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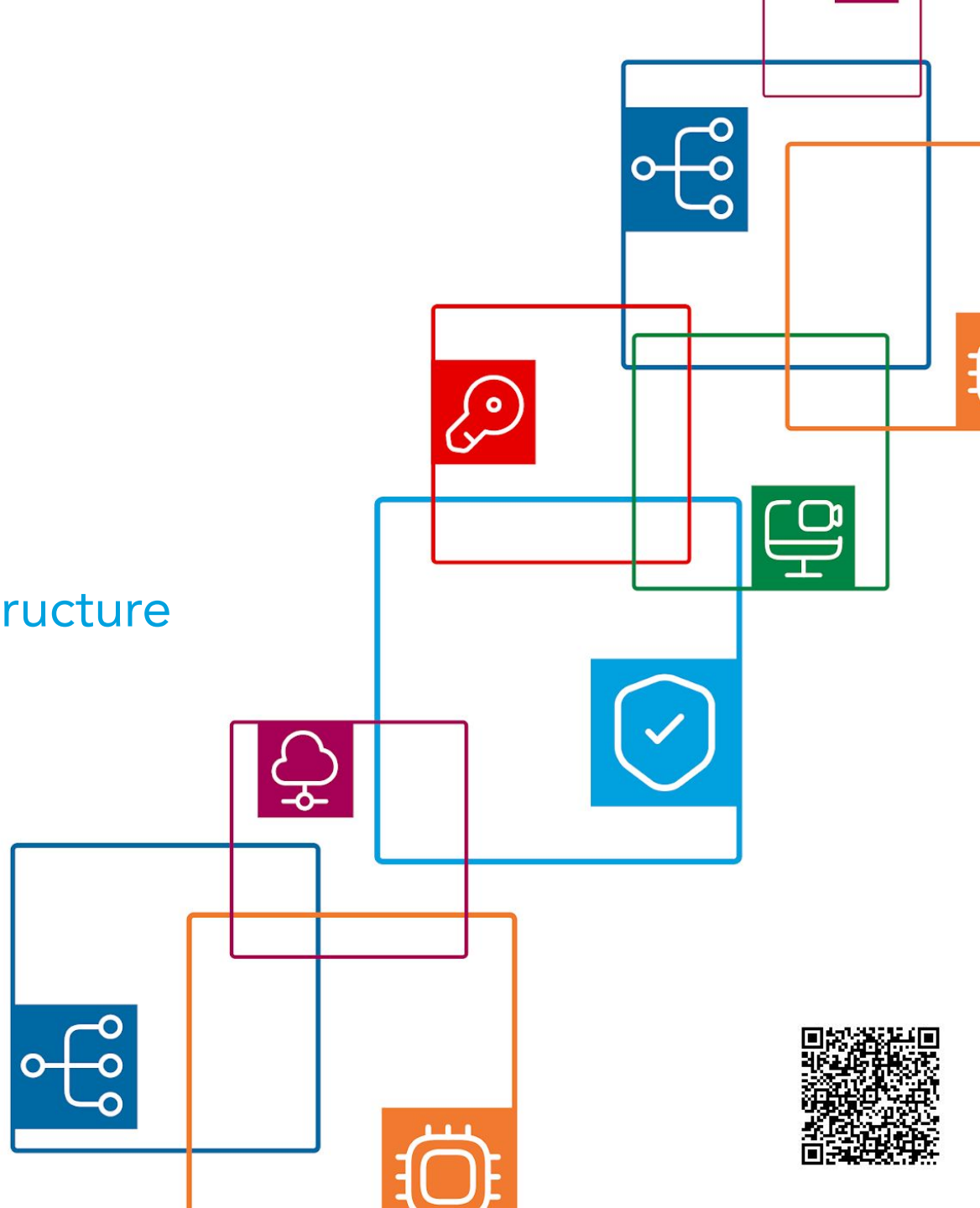
Time Travels in the L-Band

Deploying a National White Rabbit Infrastructure over Active DWDM Networks

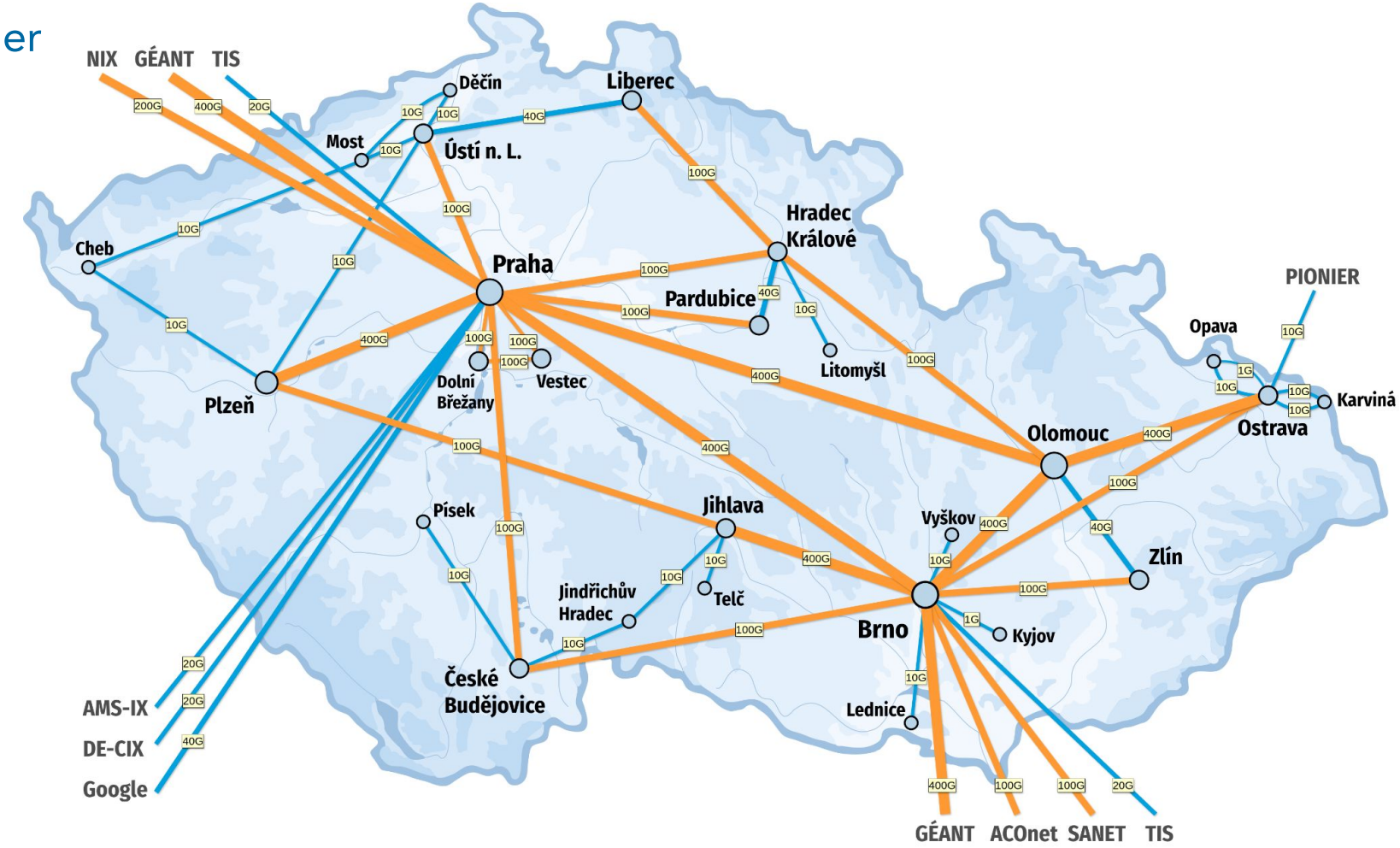
Michal Hažlinský

Helsinki, 2026-06-11, TNC26



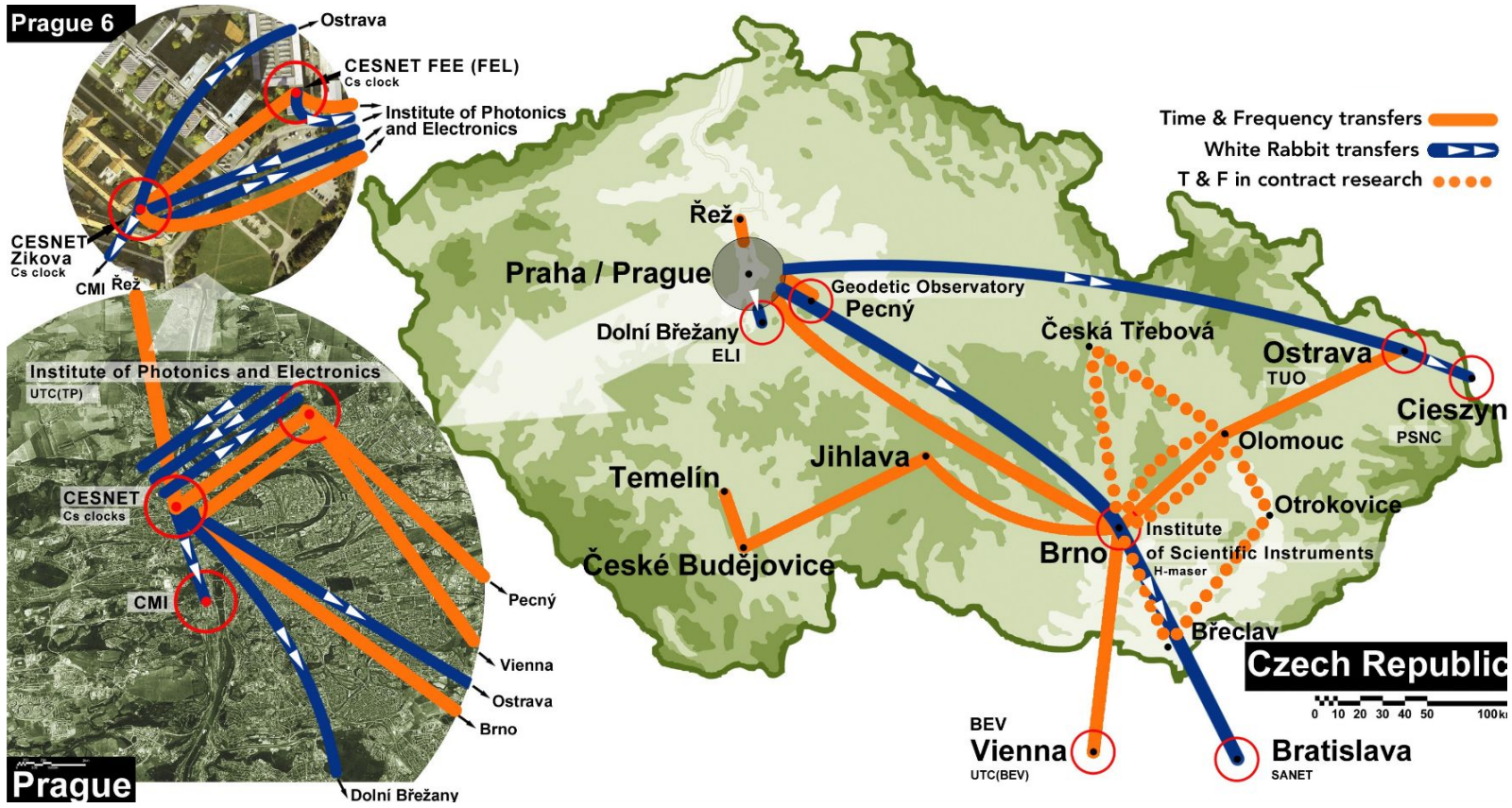
CESNET and Its Mission

- E-infrastructure service provider for R&E in Czech Republic
  - Network (CESNET 3)
  - Computing
  - Storage
  - Collaborative environment and Multimedia
  - Security
  - Identity
- Research and Development in Networking



Photonic Services in Production

- In house research since 2005
- CzechLight family of optical network equipment
- Strong know-how in special tailored photonic services
- International collaboration



