Optical Time & Frequency Activities in the GÉANT Project (Past & Future)

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Agenda

GÉANT intro

Optical Time & Frequency Activities – GN4-3 – Past Project

- Outputs
- Selected Topics
  - Share or not to Share
  - Bandwidth Reservation
  - Amplifier Lasing Issue
  - Cross-Modulations
  - TF on Raman Amplified Lines
- Monitoring

Agenda

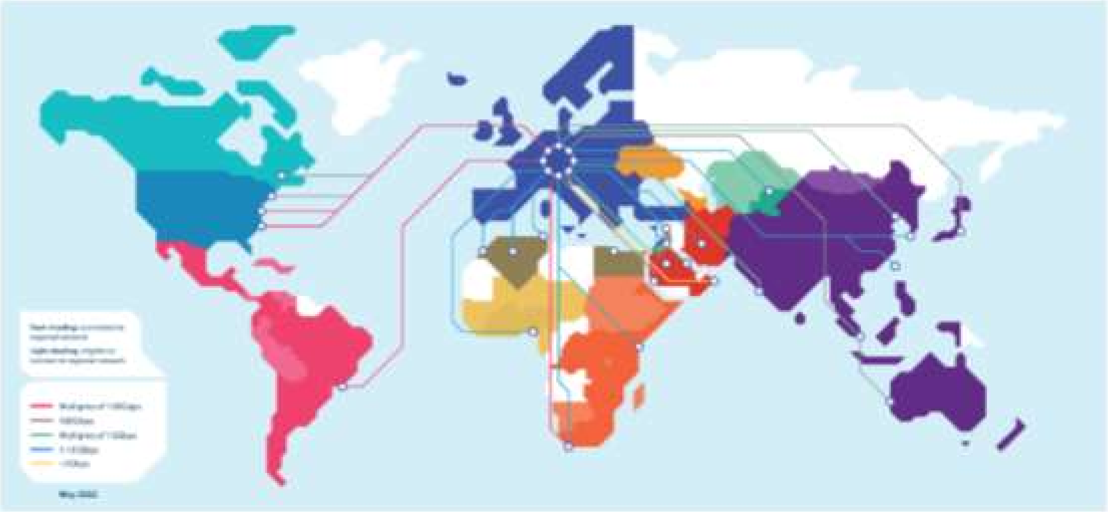
Optical Time & Frequency Activities – GN5 – Present Project

- Multi-domain monitoring
- TF knowledge exchange platform
- TF training
- TF and Quantum
- Cross border challenges

- **Conclusions**

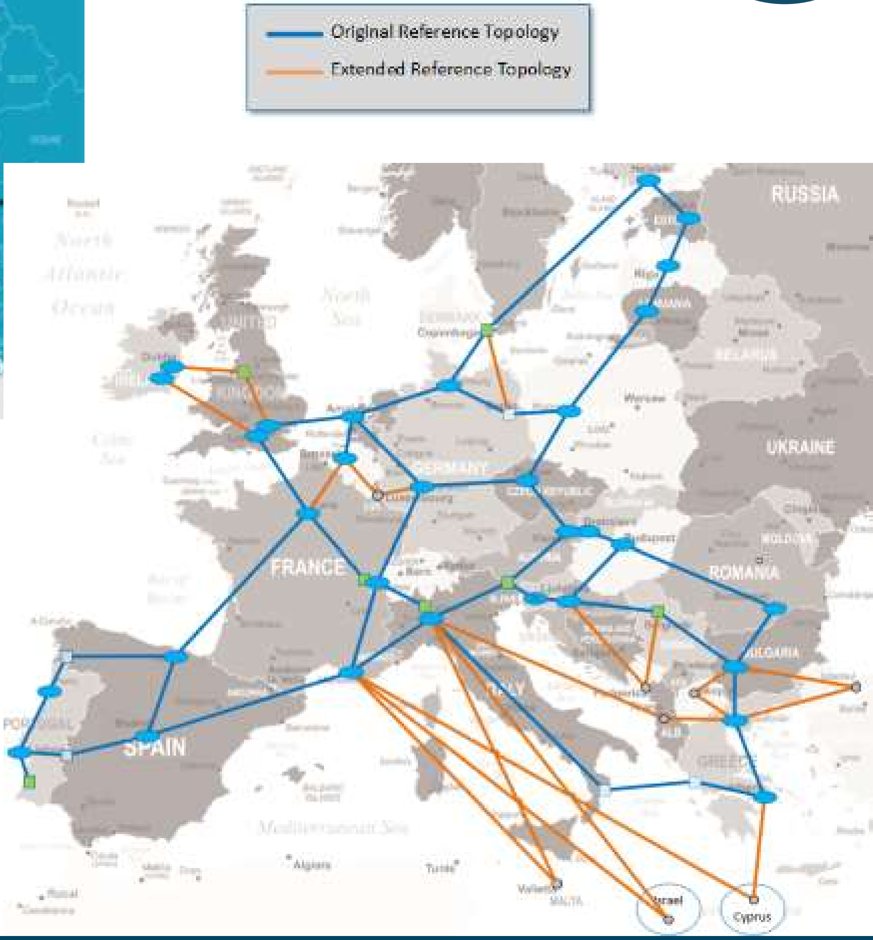
GÉANT

- GÉANT Association supports and represents over 40 NRENs across Europe.
- Together they support over 10,000 institutions and 50 million academic users.
- Strong global connectivity, 35% annual growth



GÉANT - GN4-3N

- DOI10.3030/856728
- 1 Jan 2019 31 Dec 2023
- GN4-3N project aims to increase the footprint of the backbone network and improve its capacity, resilience and flexibility. The ultimate goal is to offer 100 Gbps network access to a greater number of GÉANT partners and significantly diminish the digital divide.
- From 14 to 32 countries connected by Fibre/Spectrum
- From 8,000 to 19,000 Km Fibre
- 12,000 Km Spectrum, 7,000 Km from NRENs
- Based on 15+ years IRU
- Maximum achievable capacity per link between 6 and 24+ Tbps



GÉANT - GN4-3

- GN4-3
- DOI10.3030/856726
- Start date 1 January 2019
- End date 31 December 2022
- GÉANT is Europe’s leading collaboration on network and related infrastructure and services for the benefit of research and education, contributing to Europe's economic growth and competitiveness. The organisation develops, delivers and promotes advanced network and associated e-infrastructure services, and supports innovation and knowledge-sharing amongst its members, partners and the wider research and education networking community. It aims to help take European research to the next level, promoting scientific excellence, access and re-use of research data.

GÉANT - GN4-3

- WP6 Services Roadmap
- Task 1: Network Technology Evolution
- Optical Time and Frequency Network
- CESNET, GEANT, RENATER, PSNC, SWITCH

- GÉANT Infoshare: European Time and Frequency Services - Principles, Challenges and Use Cases
- https://events.geant.org/event/451/

- GÉANT Infoshare: Management and monitoring of time & frequency services
- https://events.geant.org/event/1207/

GÉANT - GN4-3 – WP6 T1 - OTFN

- WP6 Services Roadmap
- Task 1: Network Technology Evolution
- Optical Time and Frequency Network

- Whitepapers:
- Distributing New Performant Time and Frequency Services over NREN Networks
- https://www.geant.org/Resources/Documents/GN4-3_White-Paper_Time_and_Frequency.pdf
- Ultrastable Frequency Transfer in L-Band
- https://resources.geant.org/wp-content/uploads/2022/02/GN4-3_White-Paper_Ultrastable-Frequency-Transfer-in-L-Band.pdf
- Management and monitoring of time and frequency services
- Preliminary assessment of OC signal transfer quality on the Poznań-CERN line in an unmodified DWDM (unidirectional) network.

