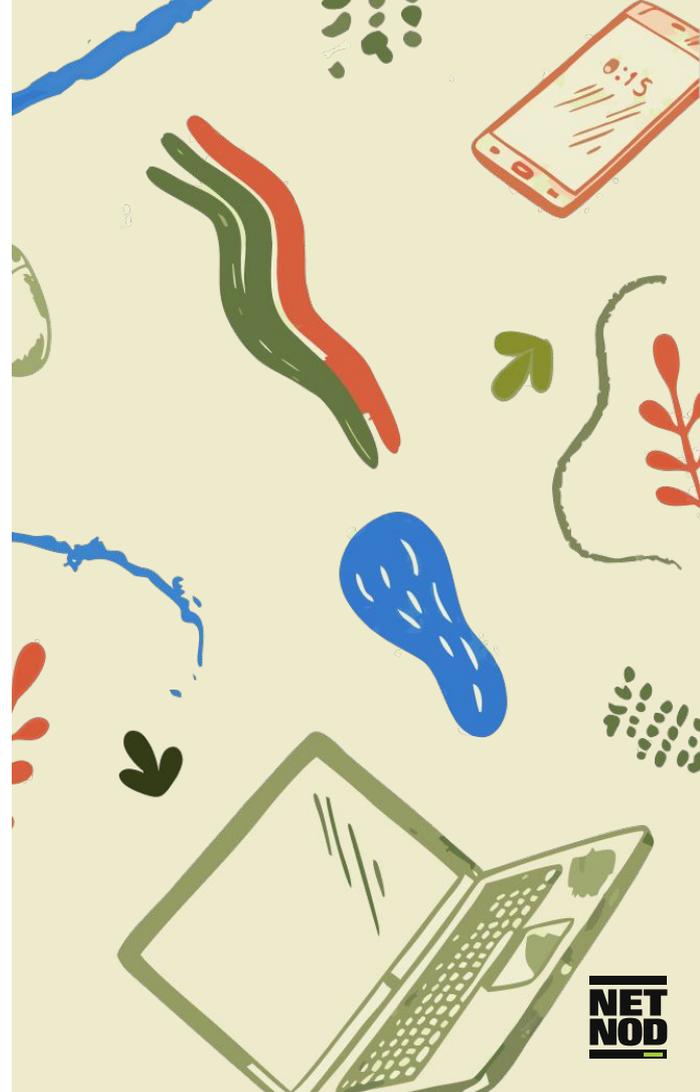
Working for the good of Time and Frequency

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9-10 March 2026

Outline

- Time dissemination in Sweden

- Why are we doing this

- "The Swedish model"

- Equipment

- Measurements

- White Rabbit connection between Gothenburg and Stockholm

- White Rabbit connection between Stockholm and Sundsvall
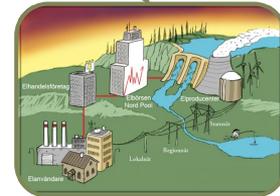
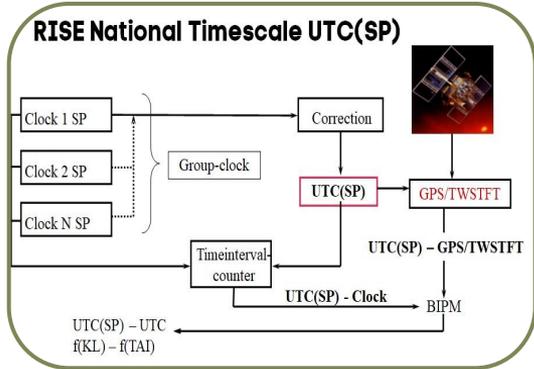- Questions

Time dissemination in Sweden

- High performance clocks in three cities.
- Distribution nodes using standard Cs clocks
- Time transfer using GNSS CV
    - Aim to replace / add with fiber optics
- Designed to maintain sufficient accuracy for more than 90 days without comparison to UTC(SP) fulfilling ePRTC standard.
- Time dissemination formats
    - NTP (free usage)
    - NTS (free usage)
    - PTP (service charge)
    - GNSS CV (service charge)
    - Special solutions (service charge)
- Financially supported by PTS, Swedish Post and Telecom Authority

Why a national distribution system for Time and Frequency?

- Citizens and critical public services depends on the availability of electronic communications

- Electronic communications depend on accurate time and sync/frequency

- Time and frequency distributed with GNSS can be easily disrupted and is a factor of uncertainty

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Netnod Time and Frequency Distribution

RISE National Timescale UTC(SP)

Clock 1 SP → Correction

Clock 2 SP → Group-clock

Clock N SP

UTC(SP)

GPS/TWSTFT

Timeinterval-counter

UTC(SP) – GPS/TWSTFT

UTC(SP) - Clock

BIPM

UTC(SP) – UTC
f(KL) – f(TAI)

MEASUREMENT- AND WEB SERVERS
NTP SERVERS
IP NETWORK MANAGEMENT
PTP AND GNSS
FREQUENCY DISTRIBUTION
FREQUENCY MEASUREMENT
FREQUENCY AMPLIFIER
FREQUENCY AND PHASE ADJUSTMENT
FREQUENCY GENERATOR (CS)

"The Swedish Model"

- Distributed by Netnod, traceable to UTC(SP)@RISE

- 6 time nodes located in secure rock caverns at 5 different locations around Sweden

- Time distribution servers

- Time scales are steered towards UTC(SP)

- Both free and commercial services with SLA

LULEÅ ●

SUNDSVALL ●

2x STOCKHOLM ●

● GÖTEBORG

● MALMÖ/COPENHAGEN

NET NOD

A national distribution system for Time and Frequency

- A system independent of GNSS that, from a national perspective, can guarantee robust and secure time.

- The system must be robust and available throughout the country on equal terms.

- Services provided through the system must be affordable for operators so that price is not a stopping factor.

- Regulatory authorities must be given transparency and direct access to the infrastructure, which means that it must be based in and operated in Sweden.