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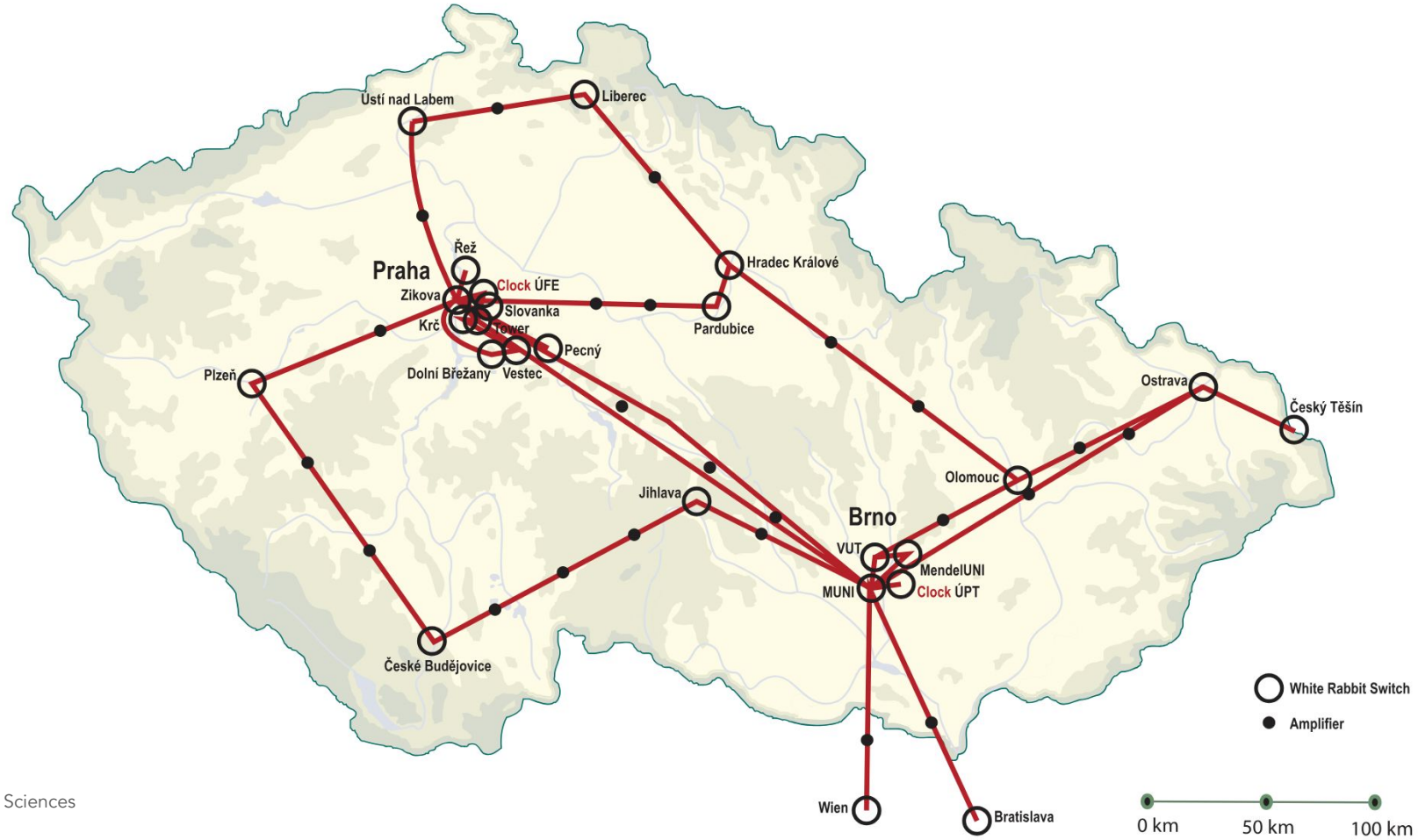
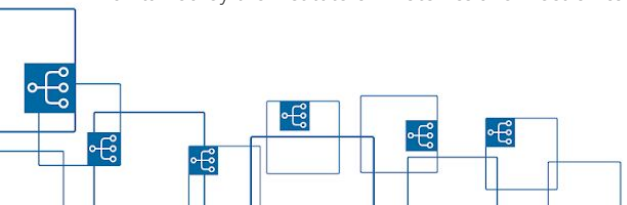
Precise Time Distribution as a Service

- 22 locations of CESNET 3
- Traceable to the national time scale
- Stability better than 1 ns
- An alternative to GNSS
- White Rabbit switches
- Client interfaces:
  - White Rabbit
  - PTP
  - (1PPS)

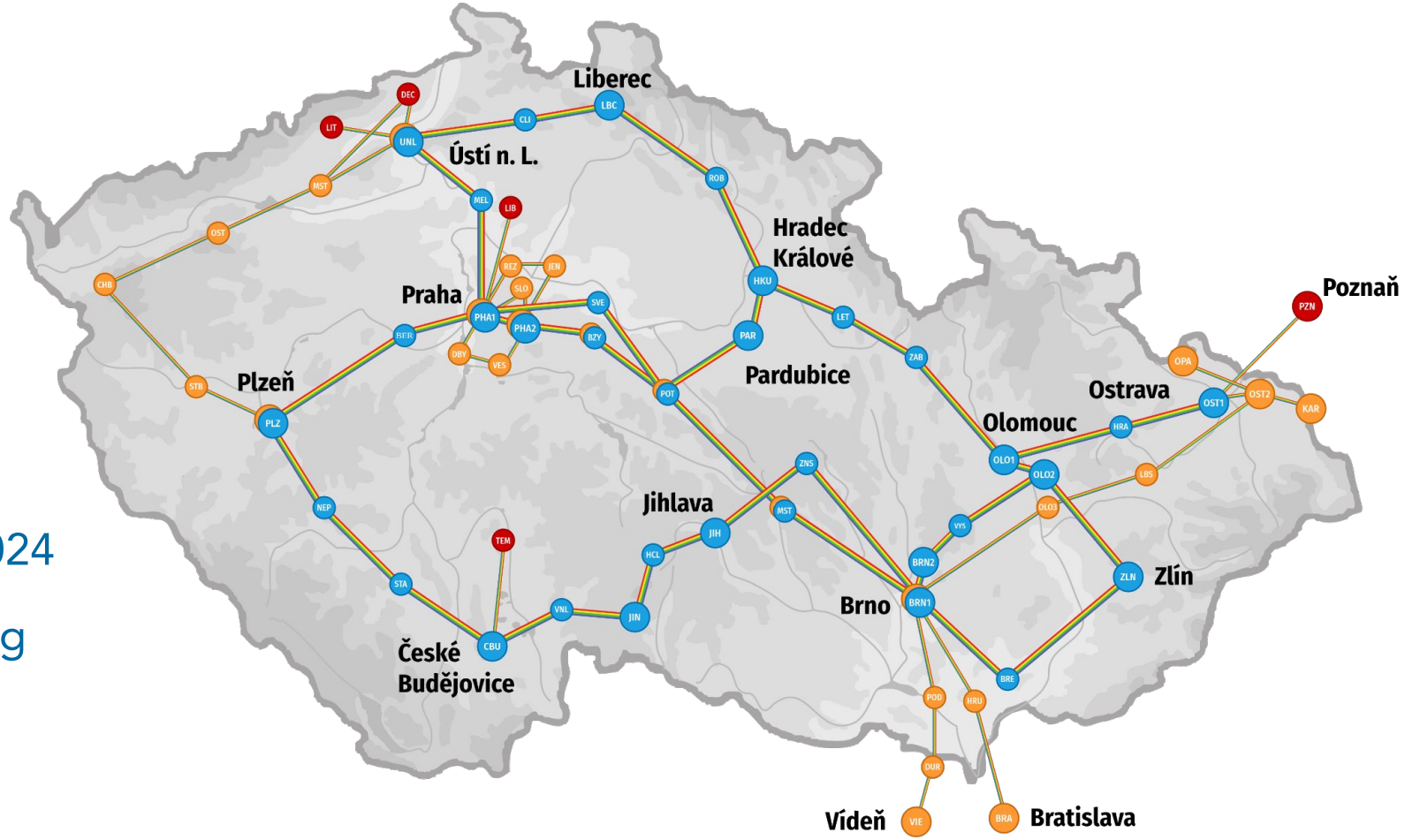


* Maintained by the Institute of Photonics and Electronics of the Czech Academy of Sciences



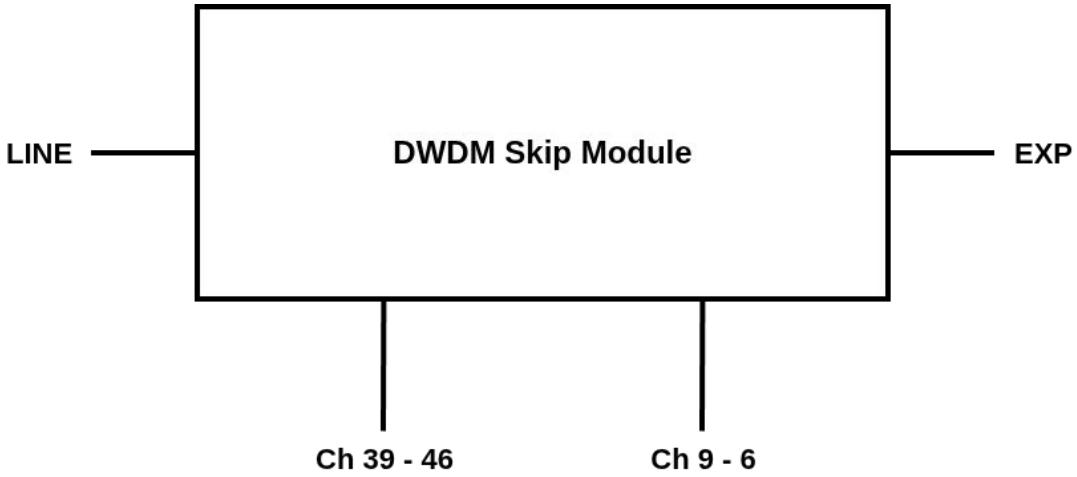
CESNET 3 Fiber Footprint

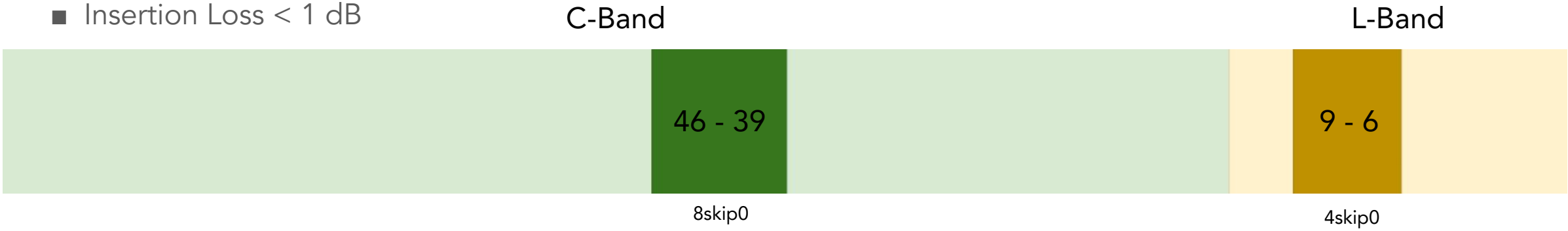
- 5700 km of fibre lines
- Partially disaggregated
- Multivendor
  - CISCO
  - Ribbon (ECI)
  - CzechLight
- Procured in 2 phases in 2019-2024
- Advanced applications (including non-data) readiness as a part of the network design



Designed for spectrum sharing

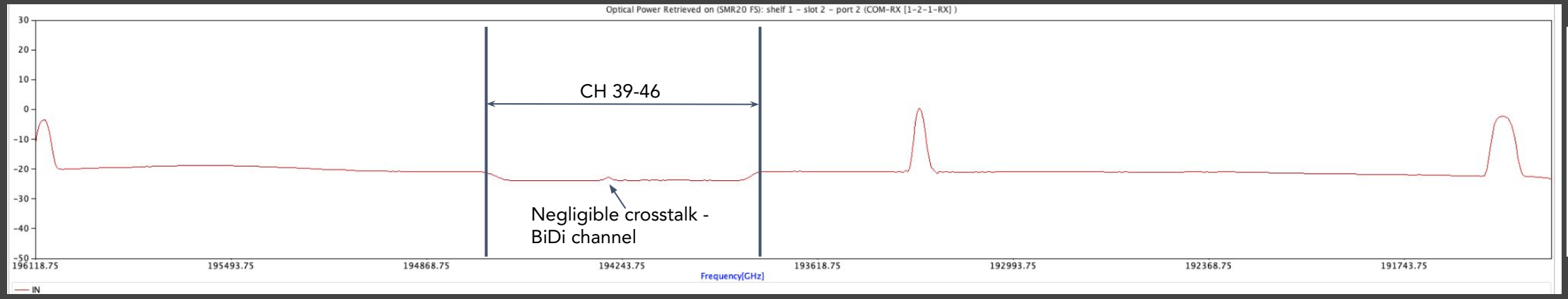
- Integral part of the CESNET 3 network design
- Part of the spectrum reserved for future special applications
- Enables Bi-Directional transmissions
- Custom channel filters at each fibre line
  - 8 channels in C-Band + 4 channels in L-Band
  - Insertion Loss < 1 dB

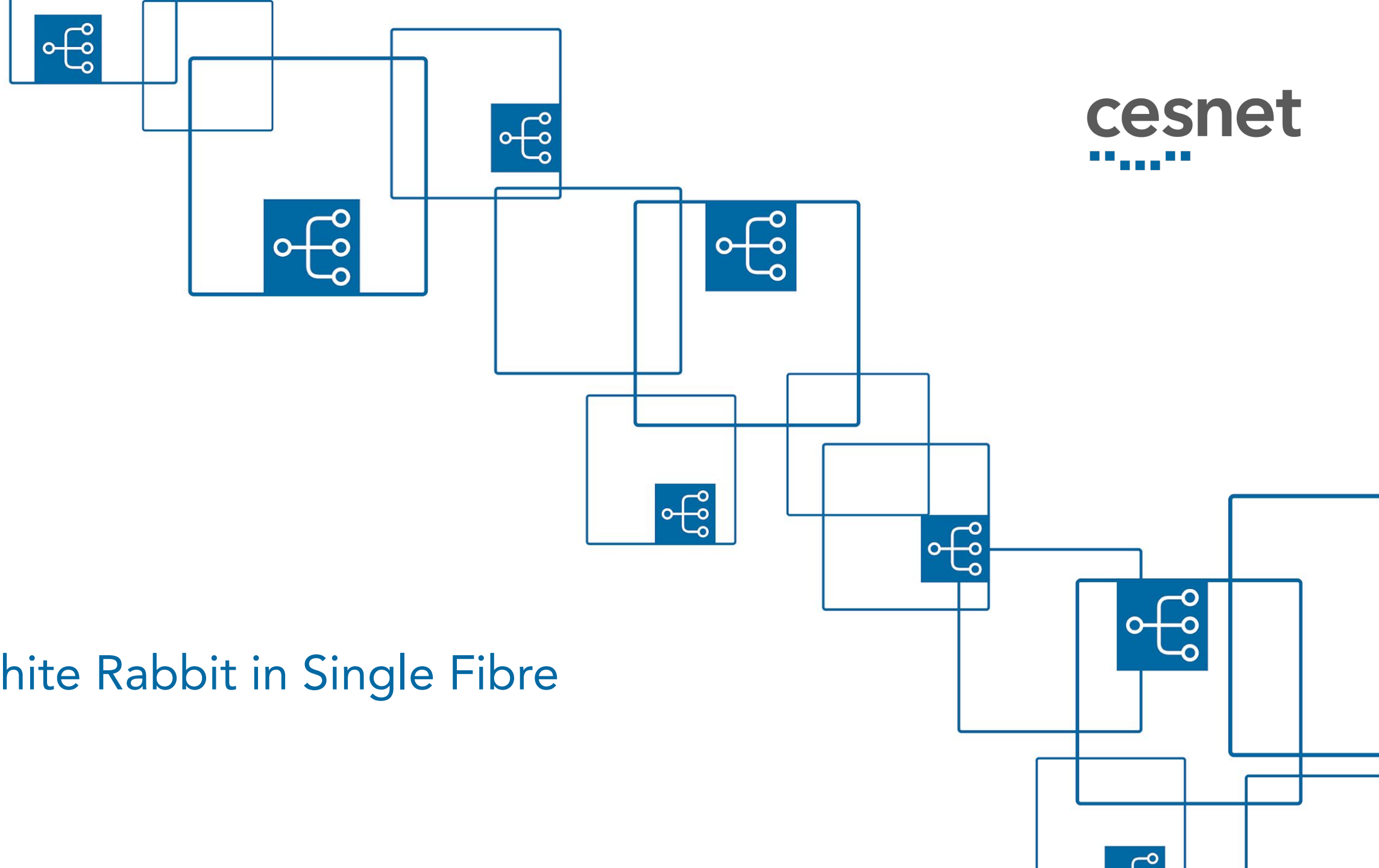





LINE
RIBBON
LINE
RIBBON
5
6
7
8
9
10
11
12
P
P
MOS-931
OPT9603
dir BRN
NCS
NCS

How does the CISCO NCS see it?