Share or not share

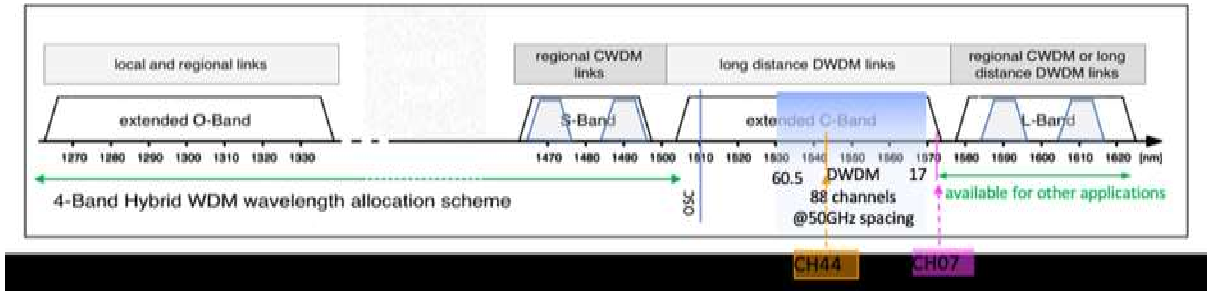
- Alien Waves or actually Spectrum Connection Service work well for data
- Unique applications Time and Frequency can't use them only at cost of performance degradation
  - Need reciprocal path there and back to compensate disturbances
- Fibers rental p.a. cost (based on average price*) 1 MEUR p.a. for 2000 km of fiber and 15y contract (CESNET)
- SWITCH 240 km @ 100k CHF p.a.
  - Housing is about 15% of total
- Share infrastructure for T+F with data is attractive, add only up to 15% extra cost

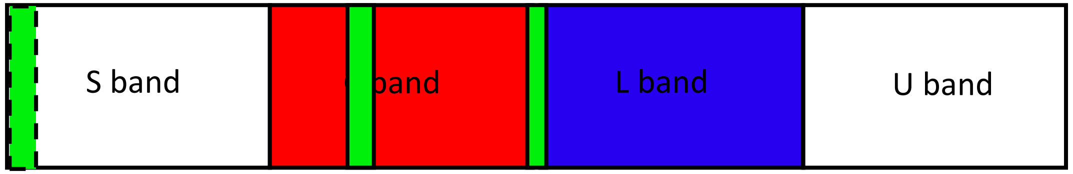
Approach	Advantage	Disadvantage
Dark channel	• Mutualise fibre and housing facilities. • Implementation of the T&F service can start immediately as no extra fibre is required.	• Adds complexity in the network due to the bidirectional signals propagating in a telco architecture. • Setting up the spectra-sharing architecture may be traffic impacting - reduced capacity for data traffic. • Optimising T&F service takes more time in order not to interfere with data traffic. • Each OADM adds up to 0.8dB of extra attenuation which degrades OSNR. • Is not ideal when attenuations/span > 25dB.
Dark fibre	• Data traffic and T&F services are using dedicated fibres and cannot interact (safest option).	• Additional high costs for fibre rent. • More fibres and the two dedicated networks need to be monitored and managed simultaneously (more manpower required).

*Sima S. et al., Deliverable D3.2v3-Economic analysis, dark fibre usage cost model and model of operations, Porta Optica project

Bandwidth Reservation

Band	OADMs single channel	OADMs band	Transmitter module for Frequency transfer	Transmitter module for Time transfer	Amplification	Operating network
S band	Available on request (custom design)	Available/ on request (CWDM/ custom design)	Commercially available (long lead time)	CWDM only	SOA, Brillouin amplifiers commercially available	SURFNET (WR) CESNET (OC)
C band	Commercially available	Available on request (custom design)	Commercially available	Commercially available for all techniques	Bidirectional EDFA commercially available	RENATER ch.44 (OC) CESNET ch.46 (OC) CESNET-BEV ch.43-46 NPL ch.44 (OC) PTB ch.44 (OC) INRIM/GARR ch.44 (OC)
Between C/L Band	Commercially available	Available on request (custom design)	1572 nm Lasers are available and tested in Lab. Koheras: from stock. RIO: high one-time costs and long distribution time for the production of a dedicated wafer. Lower costs and shorter distribution time is possible by sharing the existing wafer of SWITCH.	Commercially available (longer lead time)	Amplification - EDFA: EDFACL optimised for 1570 installed and successfully tested. Prices and specs available from CzechOS/Optokon.	SWITCH ch.07 (OC) CESNET (RF) (First field tests are promising)
L band	Commercially available (long lead time)	Available on request (custom design + long lead time)	Available on request (custom design + longer lead time) with some limits over 1585 nm	Commercially available (longer lead time)	Bidirectional EDFA commercially available	CESNET (RF)