LULEÅ ●

SUNDSVALL ●

● 2x STOCKHOLM

● GÖTEBORG

● MALMÖ/COPENHAGEN

NET NOD

Clocknodes @ Netnod traceable to UTC(SP) @ RISE

- Redundant timescale-nodes based on Microchip 5071 standard performance Cesium clocks

- NTP/NTS servers are equipped with a custom-built FPGA-based hardware implementation

MEASUREMENT- AND WEB SERVERS

NTP SERVERS

IP NETWORK MANAGEMENT

PTP AND GNSS

FREQUENCY DISTRIBUTION

FREQUENCY MEASUREMENT

FREQUENCY AMPLIFIER

FREQUENCY AND PHASE ADJUSTMENT
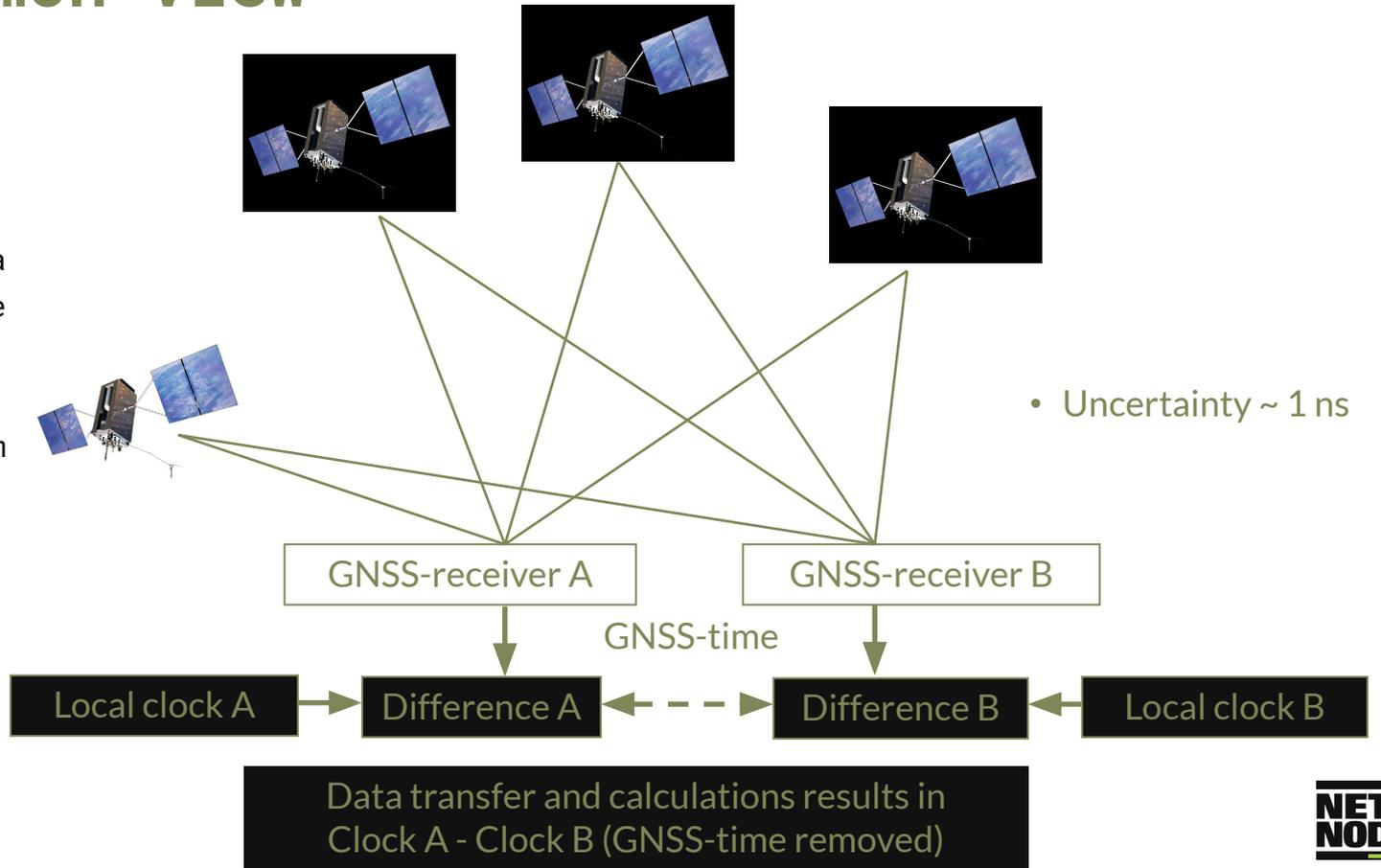
FREQUENCY GENERATOR (CS)

NET NOD

Time-node

- All equipment in the node is constantly monitored for correct time.
  -
- A node has two independent measurement systems.

Time-node

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  -
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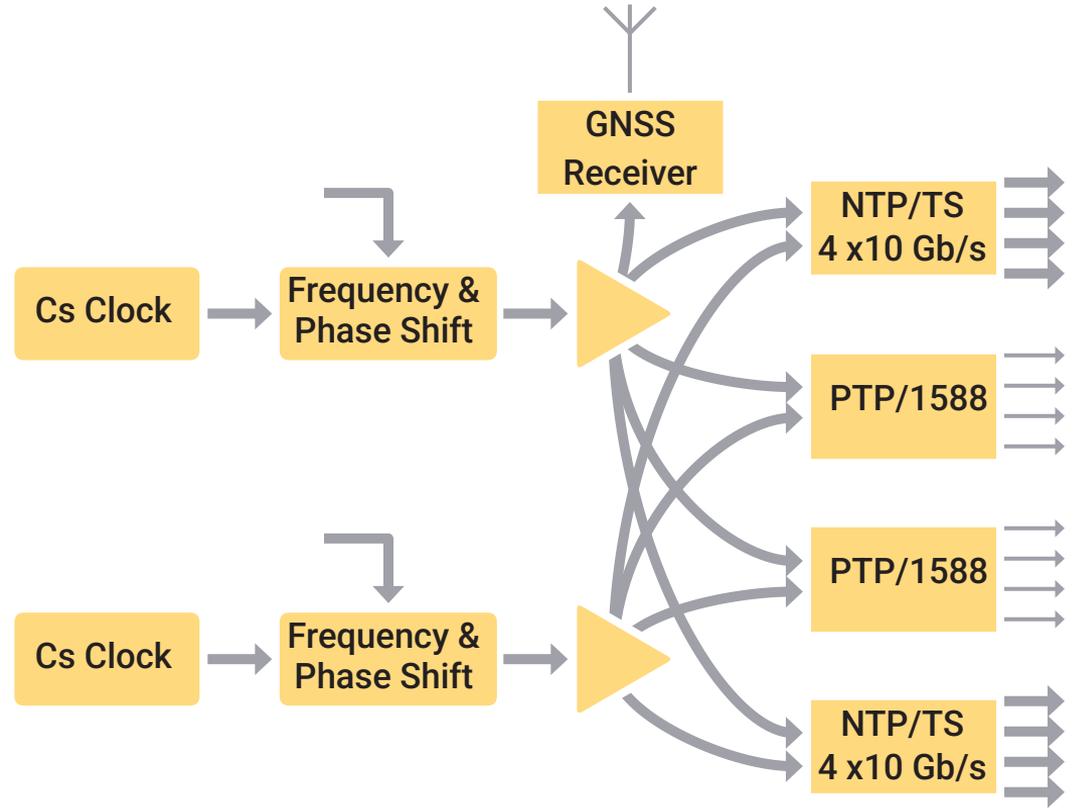
GNSS Common View