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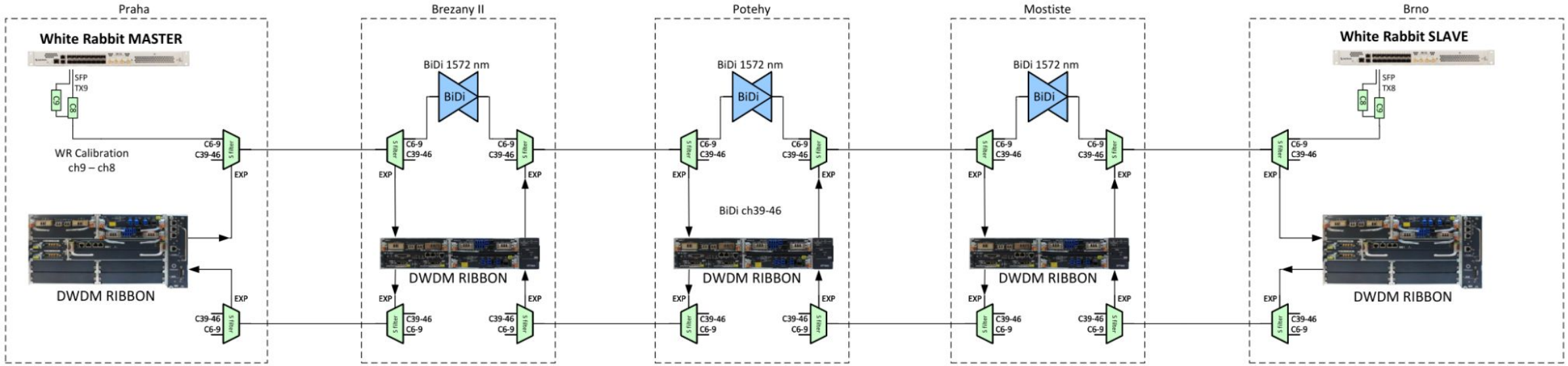
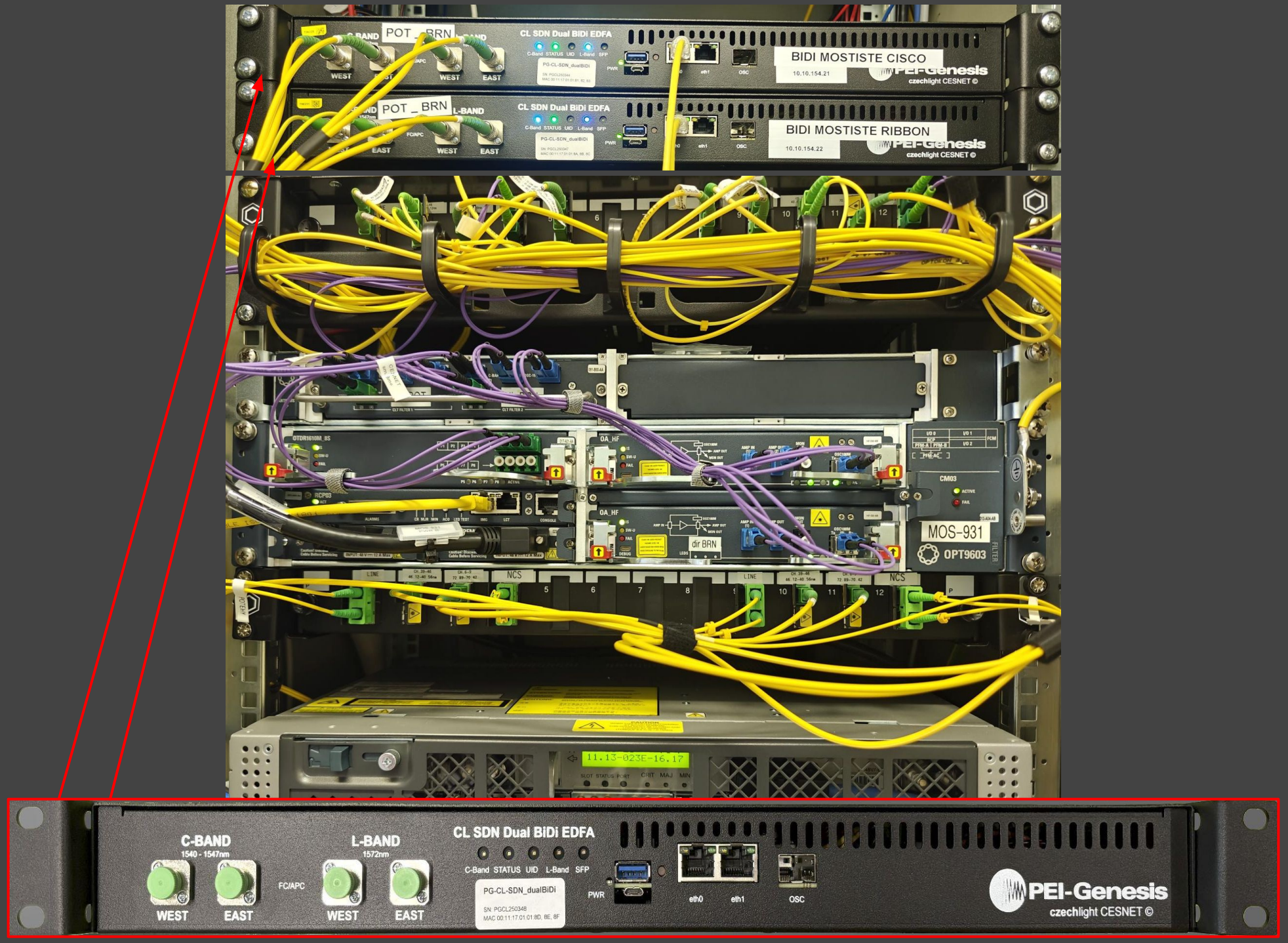
White Rabbit in Single Fibre

Single fiber Bi-directional Transmissions

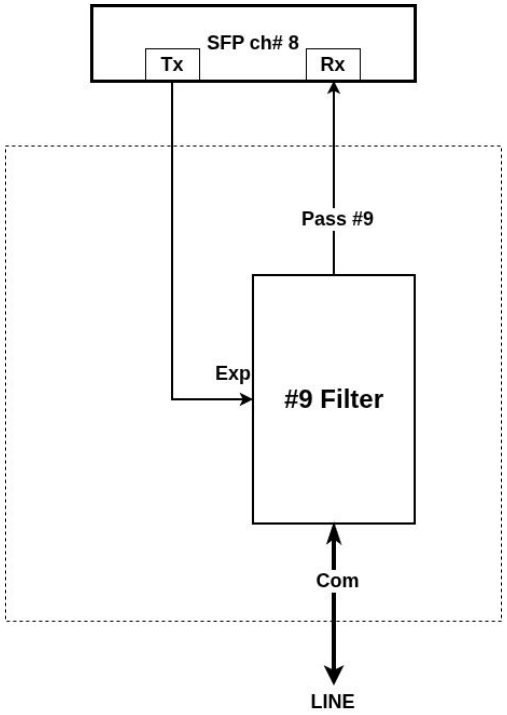
- White Rabbit —> path asymmetry is an issue —> same fibre in both directions
- 1GE DWDM SFPs, 120 km — L-Band 1571 nm and 1570 nm — ch# 8, 9
- CzechLight SDN BiDi EDFA — for long-haul links
  - Dual — C-Band + Narrow L-Band (1572 nm)



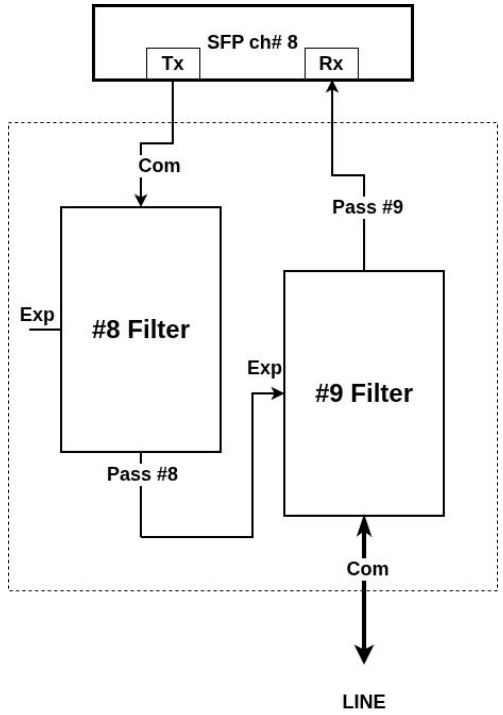

POT _ BRN
CL SDN Dual BiDi EDFA
BIDI MOSTISTE CISCO
10.10.154.21
POT _ BRN
CL SDN Dual BiDi EDFA
BIDI MOSTISTE RIBBON
10.10.154.22
czechlight CESNET ©
MOS-931
OPT9603
dir BRN
C-BAND
1540 - 1547nm
L-BAND
1572nm
CL SDN Dual BiDi EDFA
C-Band STATUS UID L-Band SFP
WEST
EAST
FC/APC
PG-CL-SDN_dualBiDi
PWR
eth0
eth1
OSC
PEI-Genesis
czechlight CESNET ©

Tx-Rx Add/Drop

- Single filter at the transceiver to “drop” Rx channel



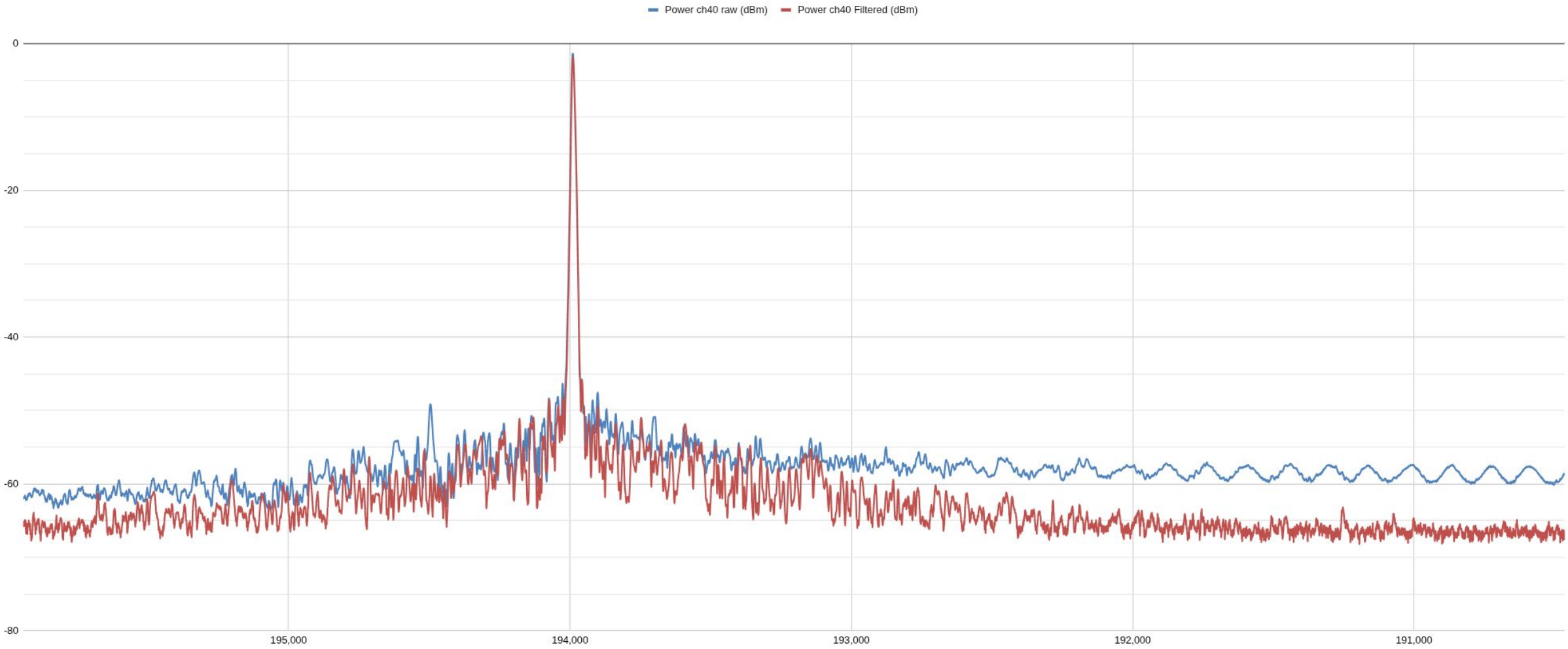
- Two filters at the transceiver to “Drop” Rx channel and isolate Tx channel
  - Prevent crosstalk and strip out side lobes