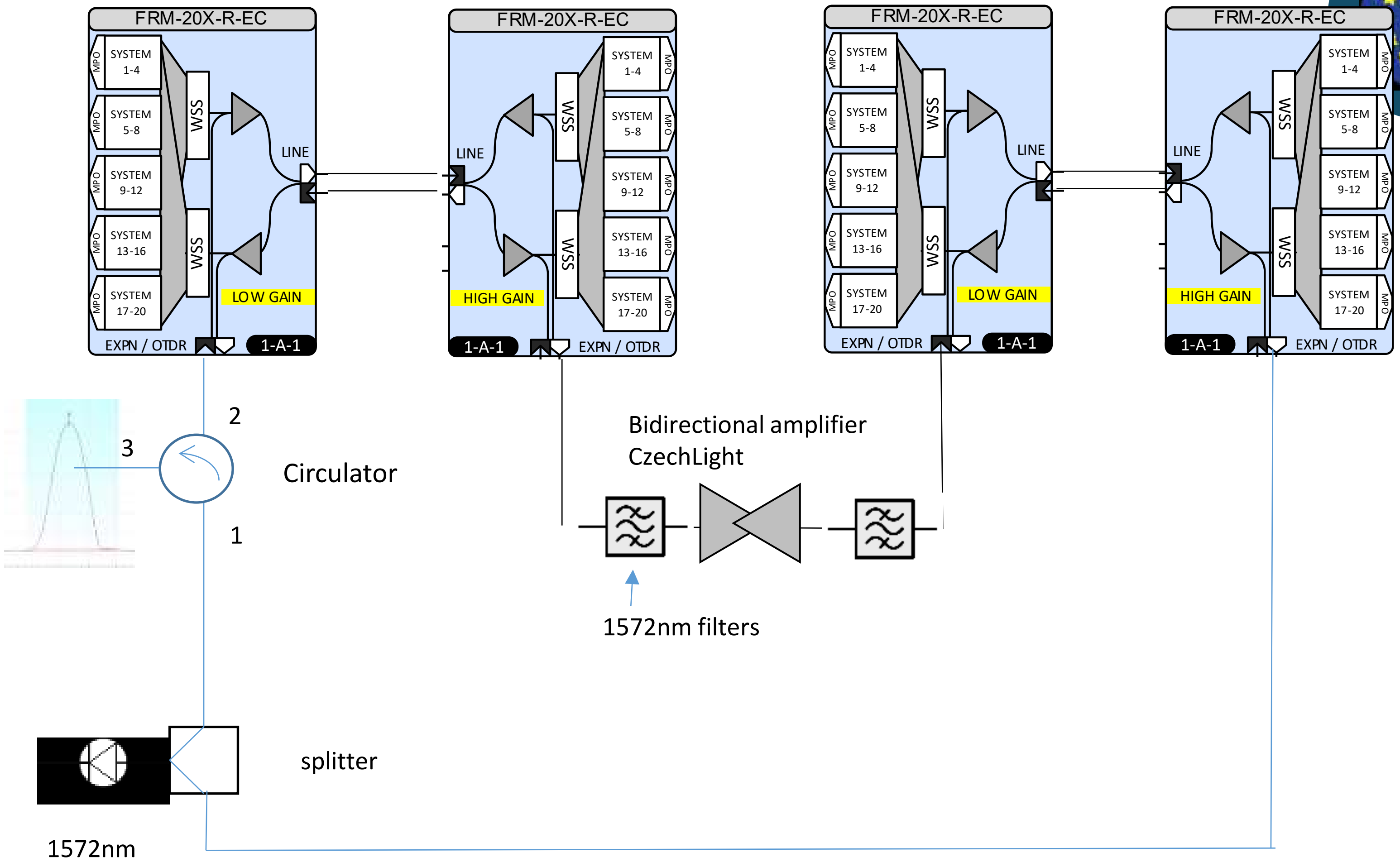




1450-1530 1530-1565 1570-1605 1605-1675

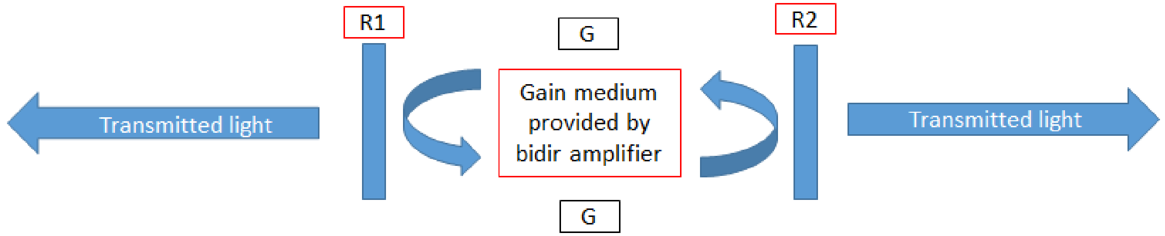
Bandwidth Reservation

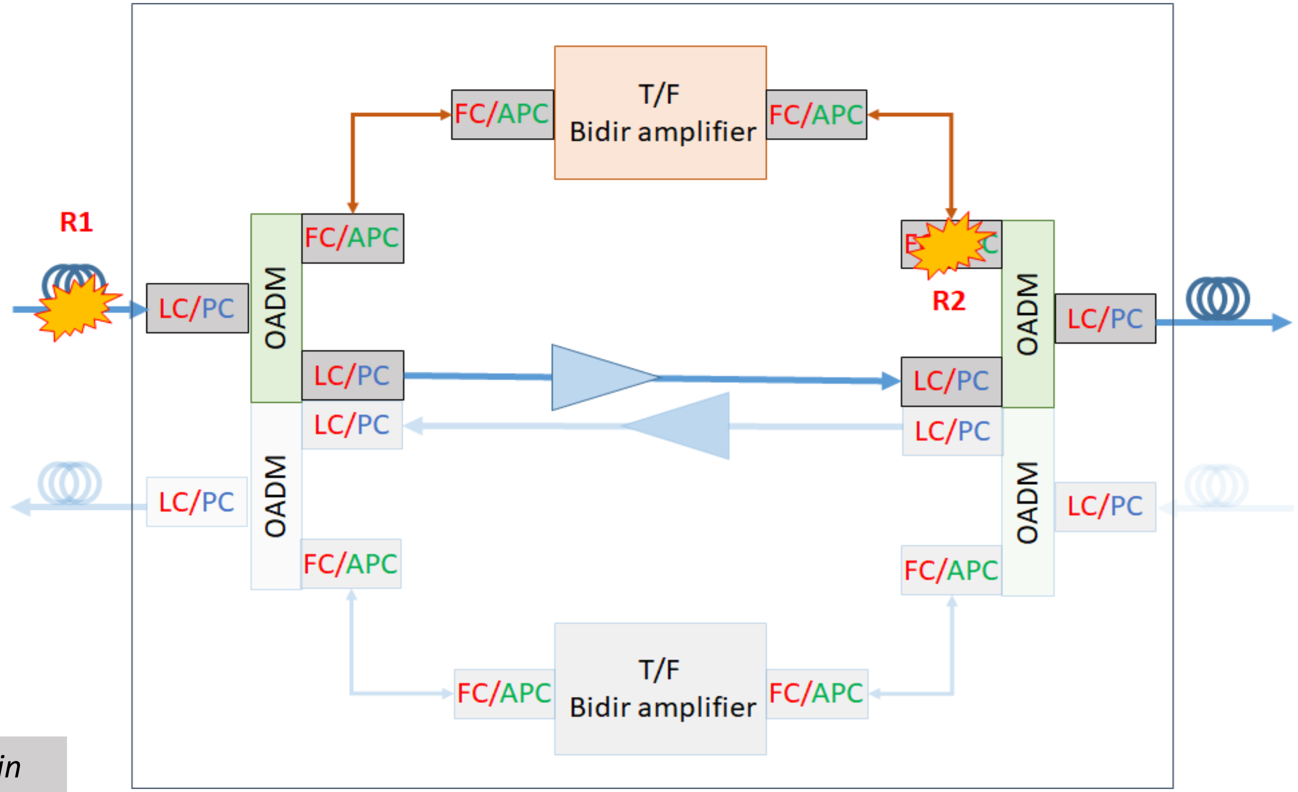
- GEANT uses DWDM system by Infinera
- C-band is unavailable for T/F due to lack of coupling of CH44 and other concerns
- L-band is being added to some core routes to support scientific needs such as time/frequency
- L-band access ports built into the switching and amplifier cards
- Lab testing has shown that time/frequency signals can be injected as a bi-directional signal on the L-band using these ports.



Amplifier Lasing Issue

- Reciprocal/bidirectional path to cancel slow changes $\tau AB = \tau BA$
- Bidirectional amplification
- Hi gain medium + feedback
  We are trying to avoid it!!
- $G^2R_1R_2 < 1$
- R composes from Rayleigh backscattering and reflections from splices, connectors etc.