- GNSS Common-View
  - Both receivers observes data from the same satellite
- GNSS All-in-View
  - Use data from all GNSS satellites visible from both receivers.

- Uncertainty ~ 1 ns

GNSS-receiver A

GNSS-receiver B

GNSS-time

Local clock A → Difference A ⬅ - - ▶ Difference B ← Local clock B

Data transfer and calculations results in
Clock A - Clock B (GNSS-time removed)

Netnod PTP

Ensure your network nanosecond level accuracy with the most robust, reliable and accurate source of time available without running your own atomic clock.

Netnod Time Direct

Get the most accurate and reliable time available over an IX port with a fully-managed, secure time service that guarantees 30µs accuracy from UTC(SP).
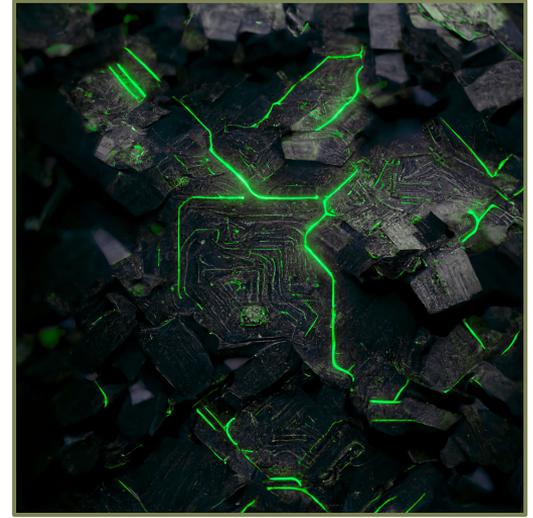
Netnod Time Remote

Get accurate and reliable time securely delivered wherever you are located in Sweden with a guaranteed accuracy of 1ms from UTC(SP).
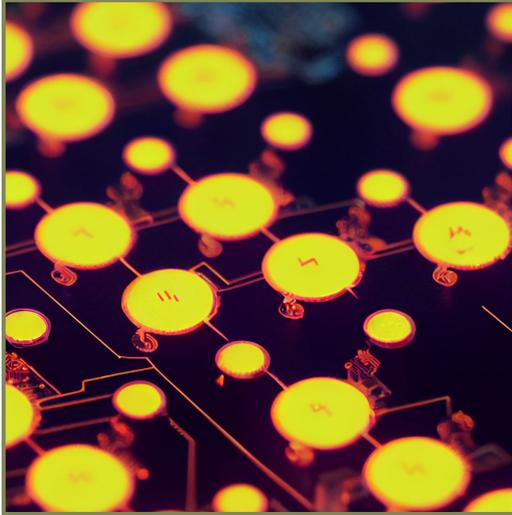
NTP service

Connect for free to one of the most advanced and secure NTP services available which also includes…
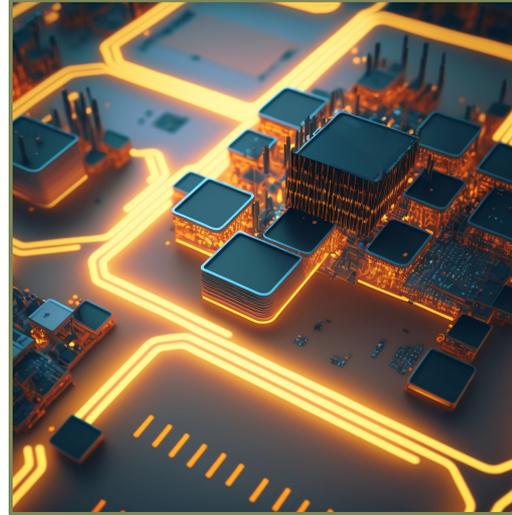
NTS service

Connect for free to ensure you are receiving secure and accurate time from a trusted source

Objectives for doing White Rabbit

- Set up a White Rabbit time comparison link between at least two time distribution nodes, and compare performance to the GNSS Common View links.

- Evaluate White Rabbit as a method for time distribution.

- Redundancy to GNSS

NET NOD

A 699 km White Rabbit link using DWDM duplex optics in a coherent network

White Rabbit in a coherent network

Total: 699km
Spans: 13
Roadm: 9
ILA: 5
Fiber: Powerlines,
Ground
EDFA gain: 320dB
Raman gain: 32dB