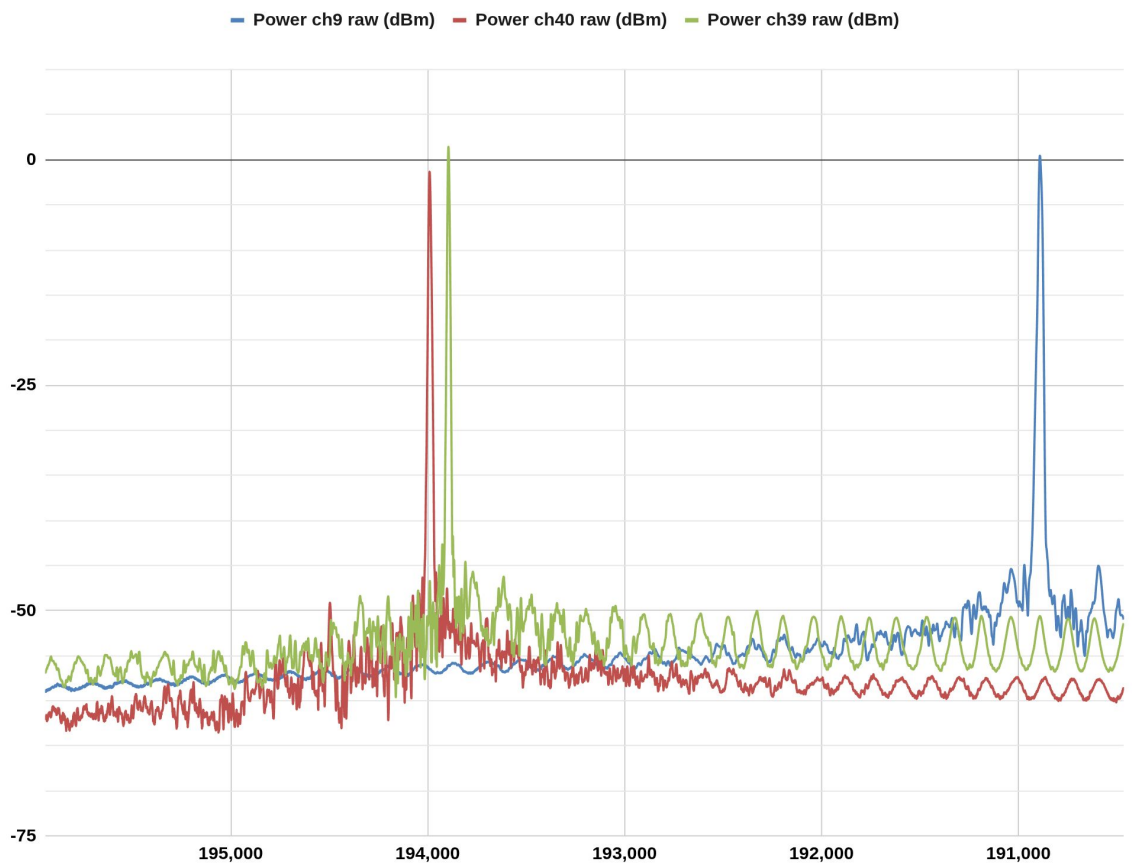
Why?

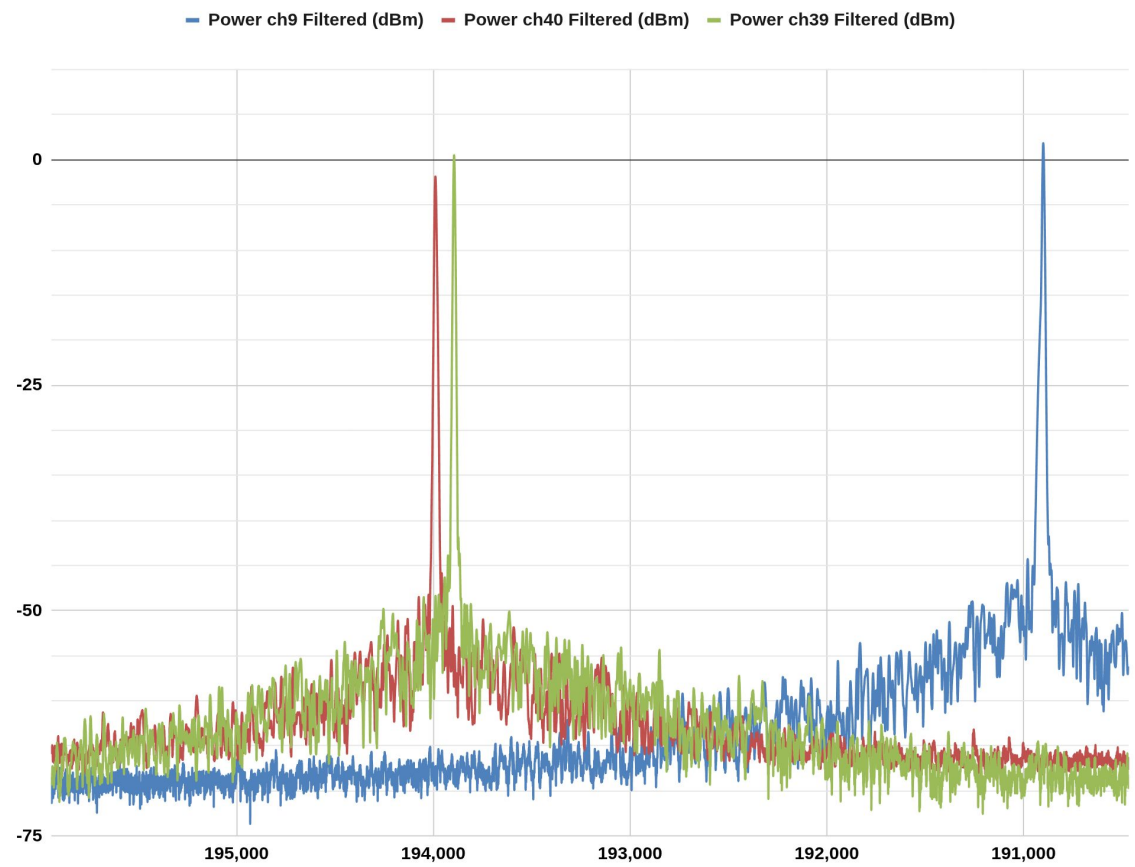
Is there a difference?

Transceivers…



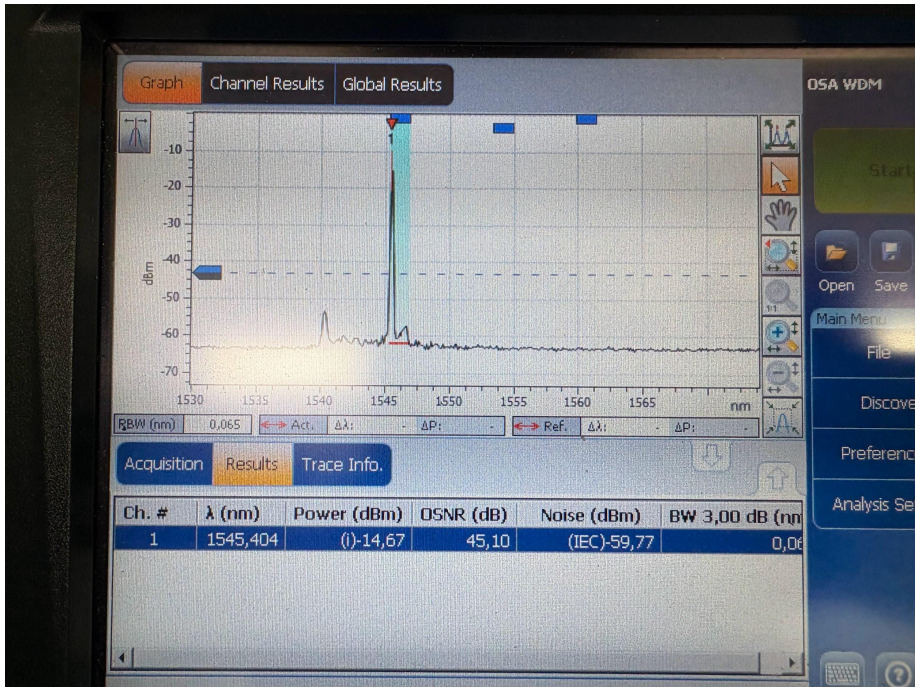
➔ OSNR budget
➔ Less noise
➔ Lasing less likely



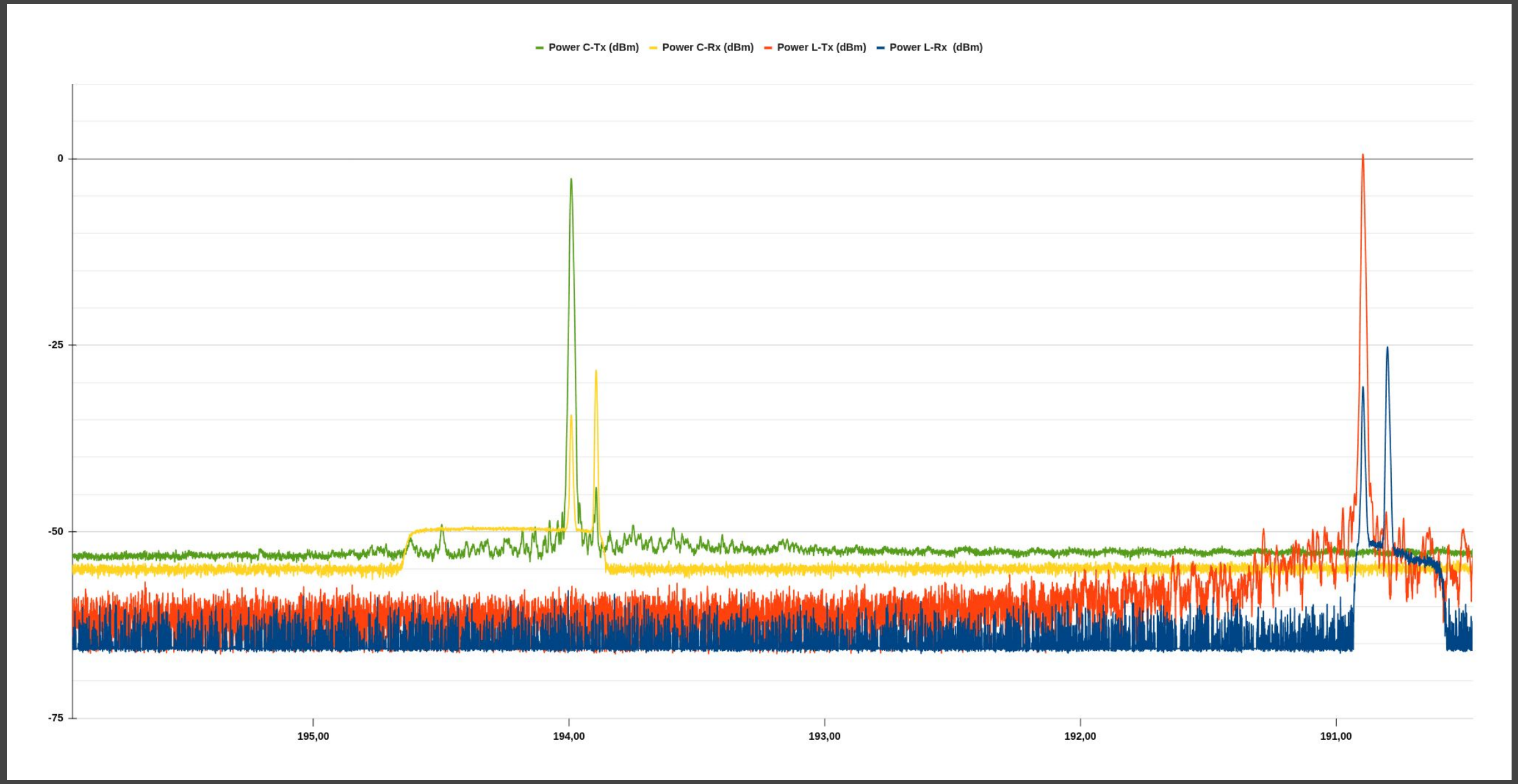


Powering up BiDi channels in single fiber

- A little bit demanding initial tuning procedure
  - Manually set up the pump current
- Use of fixed attenuators
  - Balancing power levels in both directions
  - Based on actual power levels measured on site
  - Needs hands at all inline huts and at both ends
    - *Ideally at the same time…*
- Manual pump current settings on EDFAs
  - Proved to be more stable
  - SDN and real time telemetry makes the procedure smoother

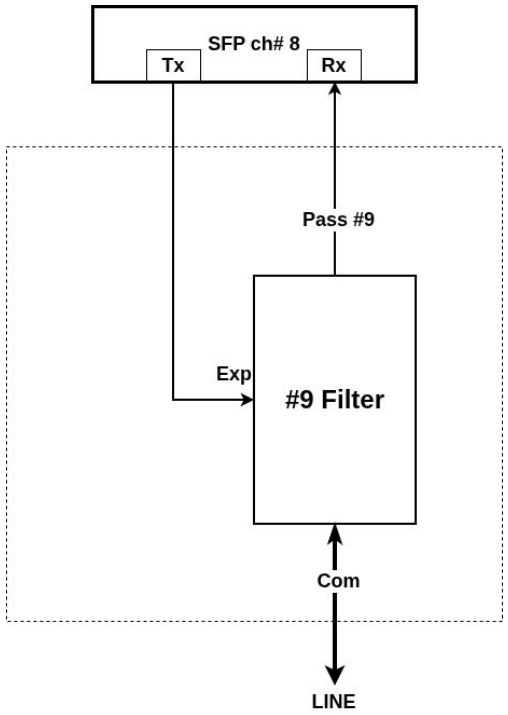


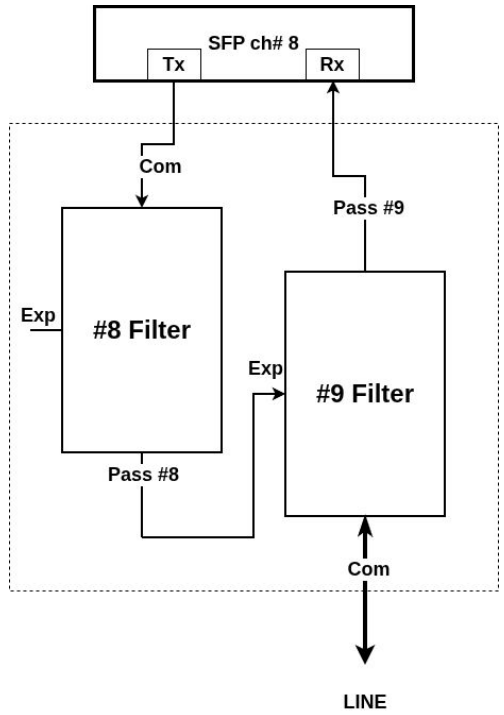
End - to - End BiDi Channels



Fighting Asymmetry: Tx-Rx Filters

- Single fiber - To ensure the same physical path X internal asymmetry of filters