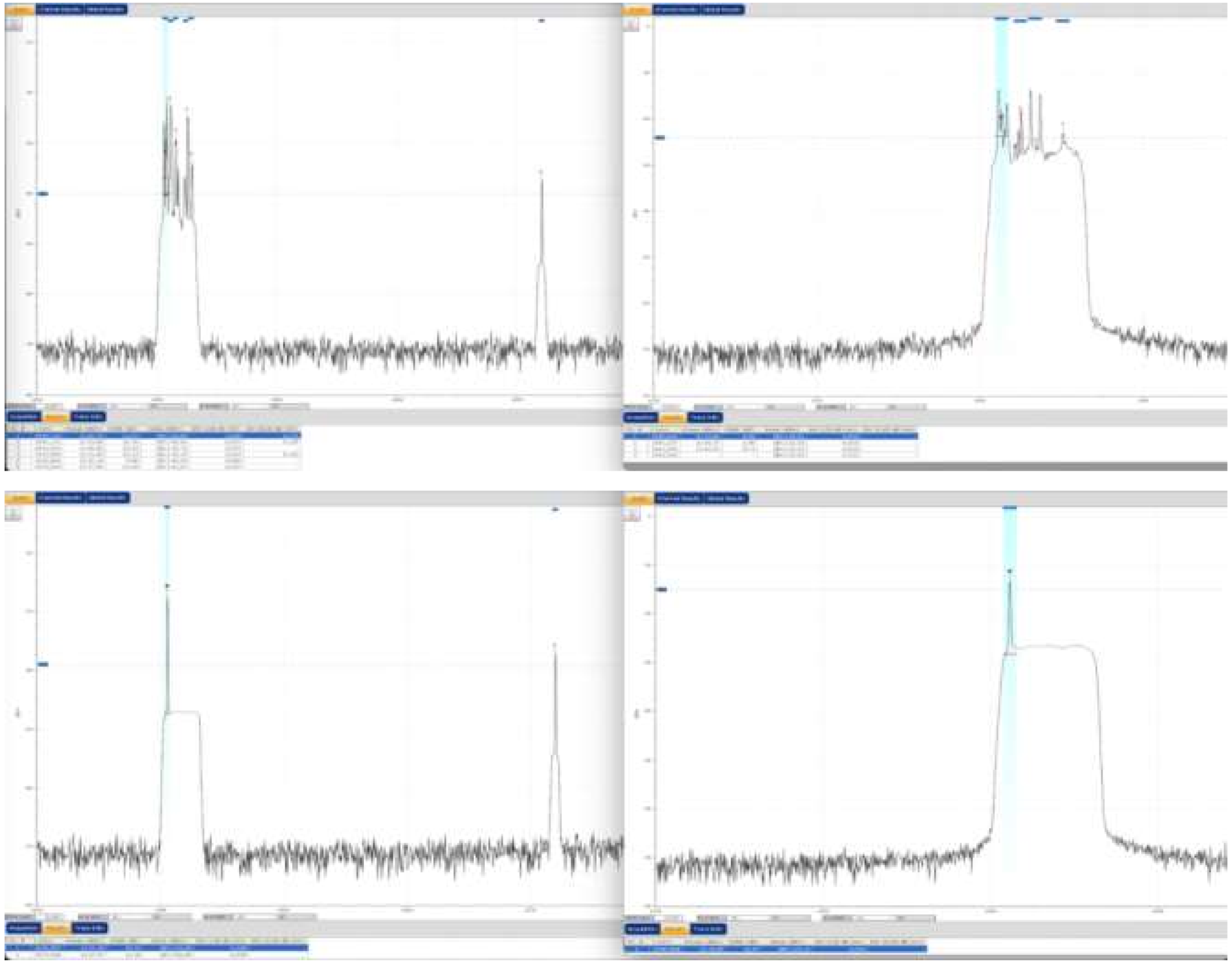




Credit: Nicolas Quintin

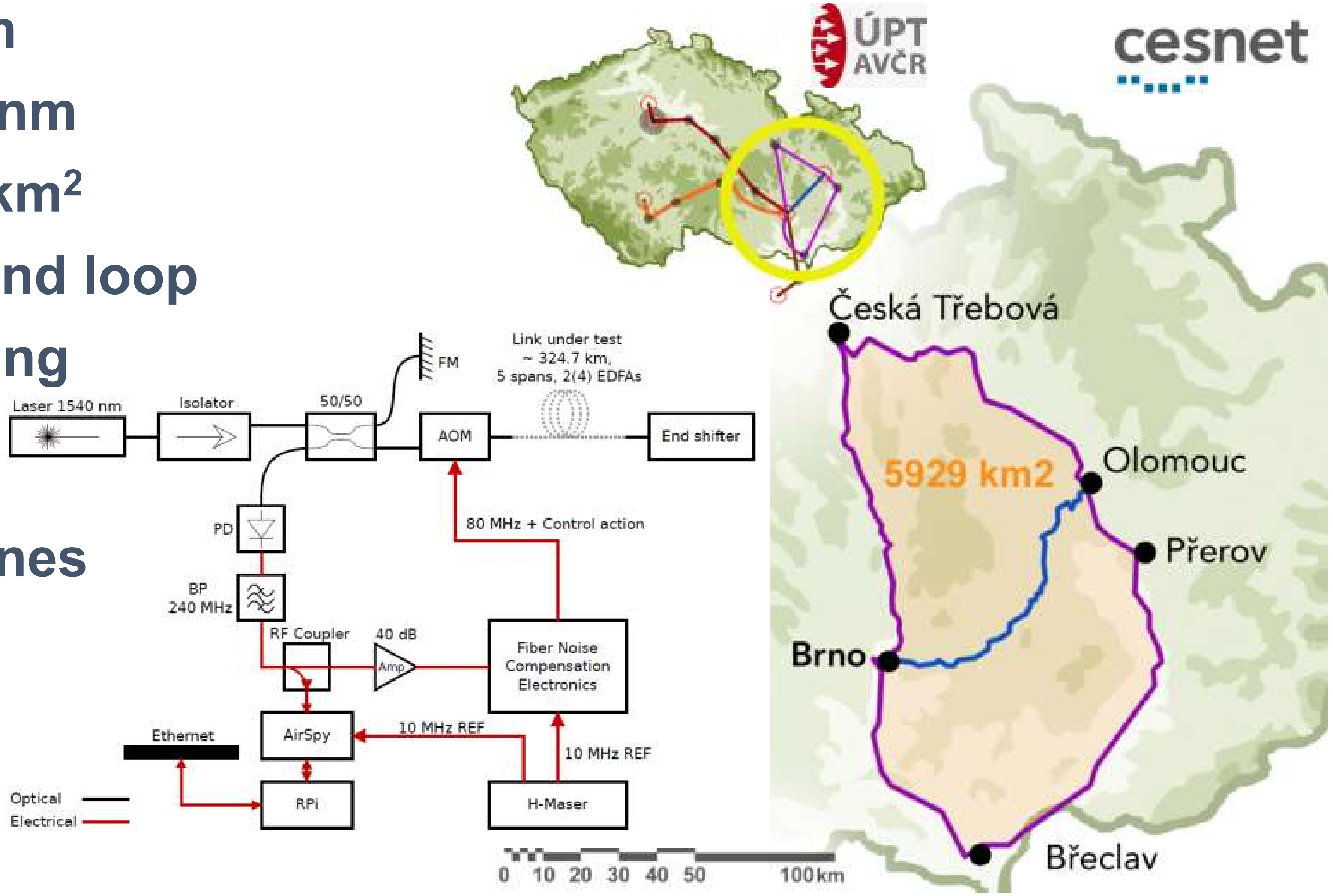
Amplifier Lasing Issue

- Only with limited gain up to 20-21 dB
- But we have in network lossy spans: 24, 27.7, 26 and 28.6 dB?



Amplifier Lasing Issue

- Waves 1540.5 + 1572.06 nm
- Brno - Olomouc also 1458 nm
- Length 352 km, area 5929 km^2
- 6 amplification points around loop
- Automatic bi-EDFA balancing deployed beat acquisition via simple SDR
- To be used on remaining lines



Crosstalks

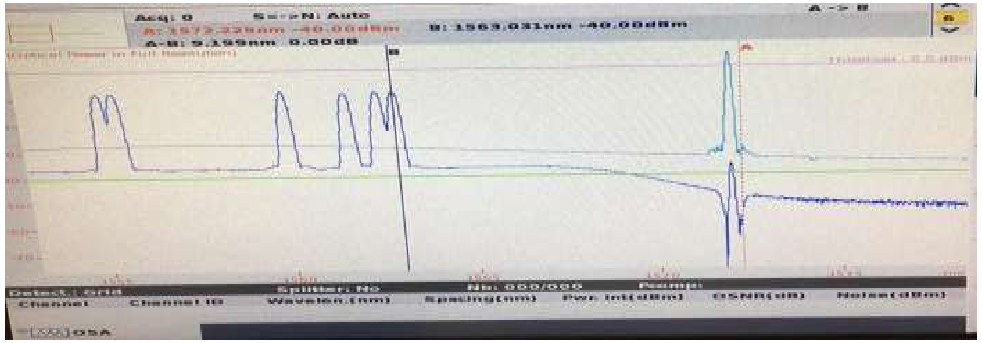
- Goal: Impact of Metrological Signal on DWDM channels
  - Transponders have Performance Data
    - Errored Sec (i.e. Out Of Frame, Background Errored sec)
  - Transponders have FECs
    - Corrected Errors
- Turn CH07 Lasers (& Amps)
  - OFF and ON
  - Any Impact to DWDM Channels?