50km
38km
62km
103km
47km
36km
95km
30k m
75km
33km
62km
56km
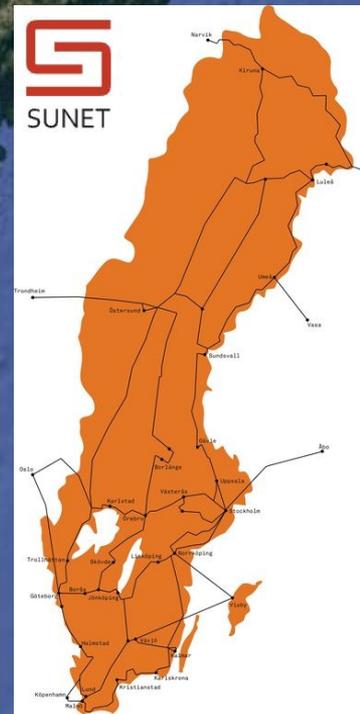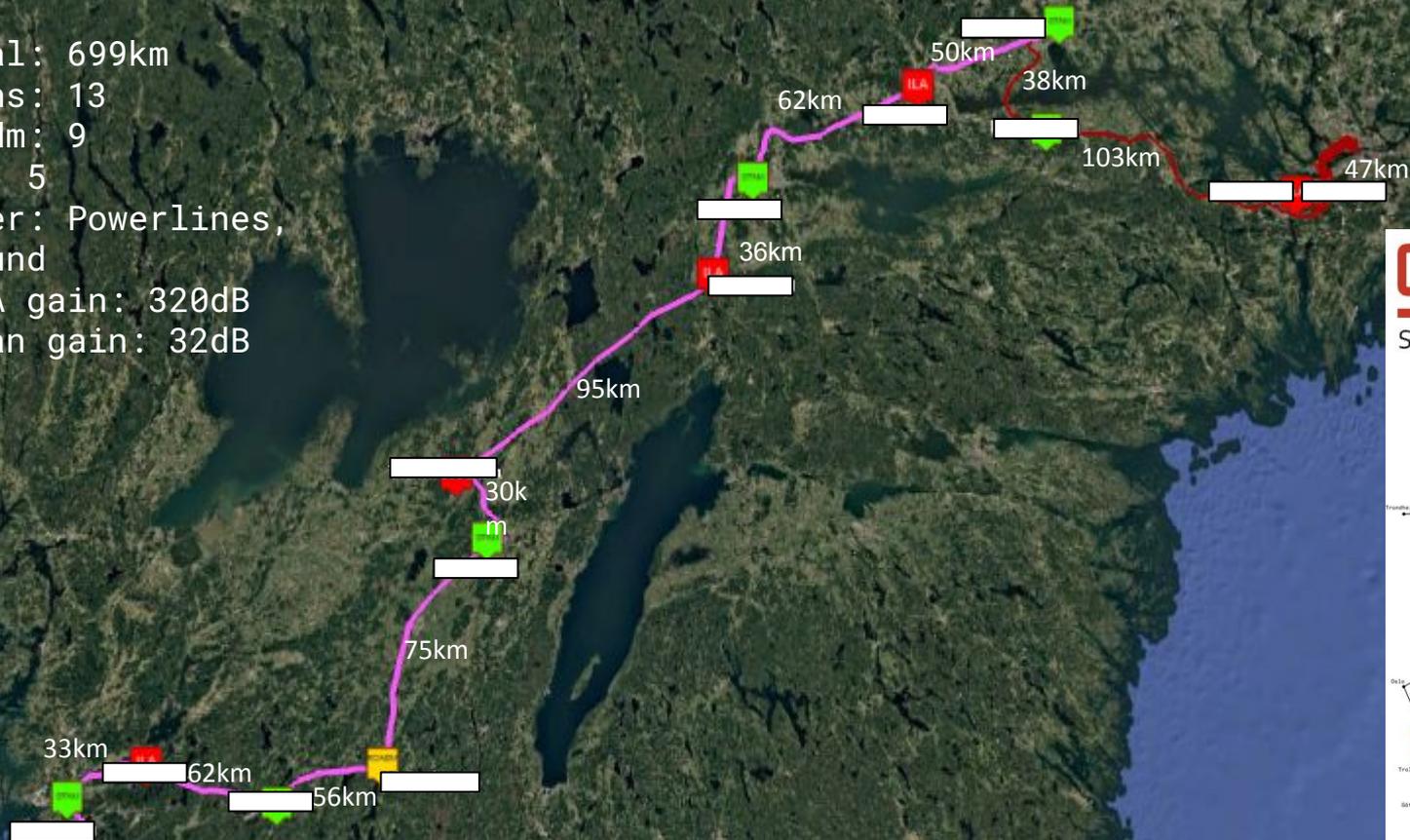
Asymmetry 200 ns and timing error 100ns

SUNET

White Rabbit in a coherent network

gbg-ts1..gbg-ts0..sty-ts0..sty-gbg-sth-wr
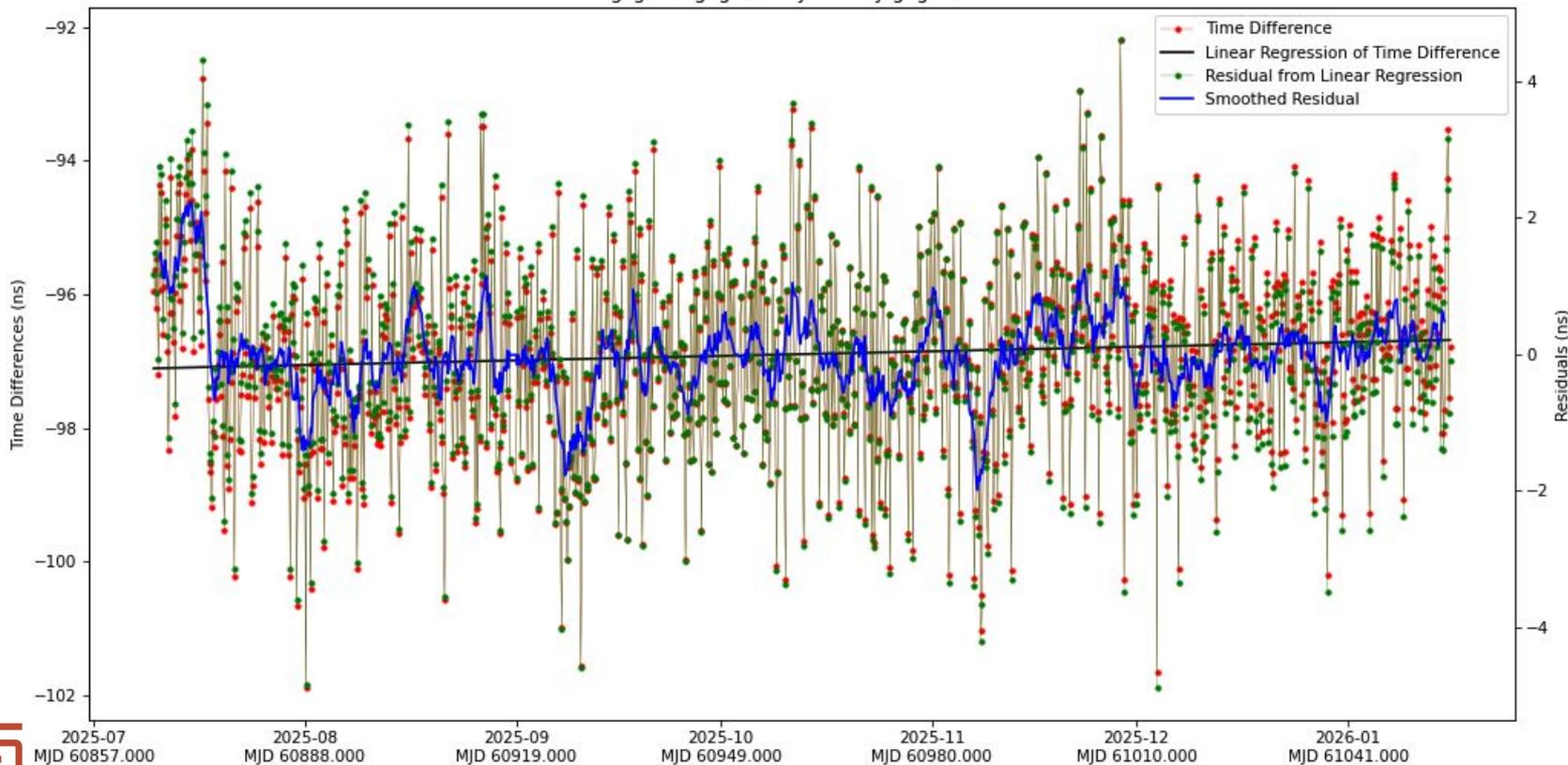
A 440 km White Rabbit link using DWDM BiDi optics in a coherent network