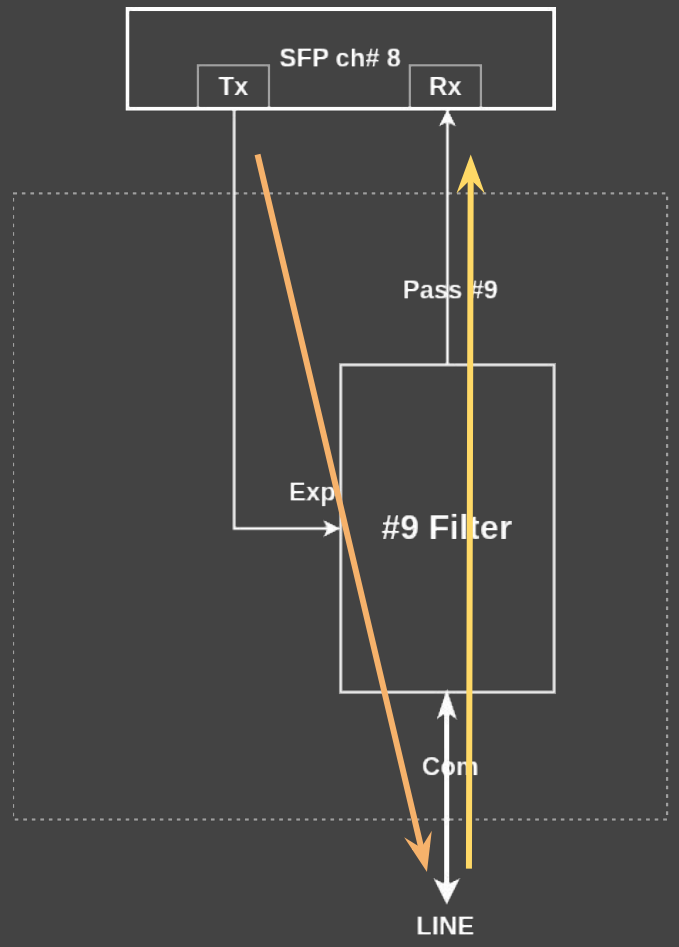


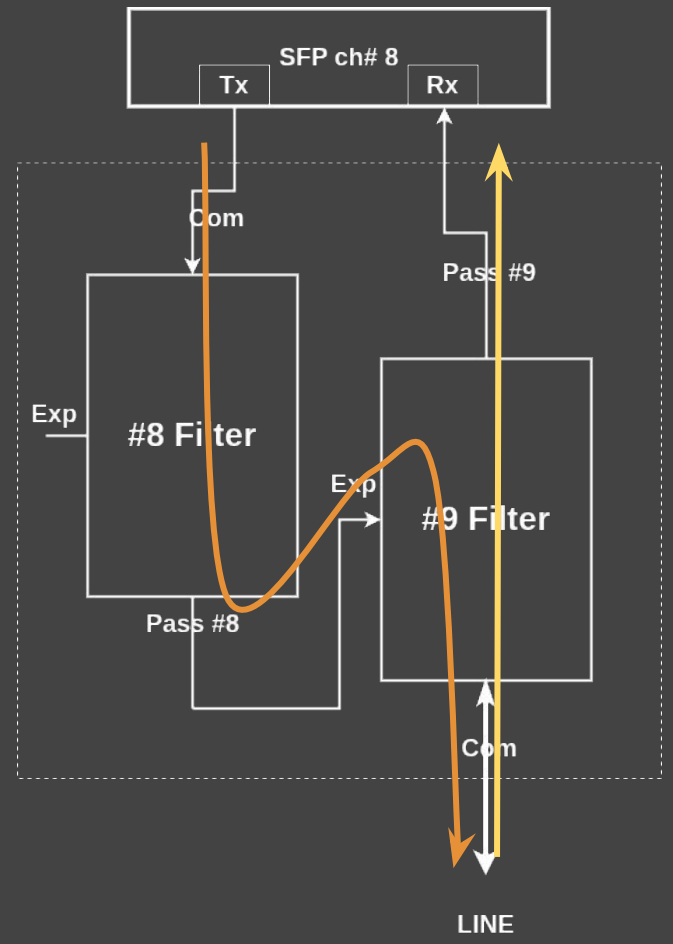


DATASHEET

Fibre Length

1m (+/- 0.05)

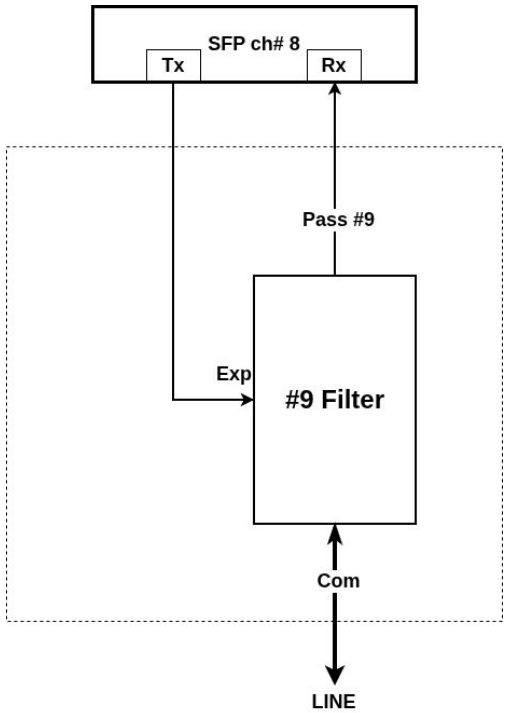




Fighting Asymmetry: Tx-Rx Filters

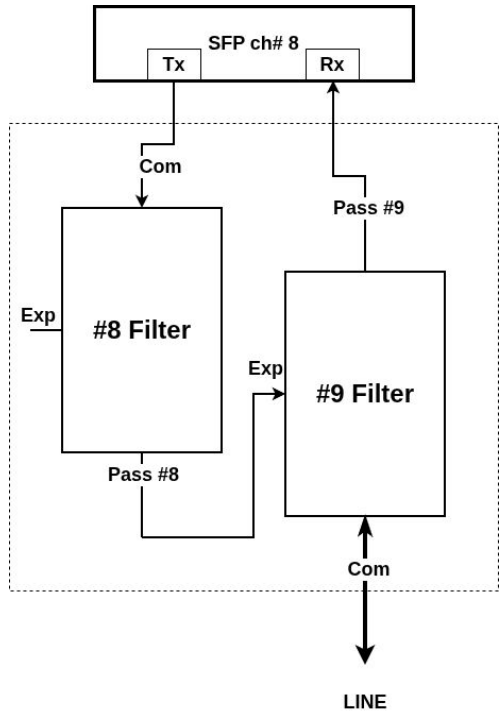
- To measure an In-Out delay between ports on filters

—> Configure WR switch to compensate



$$\delta_{Tx} = \delta_{ExpLine}$$
$$\delta_{Rx} = \delta_{ch9Com}$$

$$\delta_{Tx} \neq \delta_{Rx}$$

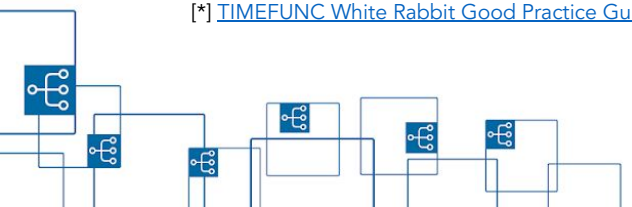


$$\delta_{Tx} = \delta_{ch8Line}$$
$$\delta_{Rx} = \delta_{ch9Com}$$

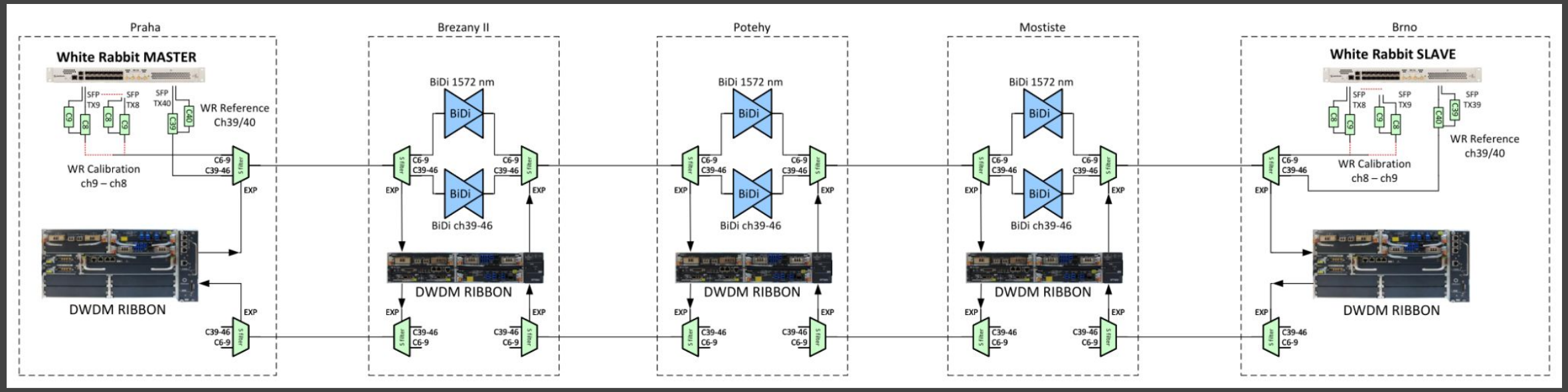
Fighting Asymmetry: Long haul fiber lines

- Chromatic dispersion
  - The signal propagation speed is different at different wavelengths
- Field calibration procedure
  - Measure the asymmetry of all fibre lines when deploying
  - Calculate the α parameter
  - Configure WRS to compensate
- Leverage the Safran Z16 feature
  - Port mode **survey** - measures delay between time signal on slave WR ports
  - Altered fibre delay asymmetry calibration procedure with switching Tx-Rx wavelengths [*]
  - No need to bring the second WRS and the external counter on site - just reference transceivers and filters
  - Z16 REST-API allows to create a simple calibration python script

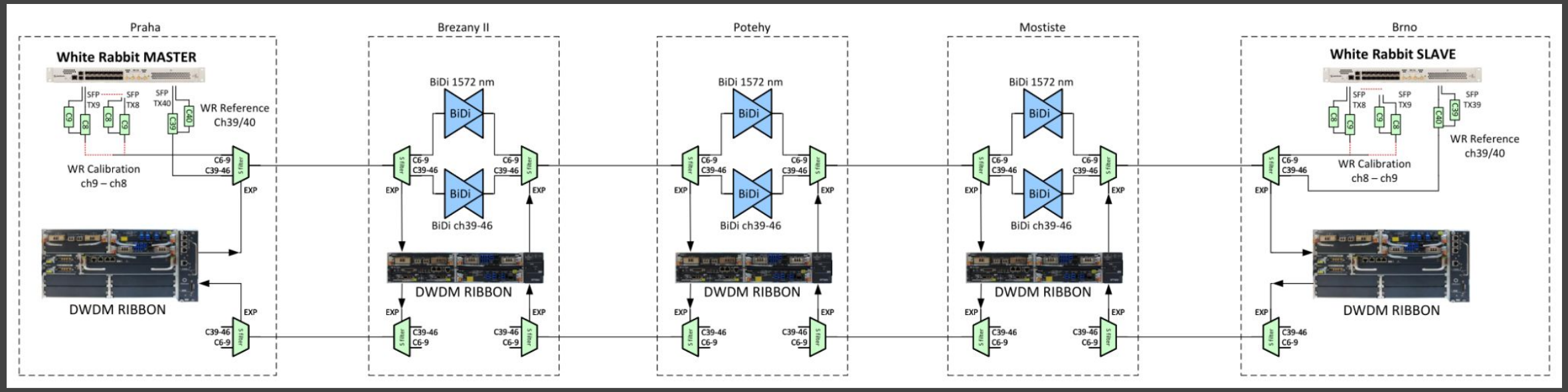
[*] TIMEFUNC White Rabbit Good Practice Guide 02 May 2019