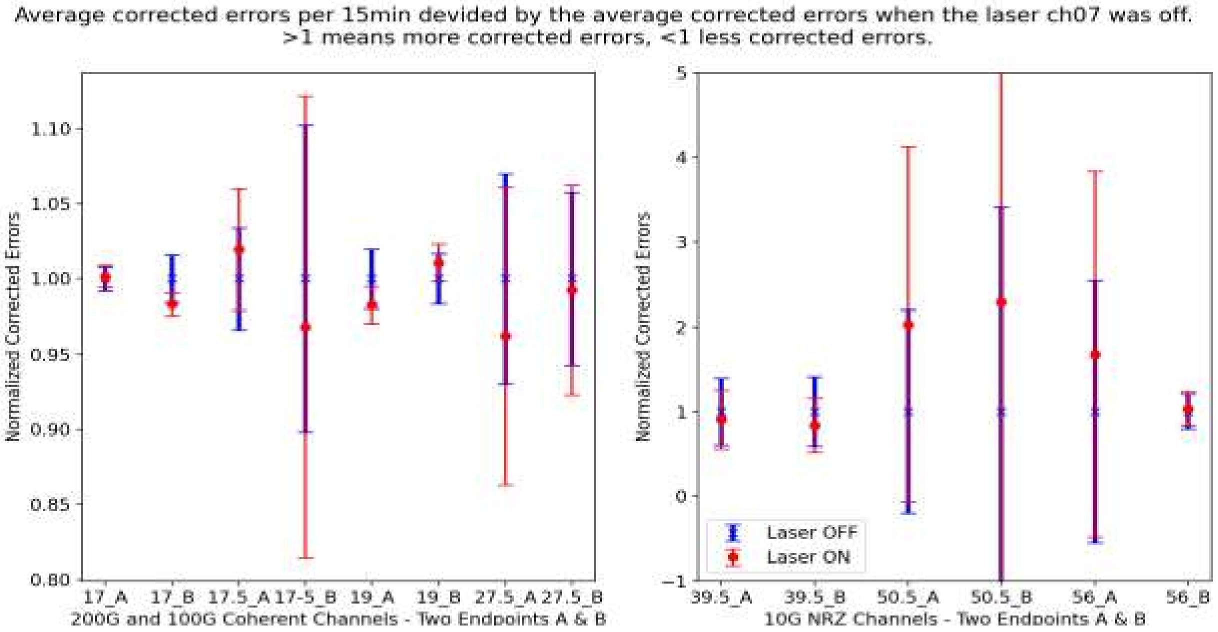
- 8 backbone DWDM channels
  - **no errored seconds** in OUT signal
    - = No Impact for clients
- Let's look at the corrected errors
  - Increased Corrected Errors? ---->
    - No clear correlation

- **No Impact on DWDM Channels**

Credit: Fabian Mauchle

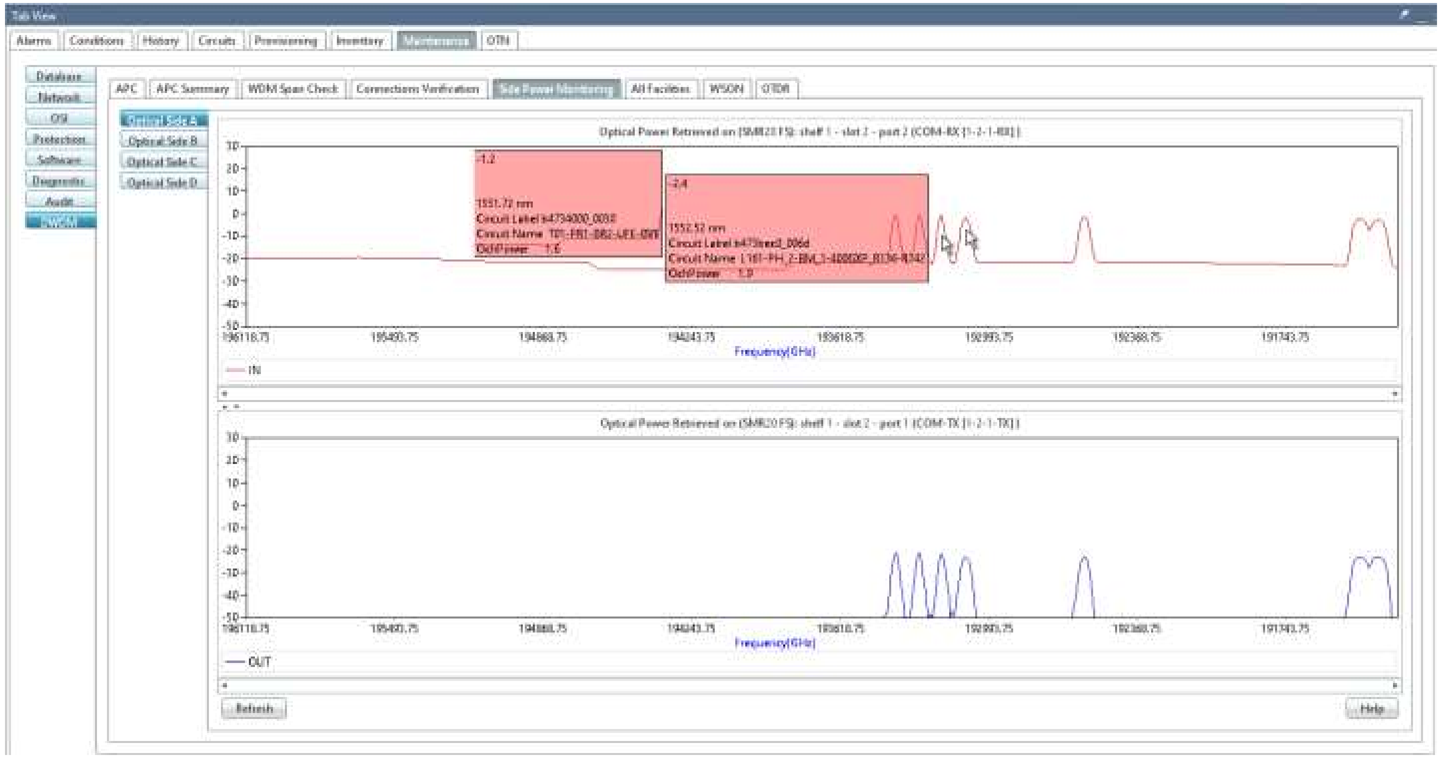
Data measurements:
120h Laser ON
38h Laser OFF





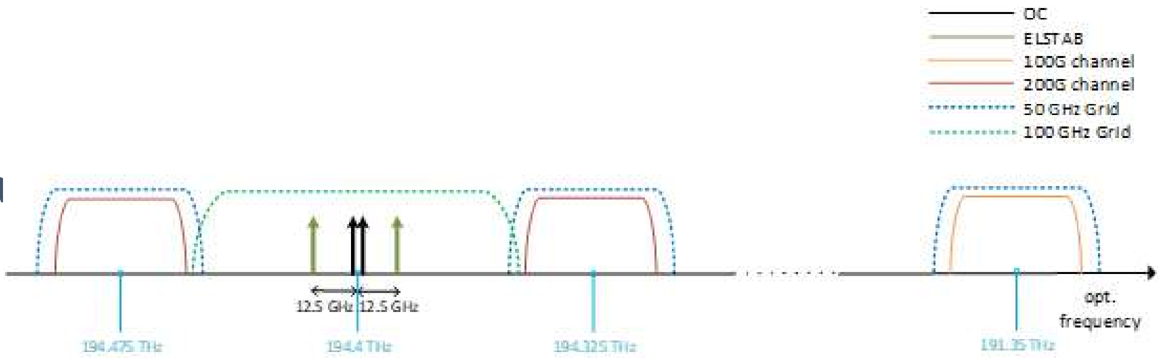
Crosstalks

- Real network, 300km, 3 ILAs, mixture of G.655 and G.652 (last miles only)
- Moving 100Gbps channel 100 GHz apart to WR signals, originally was 350 GHz
- One order drop in pre FEC BER, from 2E-9to 3E-8. All errors corrected



Crosstalks

- Tested:
- ELSTAB+OC in channel 44
- Sections of 65 and 110 km and also included Raman a
- No influence on 100 and 200 Gbps channels