Link Stockholm - Sundsvall

- Using the Swedish National Research and Eduction Network SUNET

- 8 hops, 440 km

- Use BiDi to not have to calibrate for asymmetries in the fibers, or handle varying asymmetries

- Mainly power grid top wire fiber
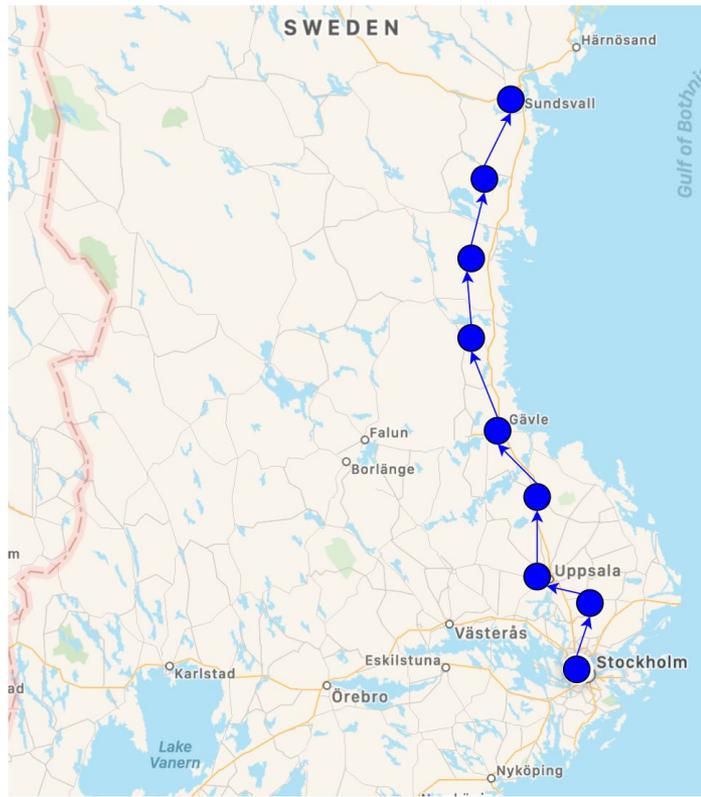
BiDi in a traditional optical network

- The ROADM network uses unidirectional transmission in the C-band

- SUNET installed OTDR:s using 1650 nm +/- 20 nm

- Breakout an extra band for BiDi with WDM filters
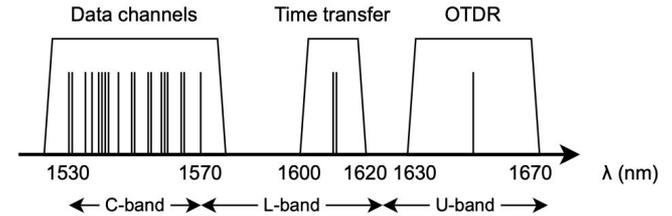
Link Stockholm - Sundsvall

- WDM filters connects to the line and split bands to the different uses

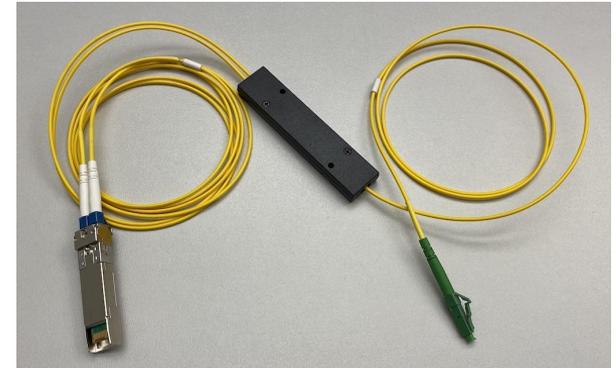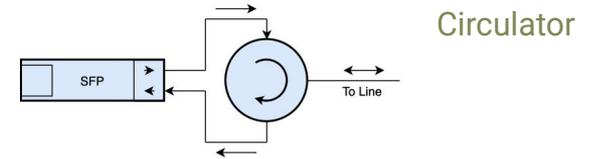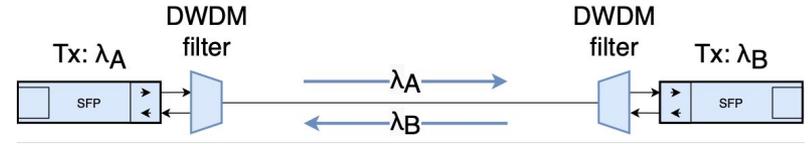- Need to amplify and/or regenerate the WR signal at each hop
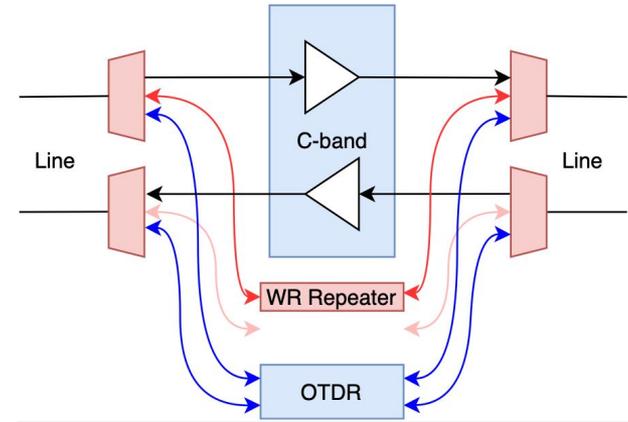
**Amplifier station**
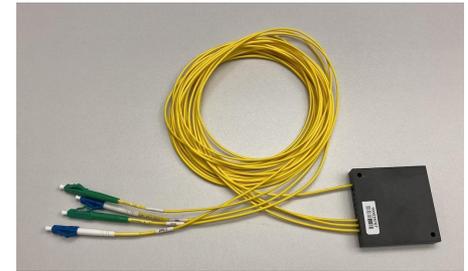
Filter