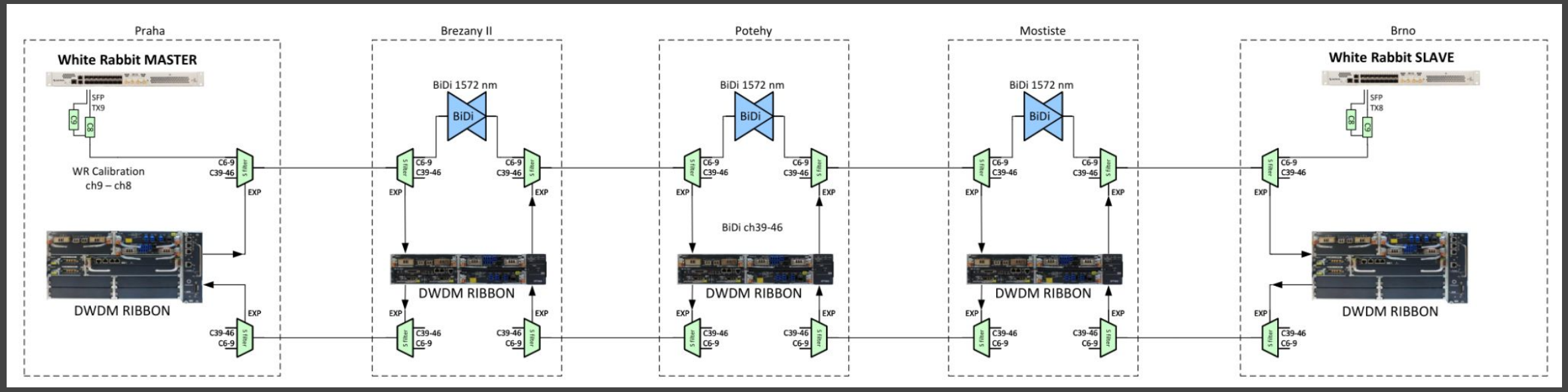
Calibration …



Calibration …



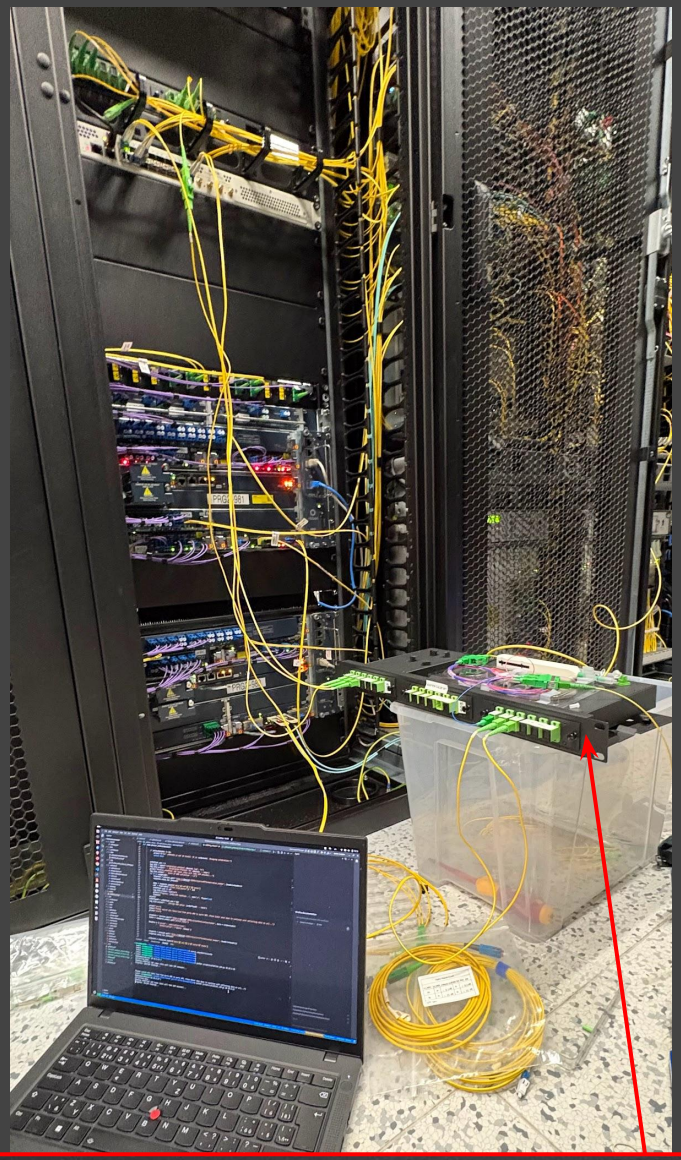
… Production



Measured λs on survey ports WR0 and WR1

$\lambda_{TxWR0} = \lambda_{RxWR1}$; $\lambda_{RxWR0} = \lambda_{TxWR1}$

Reference time signal WR15



Measured λs on survey ports WR0 and WR1

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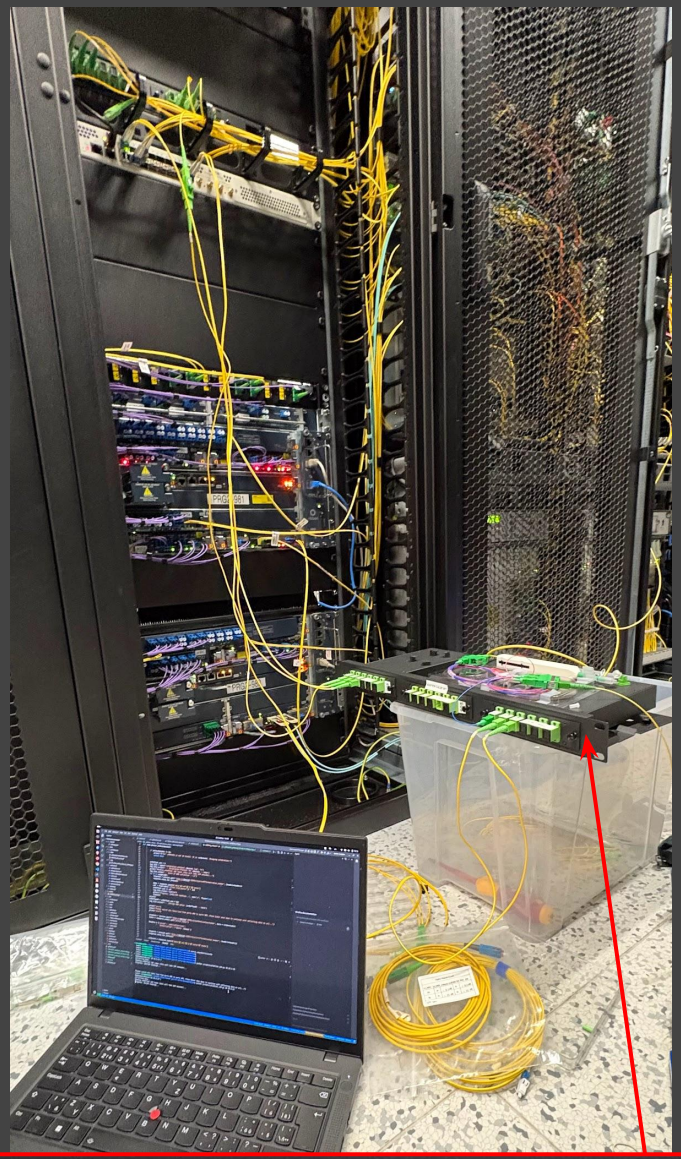
Reference time signal WR15

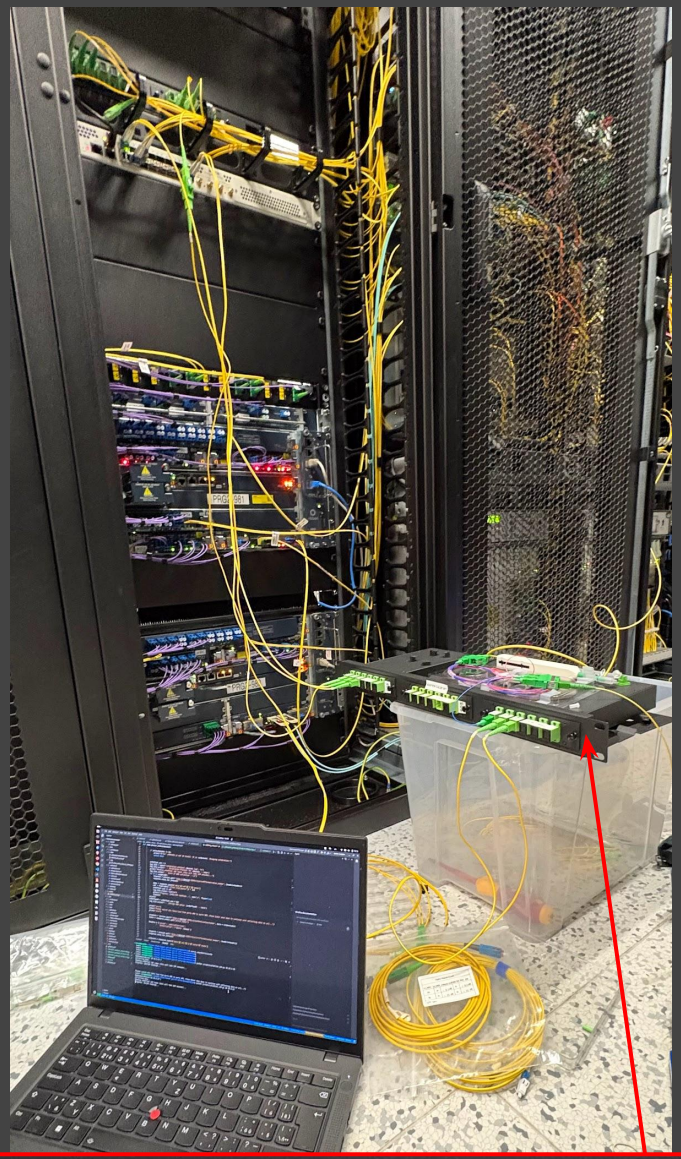


1. Read the offset from ref. on WR0 —> SA
2. Reconnect the link to WR1 and let it stabilize
3. Read the offset from ref. on WR1—> SB
4. Read the cRRT value on the slave device

Measured λs on survey ports WR0 and WR1

$\lambda_{TxWR0} = \lambda_{RxWR1}$; $\lambda_{RxWR0} = \lambda_{TxWR1}$

Reference time signal WR15



1. Read the offset from ref. on WR0 —> SA
2. Reconnect the link to WR1 and let it stabilize
3. Read the offset from ref. on WR1—> SB
4. Read the cRRT value on the slave device

$$\alpha = \frac{2(SA-SB)}{(cRTT+SA-SB)}$$

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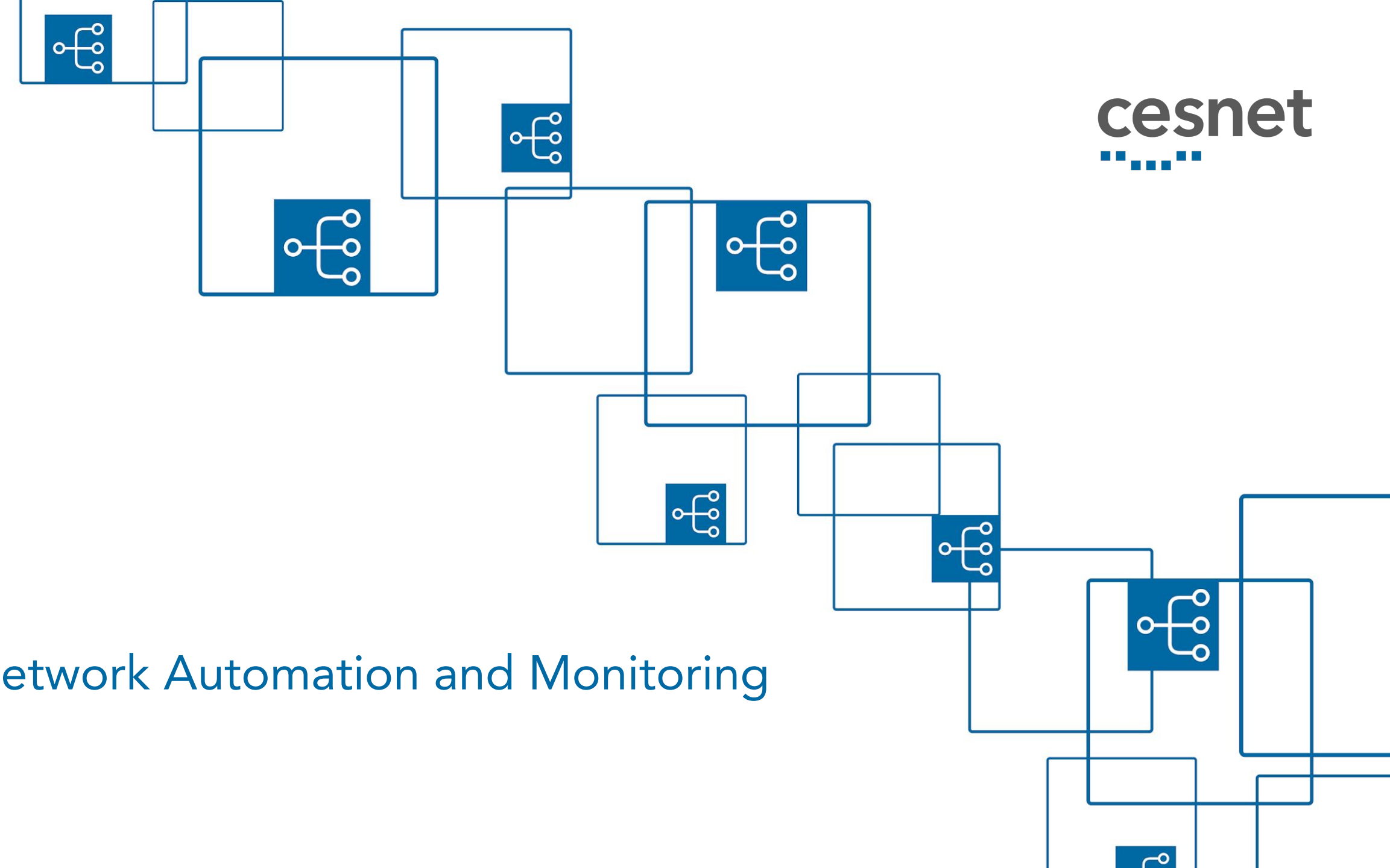
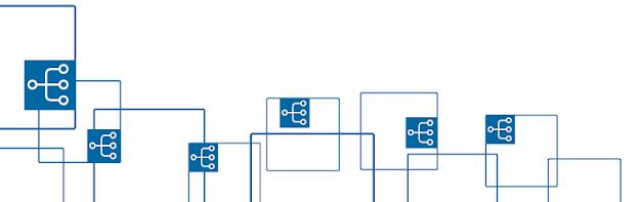