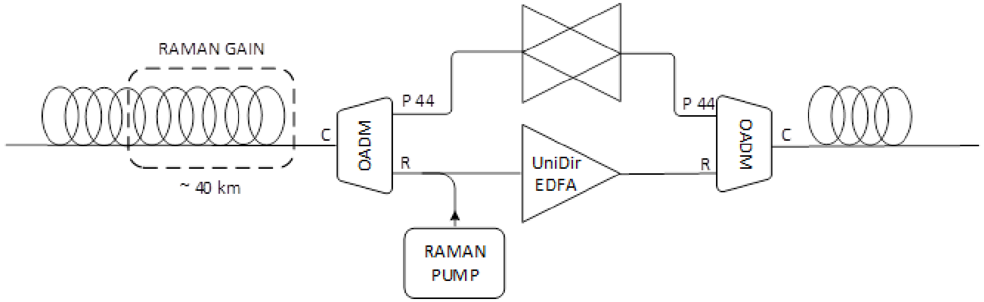


Credit: Krzysztof Turza

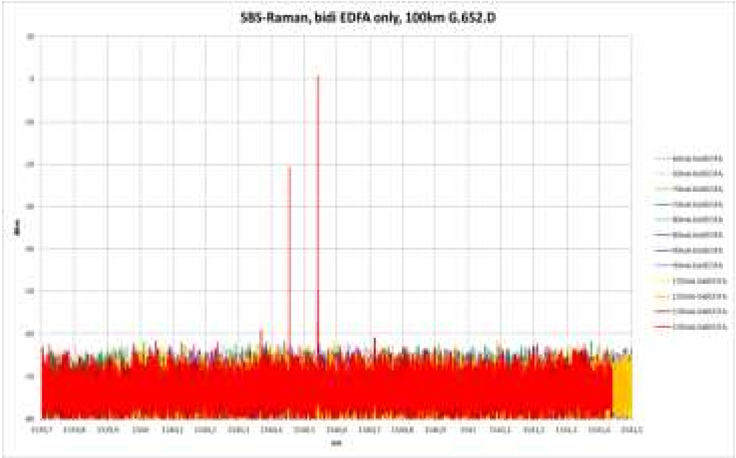
- Previously in a 1500 km loop in the PIONIER network (unidirectional) interferrence observed.

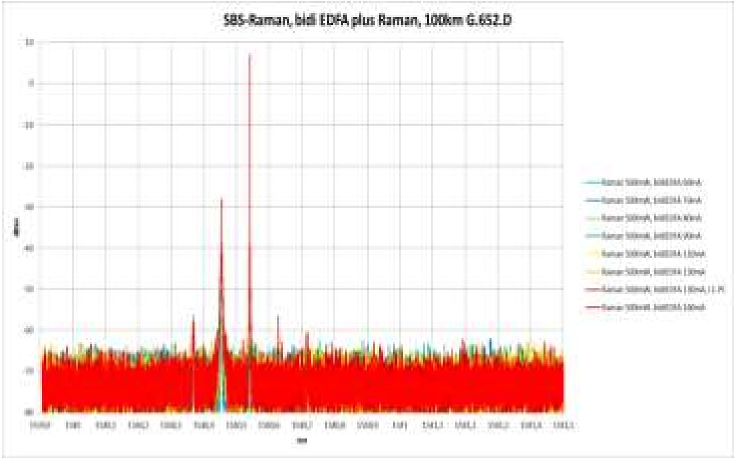
Raman amplified lines

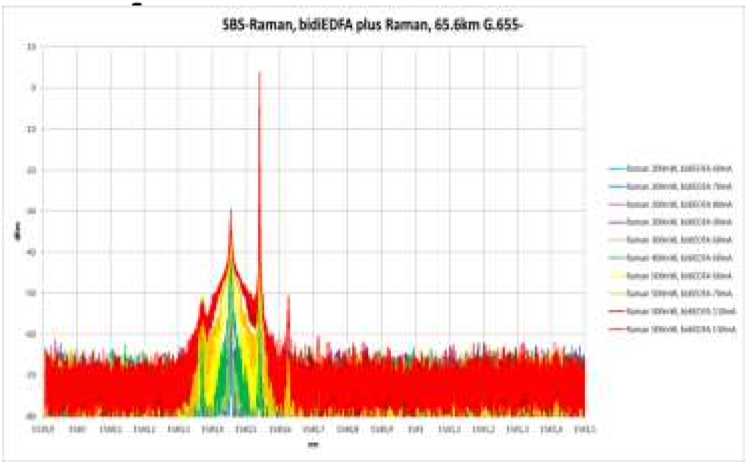
- Optical carrier – extremely narrowband
- Max launch power is limited by Brillouin scattering
- Threshold even decreased by Raman pumping
- On 655 fibers threshold is even lower