Optics

- DWDM SFP:s for wavelength stability,
  - with custom wavelength, 100 GHz DWDM grid

- Ideally, we would have WDM filters to make them BiDi

- Could not find a suitable DWDM filter, use circulators
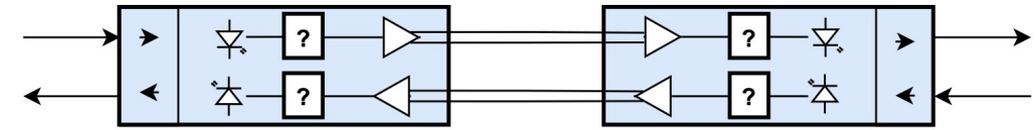 - - decreases range

Circulator

Active equipment

- DWR Switch (Low Jitter)

- O/E/O (Optical-Electrical-Optical)
  converters, connects SFP:s back-to-back
    - no retiming or similar that can
      interfere with WR
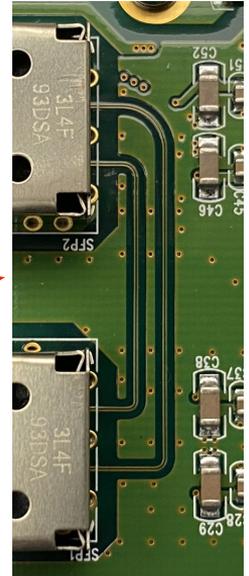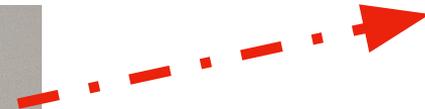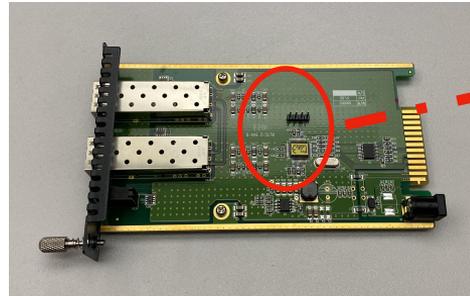
Signal distortion with SFPs back-to-back

- Hard to know what kind of discriminator the SFP uses, what kind of reshaping/retiming it does, ton/toff differences, etc


SFPs back-to-back

- Even if one batch can be measured and qualified, there is often no guarantee that the next is built the same way
- Too many hops of O/E/O and too much fiber distance may distort the signal to much to be useful
- Decided to use a switch every second hop

The entire link

- Every other node is a switch, every other O/E/O

- Swap wavelengths for each O/E/O hop-pair (in case calibration fiber spool has different CD than installed fiber)

- SFPs matched in wavelength per O/E/O hop-pair (to have similar alpha)

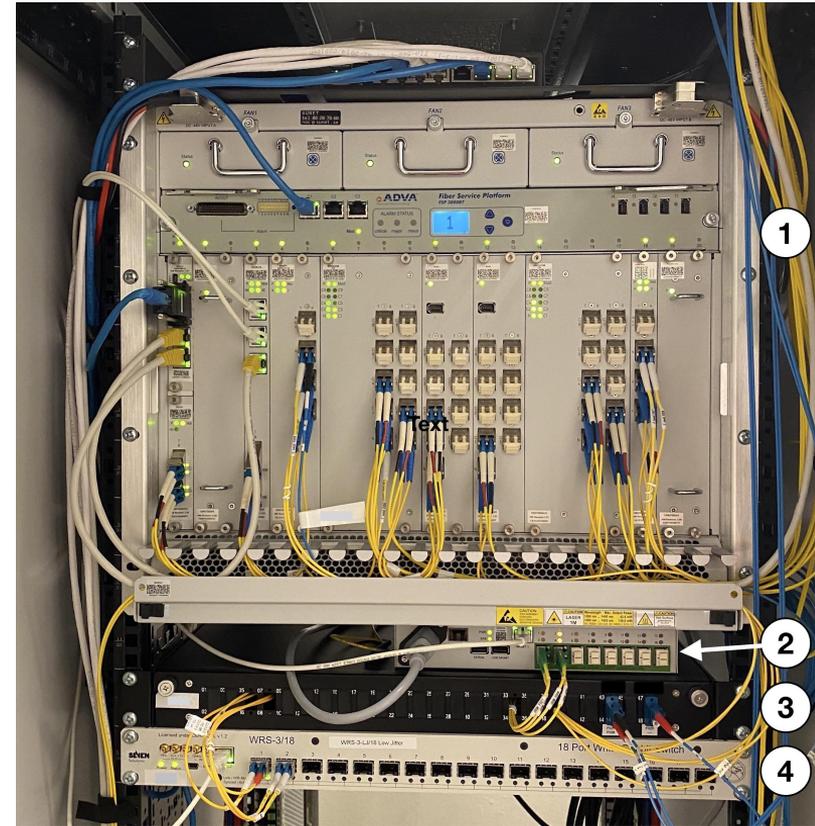- Each O/E/O hop-pair given a weighted average alpha