Network Automation and Monitoring

CzechLight SDN BiDi EDFAs

- HW designed by CESNET, manufactured by PEI-GENESIS
- Variable HW configuration
  - C-band and L-band modules in one chassis
  - Optional OSC channel support
  - Optional precise OCM
- Open Source OS maintained by CESNET
  - NETCONF, RESTCONF, local CLI
  - YANG data model
  - Streaming optical telemetry (IETF YANG-Push)

```
module: czechlight-bidi-amp
  +--rw c-band {dualband-c-plus-1572}?
  |  +--rw pump
  |  |  +--rw (control)?
  |  |  |  +--:(disabled)
  |  |  |  |  +--rw disabled?   empty
  |  |  |  +--:(agc)
  |  |  |  |  +--rw agc    gain-dB
  |  |  |  +--:(manual-current)
  |  |  |     +--rw manual-current    laser-current-mA
  |  |  +--ro measured-current?   laser-current-mA
  |  +--ro east-to-west
  |  |  +--ro input-power          odt:optical-power-dBm
  |  |  +--ro output-power         odt:optical-power-dBm
  |  |  +--ro output-spectrum (c-band-ocm}?
  |  |     +--ro lowest-frequency frequency-ghz
  |  |     +--ro step             frequency-ghz
  |  |     +--ro p?               anyxml
  |  +--ro west-to-east
  |  |  +--ro input-power          odt:optical-power-dBm
  |  |  +--ro output-power         odt:optical-power-dBm
  |  |  +--ro output-spectrum (c-band-ocm}?
  |  |     +--ro lowest-frequency frequency-ghz
  |  |     +--ro step             frequency-ghz
  |  |     +--ro p?               anyxml
  |  +--rw ocm-period?
cla-common:spectral-scan-frequency (c-band-ocm}?
  |
[...]
```



BuildRoot
Making Embedded Linux Easy

RAUC

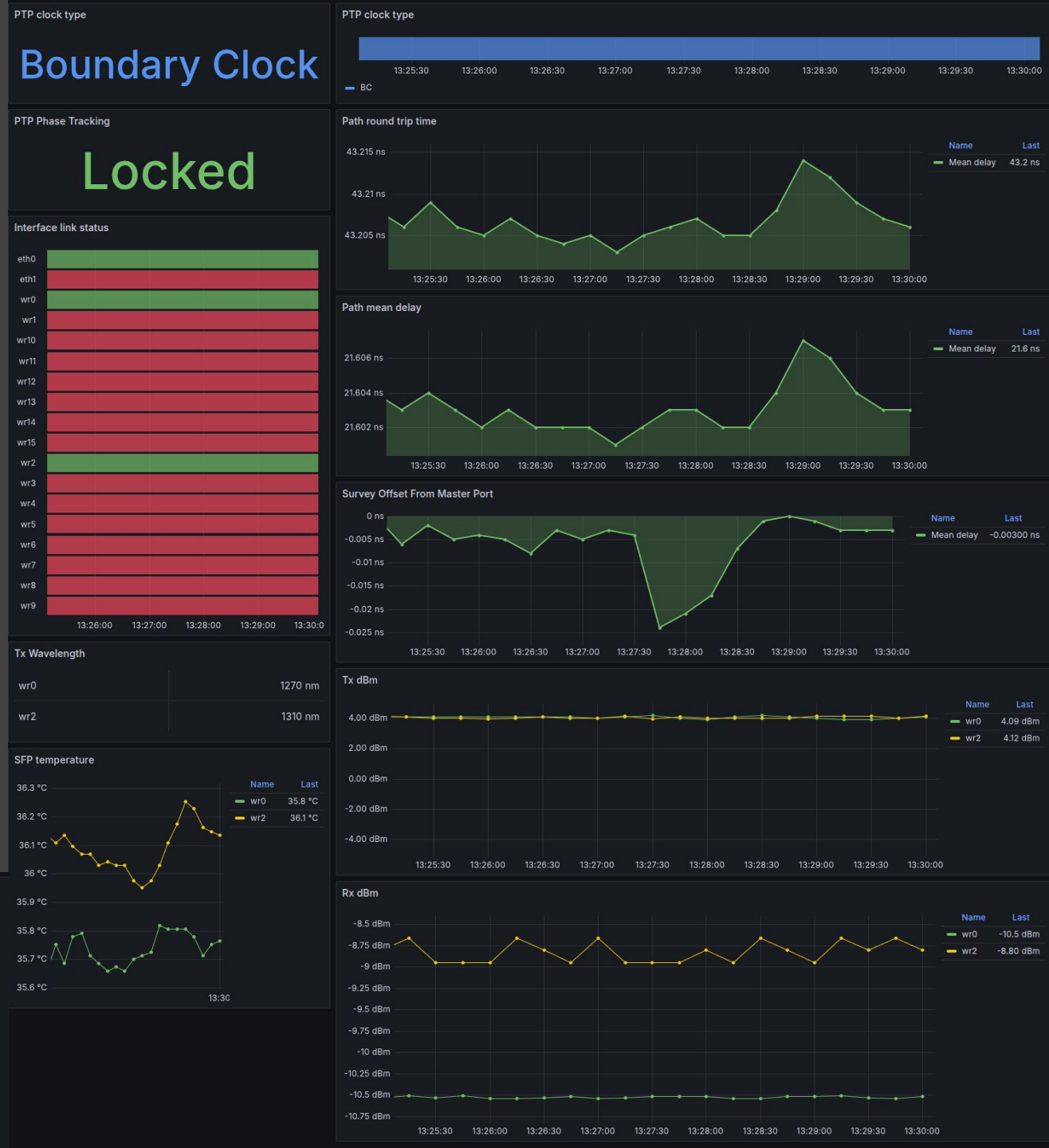
A B

Bootloader

Telemetry and Monitoring

- Streaming Telemetry
  - All the metrics from BiDi EDFAs
  - Sub-second latencies
- I/O Formats
  - IETF YANG-push
- Combined with active polling of WR switches
  - Custom Python agent

VICTORIA METRICS



Automation - DevOps on L0

Ansible project structure for BiDi amplifiers

```
/
├── bidi-configure.yaml
├── inventory/
│   └── netbox-inventory.yml
├── host_vars/
│   ├── CzechLight-BiDi-A.yml
│   └── CzechLight-BiDi-B.yml
├── roles/
│   └── cl-bidi/
│       ├── tasks/
│       │   └── main.yml
│       ├── templates/
│       │   └── edfa_pump.j2
│       └── defaults/
│           └── main.yml
└── vault-password.txt
```

```
channels:
  narrow-1572:
    edfa_mode: "acc"
    edfa_setting: "84"
  c-band:
    edfa_mode: "off"
    edfa_setting: "0"
persistent: true
```

Configuration play

```
---
- name: "Configure CL BiDi"
  hosts:
  - "CzechLight-BiDi-A"
  - "CzechLight-BiDi-B"
  gather_facts: no
  tasks:
    - name: "Configure CL BiDi using restconf"
      include_role:
        name: "cl-bidi"

      vars:
        channel: "{{ item.key }}"
        edfa_mode: "{{ item.value.edfa_mode }}"
        edfa_setting: "{{ item.value.edfa_setting }}"
      loop: "{{ channels | dict2items }}"
```

Netbox names

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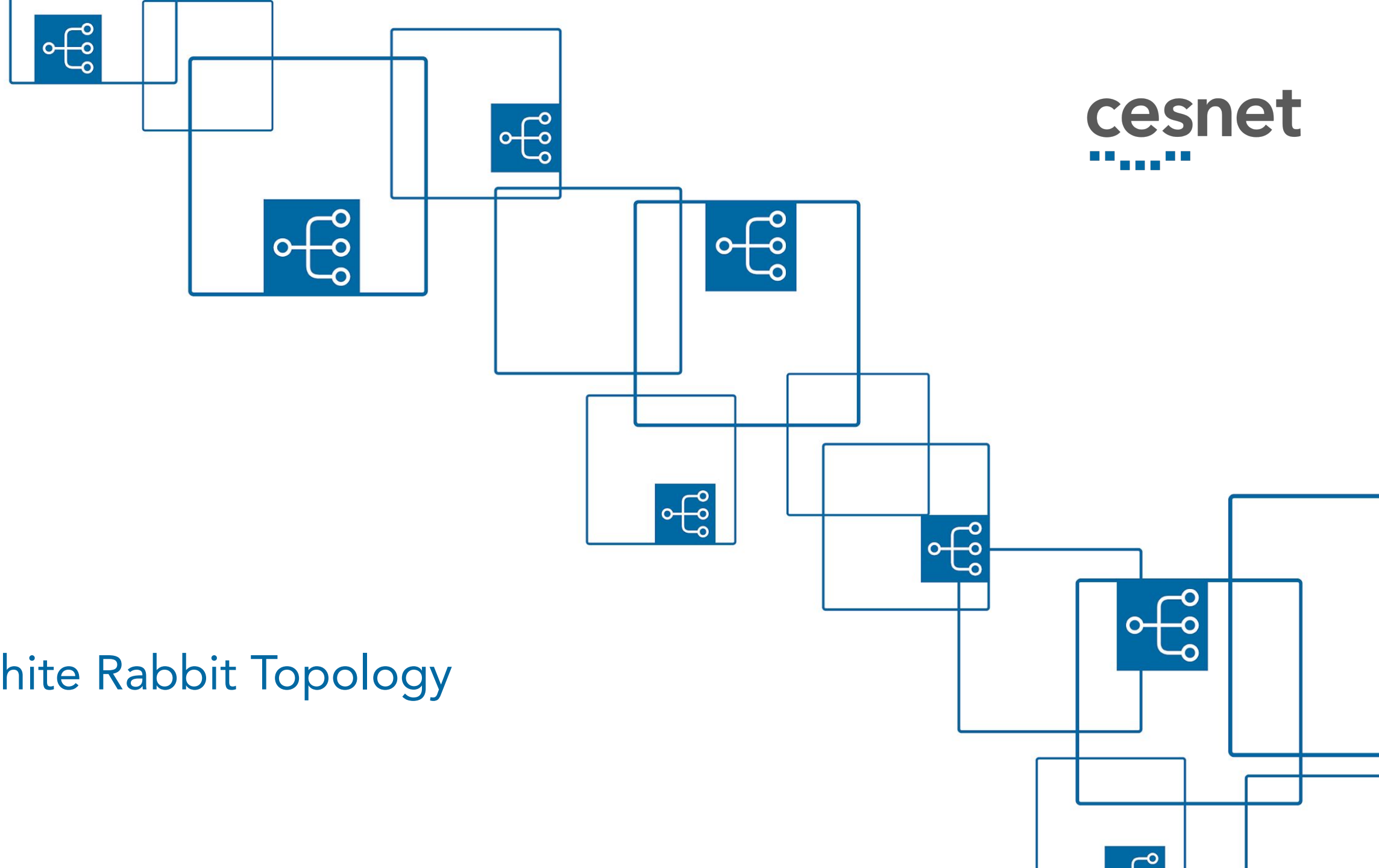
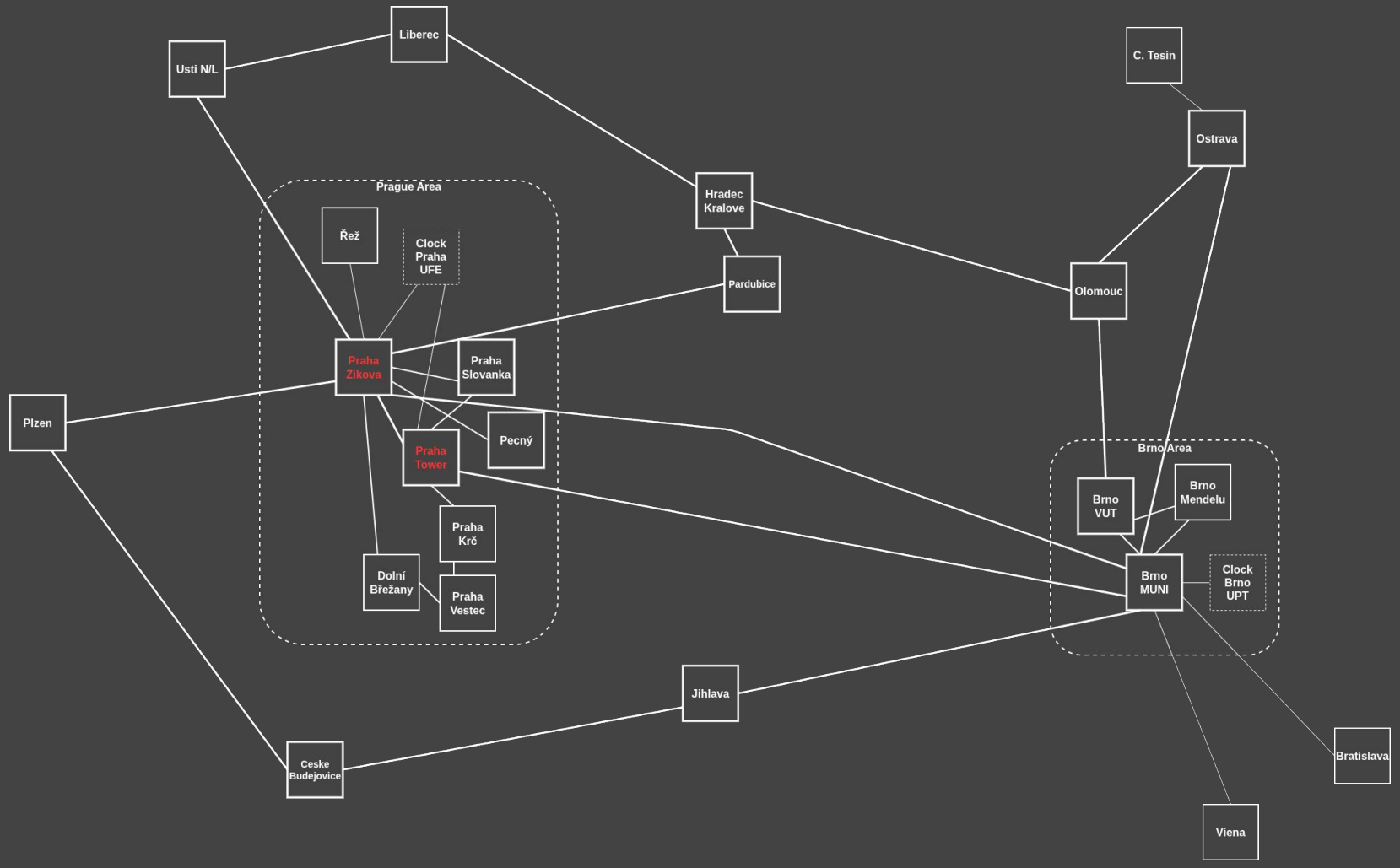