Credit: Krzysztof Turza

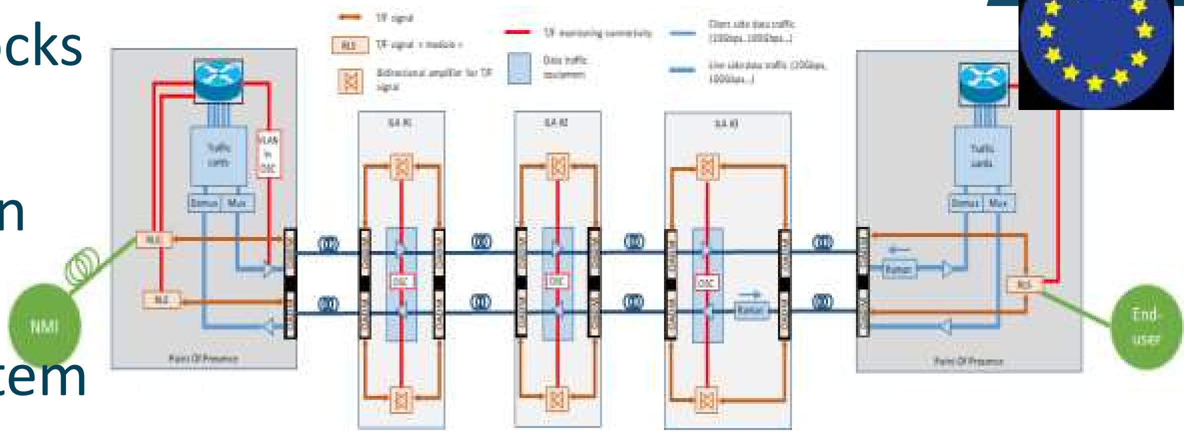




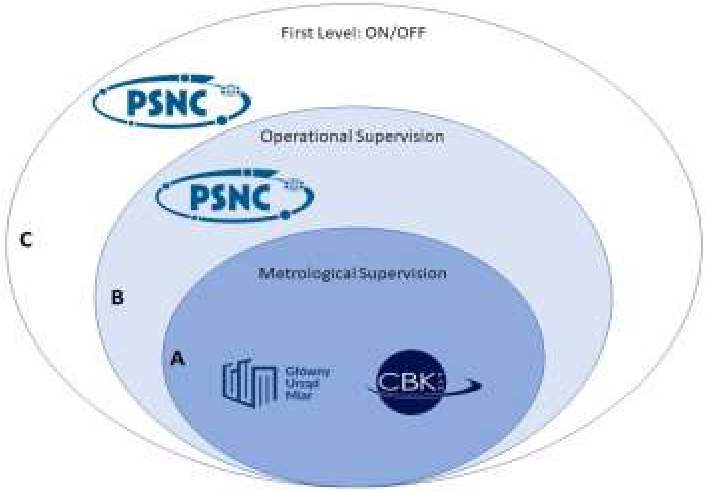


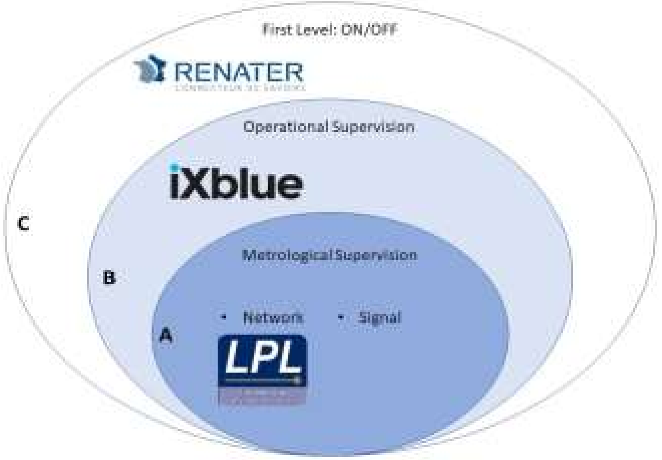
Monitoring

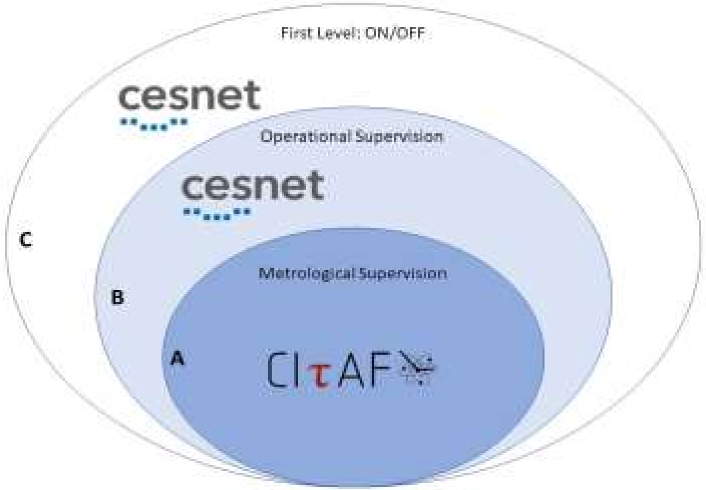
- A - Metrology signal sources (typ ultra-precise clocks located in metrology laboratories)
- B - The metrology signal transfer and regeneration system
- C - The telecommunication data transmission system (DWDM)