WR Switch

O/E/O

λ_1 λ_2

λ_2 λ_1

} O/E/O hop pair
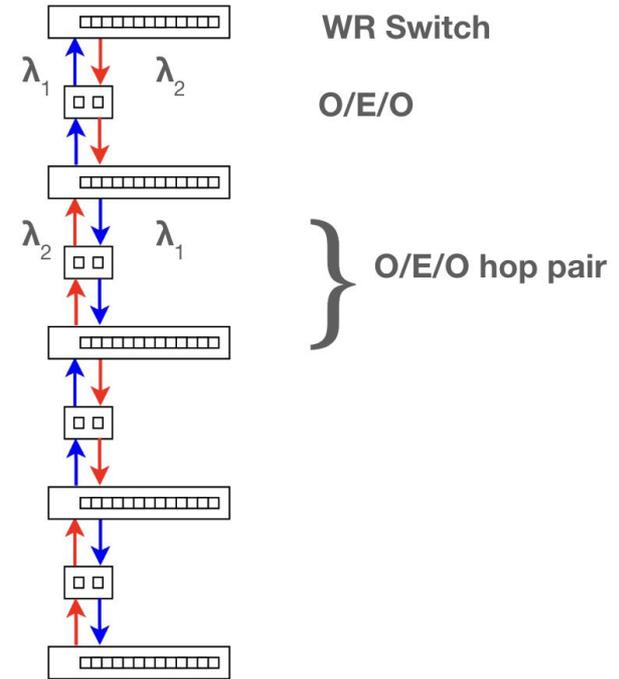
-48 V DC power

- Switches were adapted for -48 V DC

- O/E/O chassis was bought with DC power
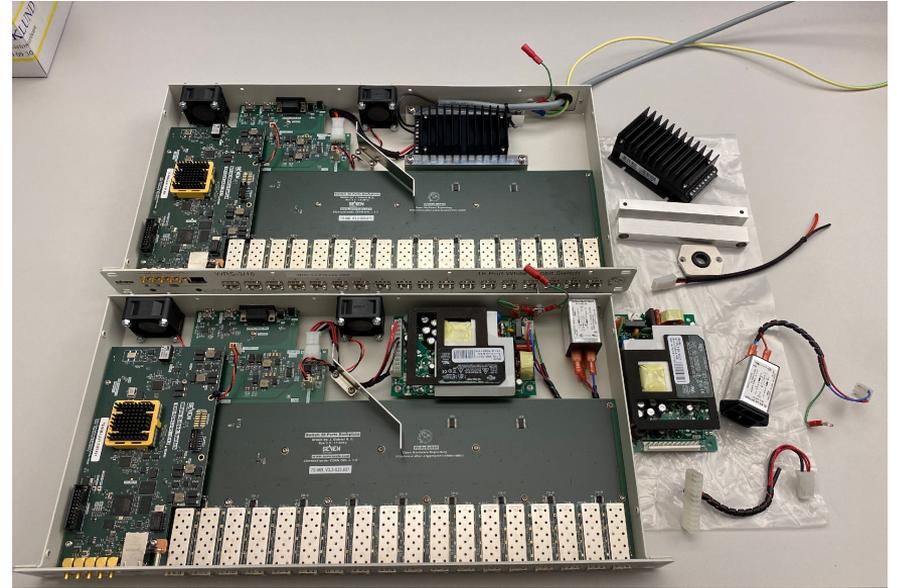
ROADM station