White Rabbit Topology

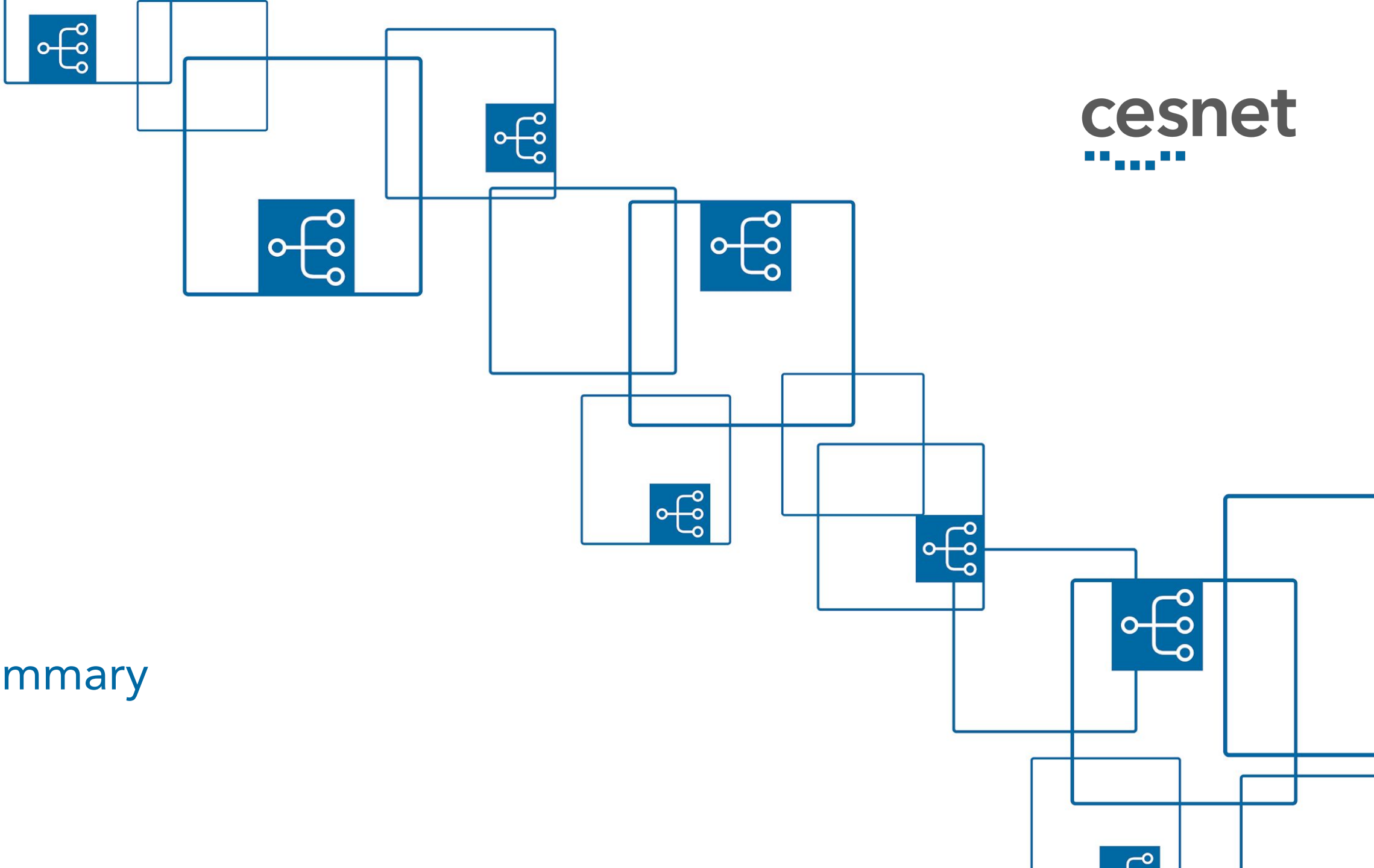
Primary Grand Master Time Source

Hydrogen Maser in the chamber with controlled and stable environment

Time Distribution Topology



- Primary and Secondary Grand Masters in Prague
- Multiple rings –> Monitoring and Redundancy



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Summary

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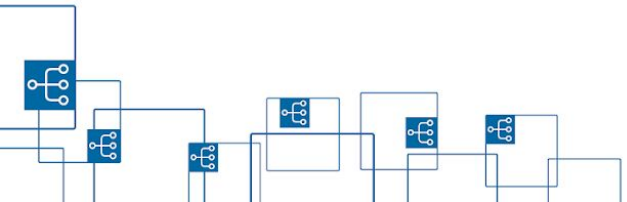
Lessons Learned

- Monitor ports on In-Line filters - Nice to Have
- Slightly different Tx power of individual transceivers
  - When some transceiver must be replaced, the power budget on the link must be recalculated
  - If needed, change fixed attenuators —> Keep them close (in reachable locations)
- Reconfiguration of the time distribution logical topology sometimes require reboot of the WRS
  - TODO: more investigation, looking for workaround



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TL;DR

- Resource sharing works!
  - Triumph of interoperability on optical layer
- Different technologies and services can coexist over the same fiber
  - With proper design
- Open design and Open Source is an advantage
- Standard APIs are “MUST HAVE”!

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Thank you…

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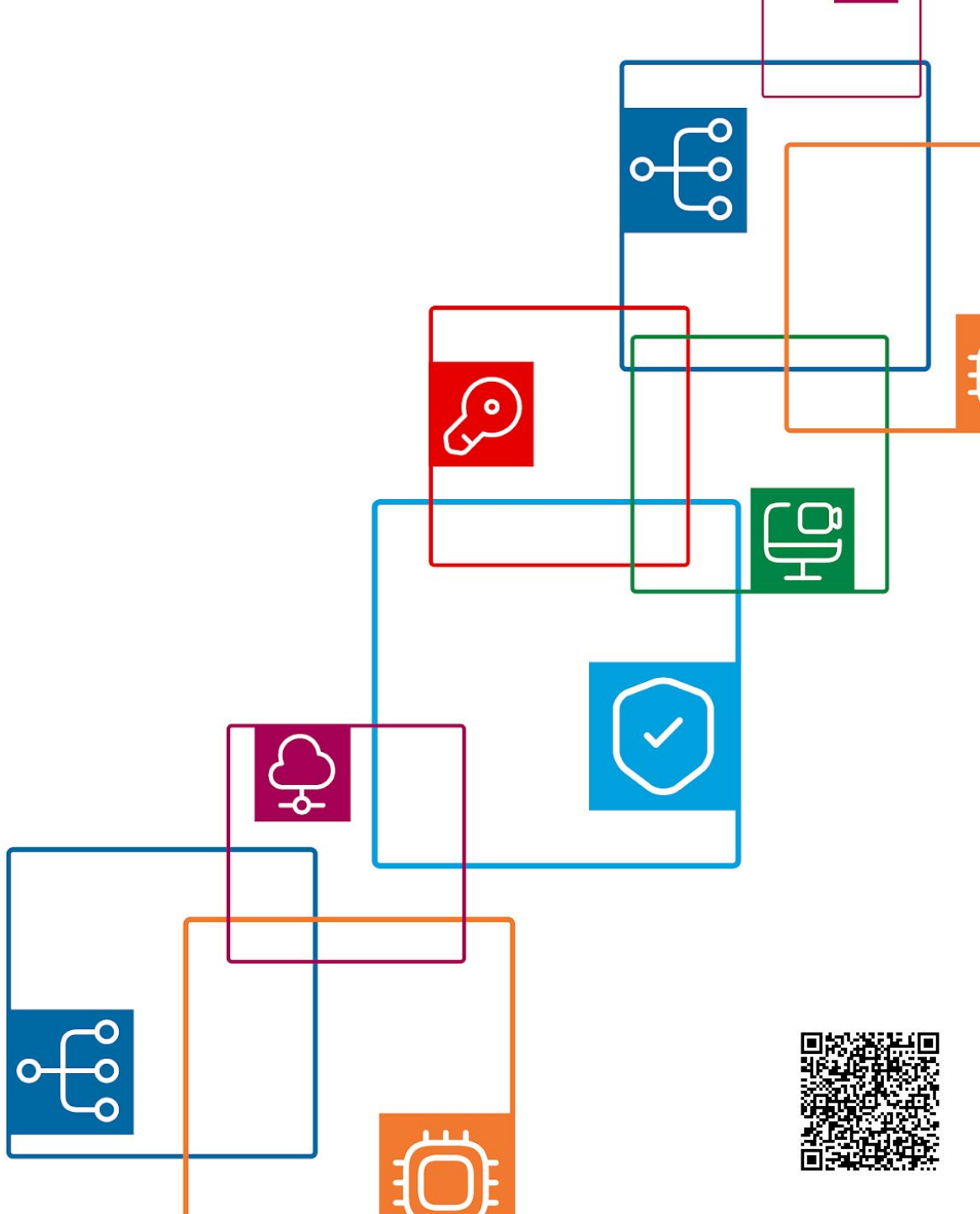

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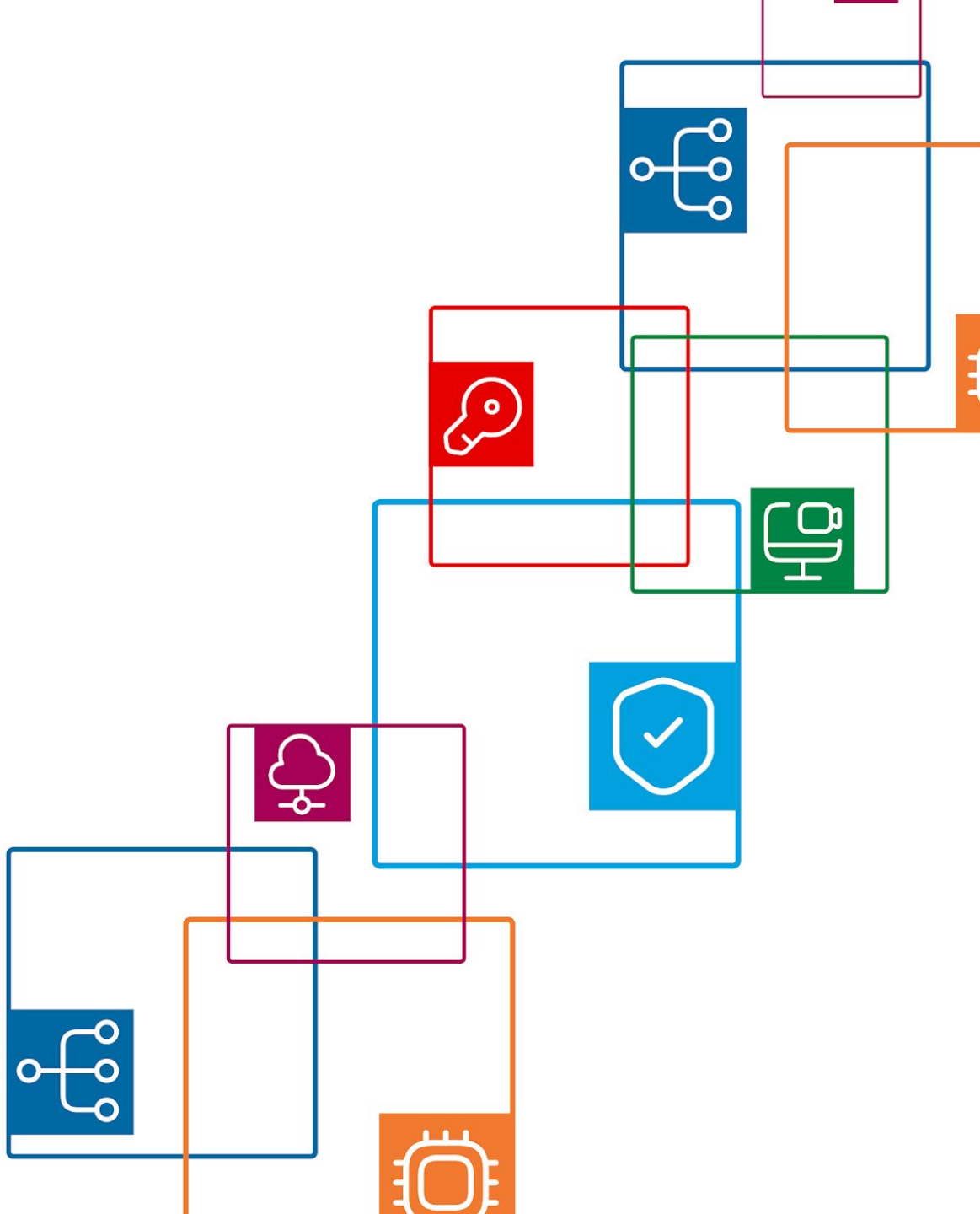
Offline reading



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Geant WP6 - WR Incubator

Geant WR incubator and field trial with CESNET:

- https://events.geant.org/event/2110/contributions/2556/attachments/1428/2141/WR_Incubator_Infoshare_13_5_2026_LAB_Field_Tests_Sima.pdf
- https://doi.org/10.5281/zenodo.20141829 – GN5-2 WP6 White Papper