1. ROADM and amplifiers chassis

2. OTDR
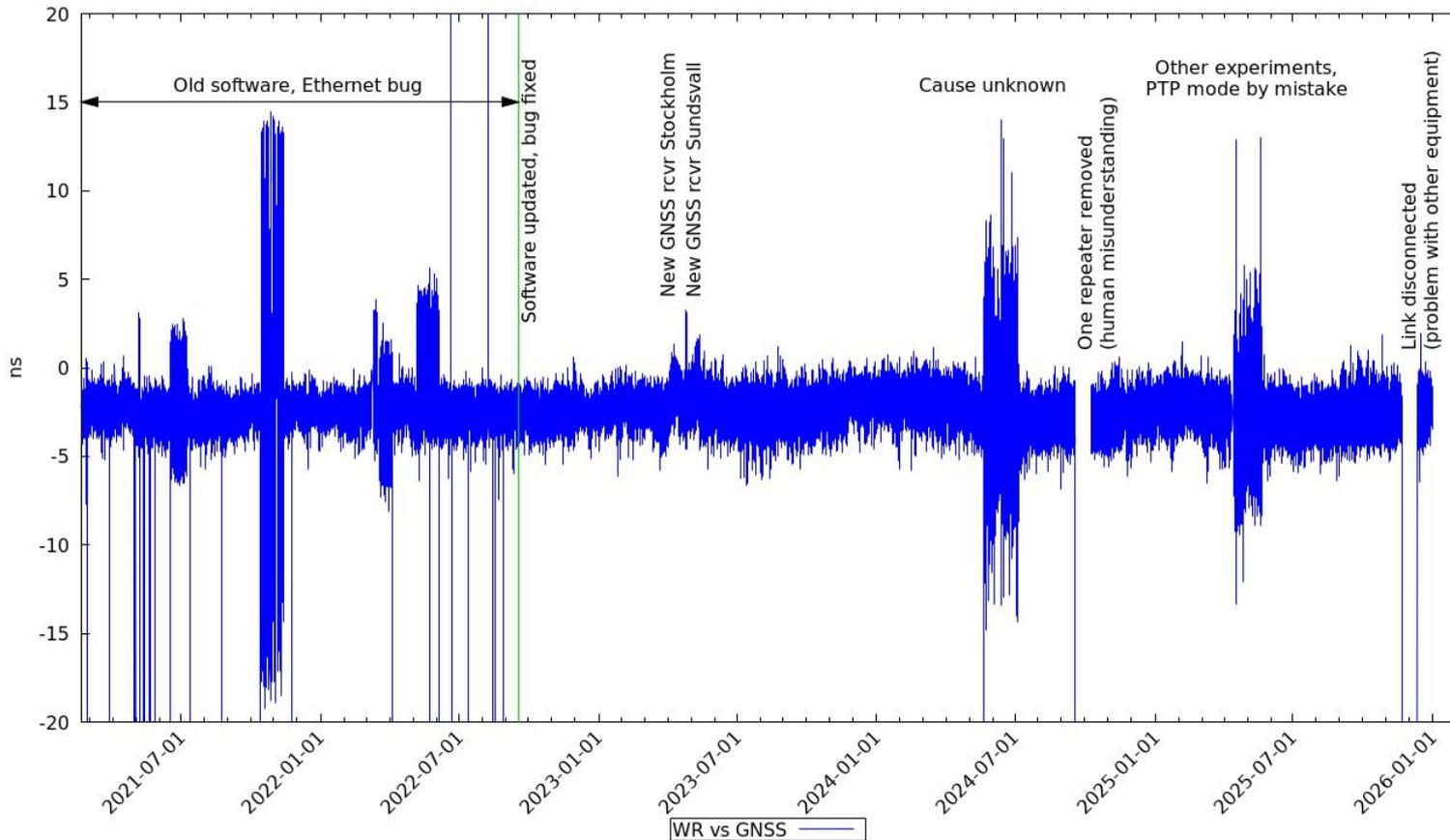
3. WDM Filters in ODF box

4. White Rabbit switch

Amplifier station

1. -48 V DC distribution

2. C-band amplifiers (EDFA + Raman)

3. O/E/O WR repeater

4. New WDM Filters in ODF box

In operation for >4.5 years

White Rabbit (BiDi) vs GNSS Common View (code only), Stockholm - Sundsvall, raw data plot

Results

- The link is less noisy than the reference GNSS Common View time comparison (when working as intended).

- There were several outages and other anomalies. With newer firmware in the switches, these are gone.

- Almost all problems were on one link, likely because the fiber connection has some problem with reflections. With WDM filters for the SFPs instead of circulators, this could possibly be mitigated.

- O/E/O converters with WR compatible symbol retiming could make things cheaper and maybe more stable. For future study.

- There are so far no obvious seasonal variations.

Questions?

Link calibration

- All equipment, active and passive, mounted and connected

- Switch port calibration of the first 4 ports

- Each SFP+circulator calibrated for asymmetry (fiber pigtails varies in length), in case one has to be replaced later

- Each hop, 2 x (SFP+circulator) calibrated for alpha and phase
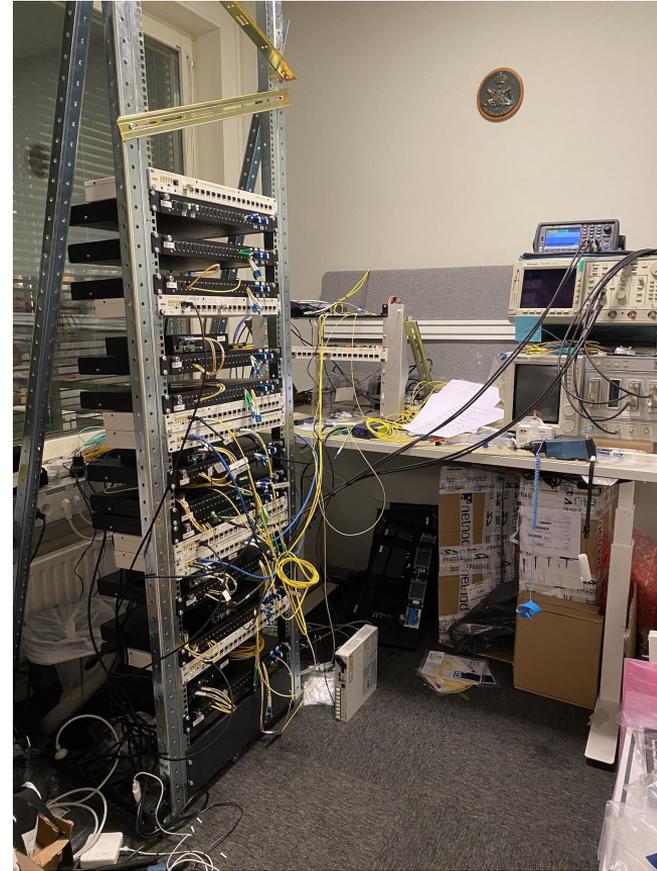
Link calibration continued

- Each O/E/O hop pair was given an alpha average, weighted with the expected fiber span lengths of the hops

- For each additional switch hop, phase was calibrated from the master switch, to minimise impact of systematic phase errors in the measurements, such as not perfectly calibrated coaxes, imperfect TIC calibration, etc.

- All calibration could be done using the 10 MHz, since the uncalibrated phase error for 80 km was about 7 ns so there could be no ambiguity (<50 ns).
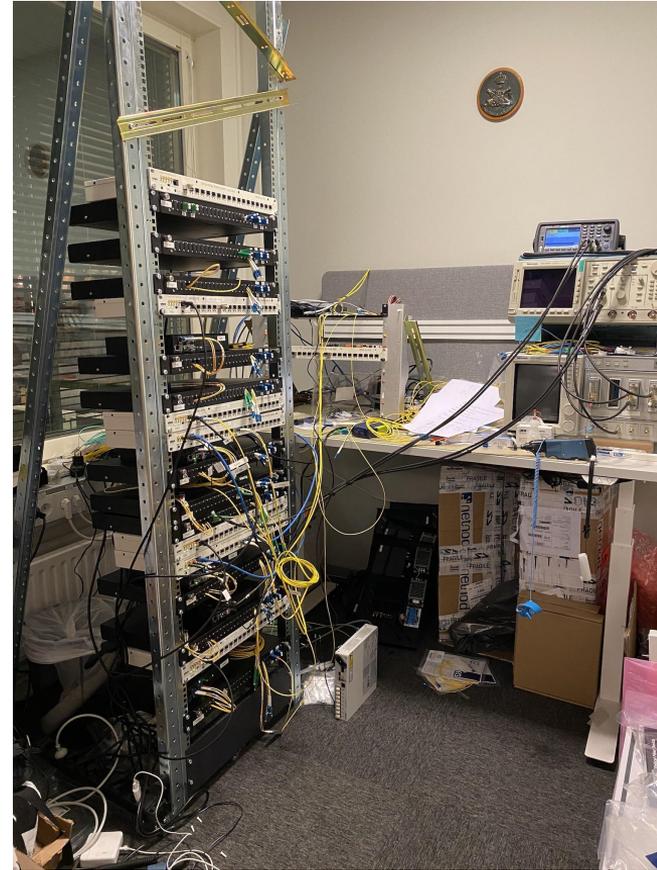
Sven-Christian Ebenhag

Senior Systems Architect, Head of Time & Frequency

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