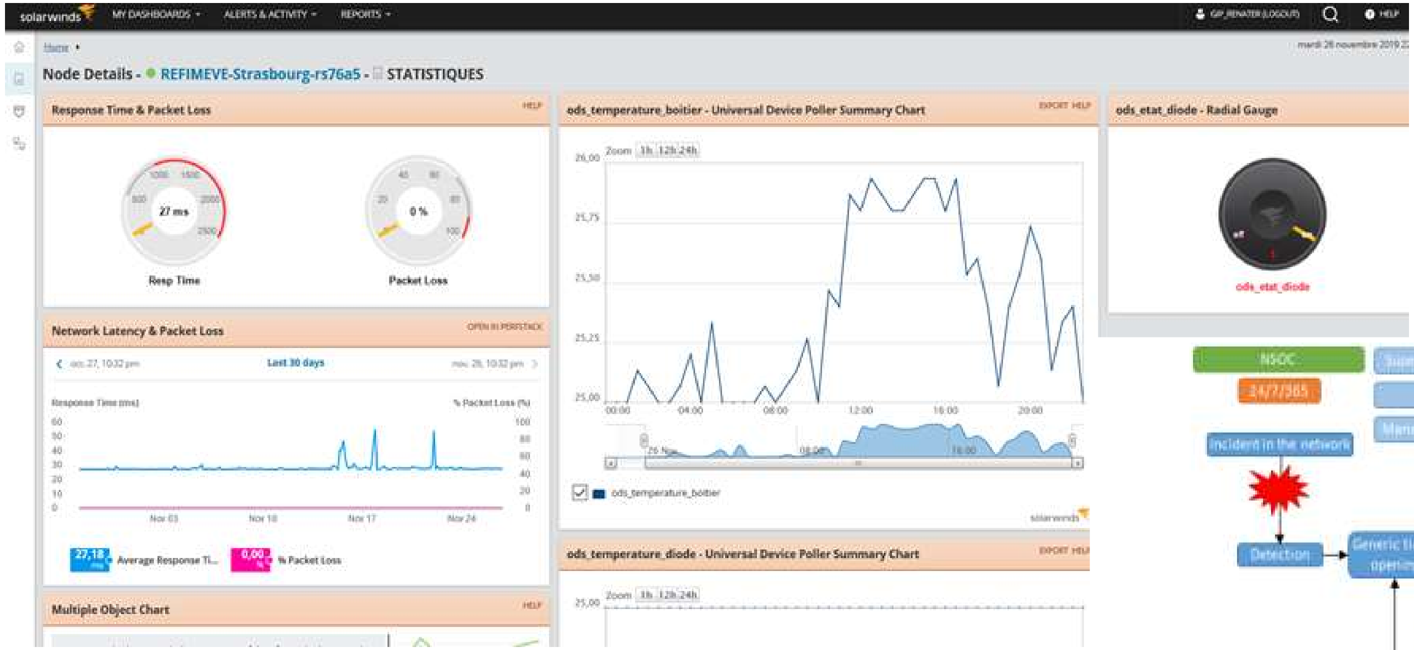
Credit: Nicolas Quintin



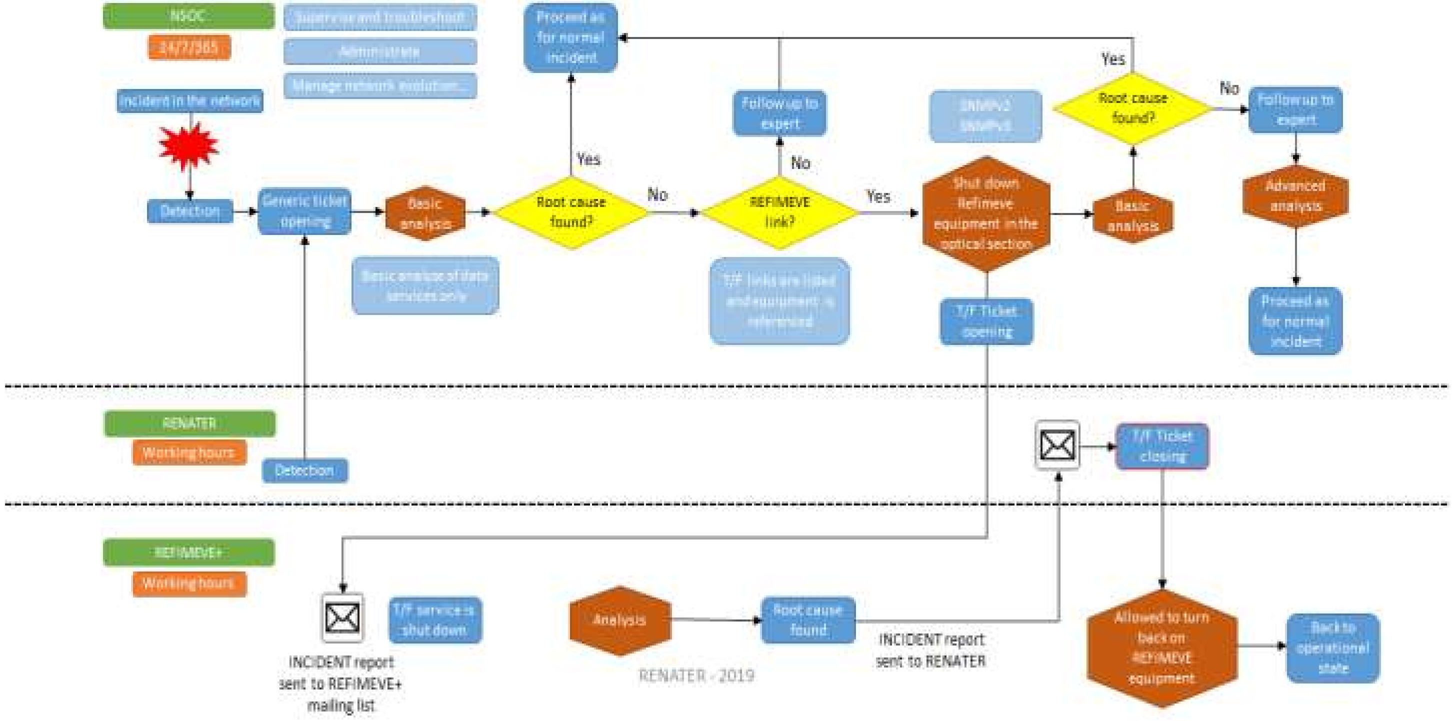




Monitoring - RENATER



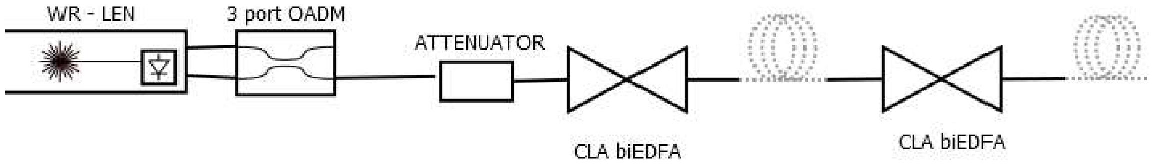
RLS monitoring by the RENATER NOC in Strasbourg (laser diode state at the top right)



Monitoring - CESNET

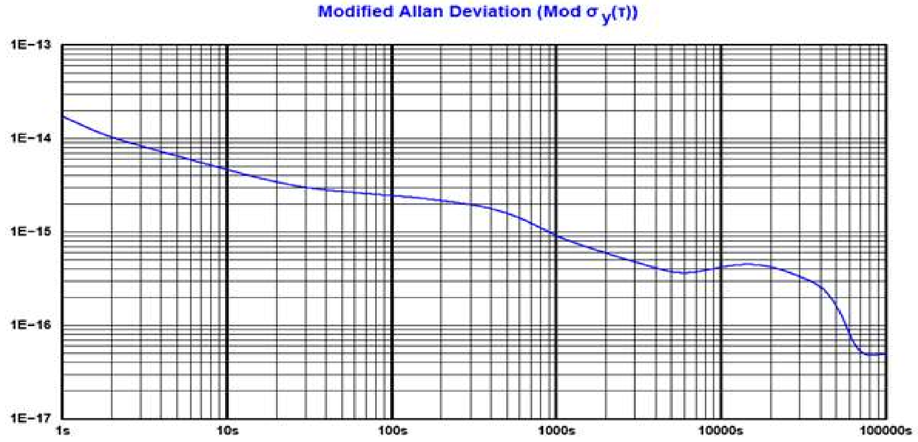
CITAF – CzL bidi AMP : Grafana dashboard - graphical representation of significant parameters through time

(Dark) bidi spectrum

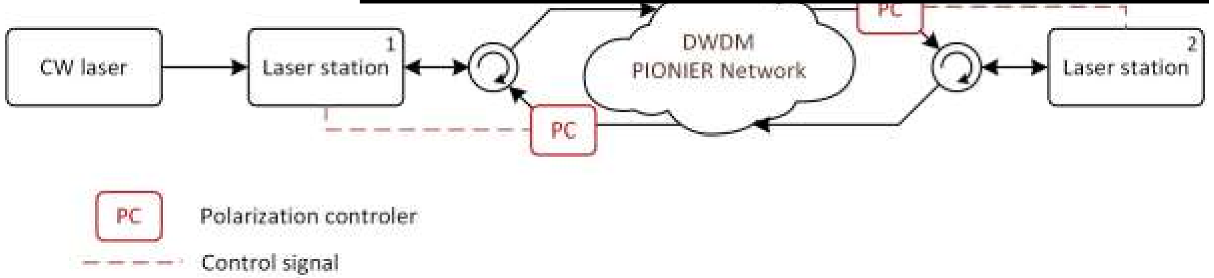


Only WR shutdown - via nearest bidi EDFA or external shutter

OC over Telecomm Lambdas



2100km over coherent DWDM system



Agenda

Optical Time & Frequency Activities – GN5 – Future

- Multi-domain monitoring
- T/F knowledge exchange platform
- T/F training
- T/F and Quantum
- Cross border challenges

Optical Time & Frequency Activities – GN5

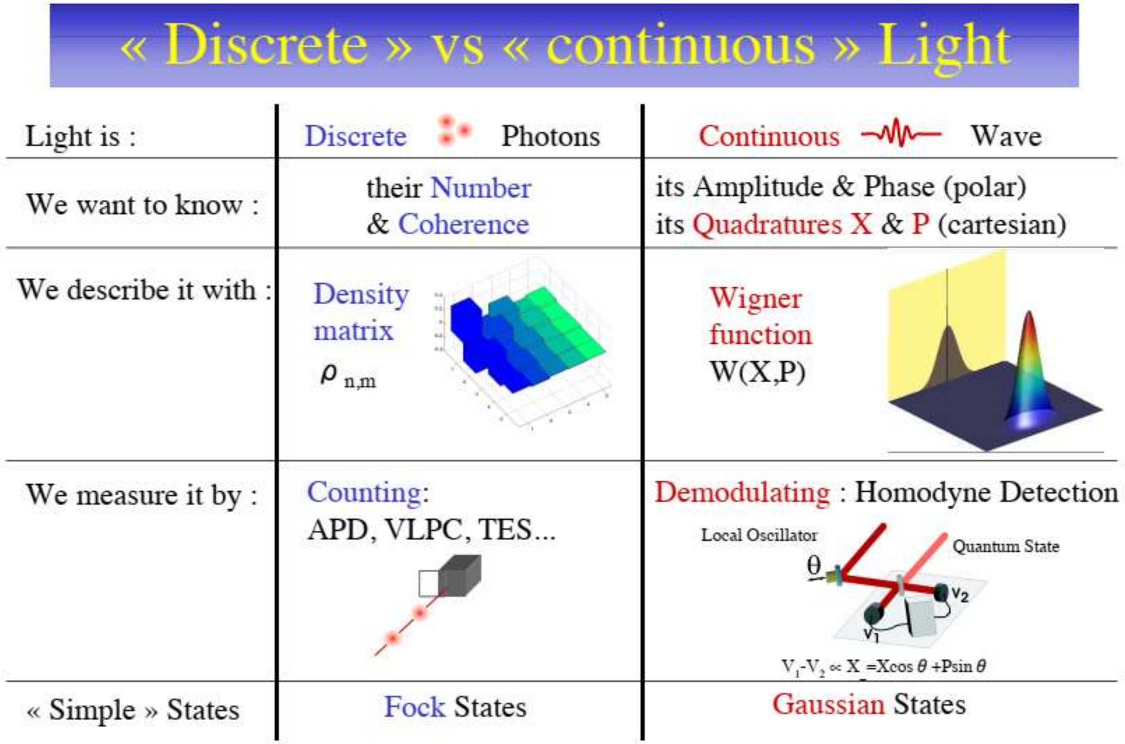
- Multi-domain monitoring
  - Especially for time signal, not only output signal is important, but also link calibration
  - This is difficult in deployed networks
  - If calibration is lost link must be re-calibrated
  - No standards for this yet
  - No competition to NMIs, but present situation for NRENs from a network perspective
- T/F knowledge exchange platform
  - To support NRENs with links offering information concerning time distribution in networks, support interest in telemetry
  - Over time build wiki portal to link important deliverables, standardisation documents, etc.
  - Exchange of experiences
  - Collect information on equipment
- T/F training
  - Produce how-to videos on lab setup, calibration, measurements

Optical Time & Frequency Activities – GN5

- **T/F and Quantum**
- **In cooperation with T1-QT subgroup**
- **Planned - whitepaper on timing requirements for Quantum**

Synergy with QKD

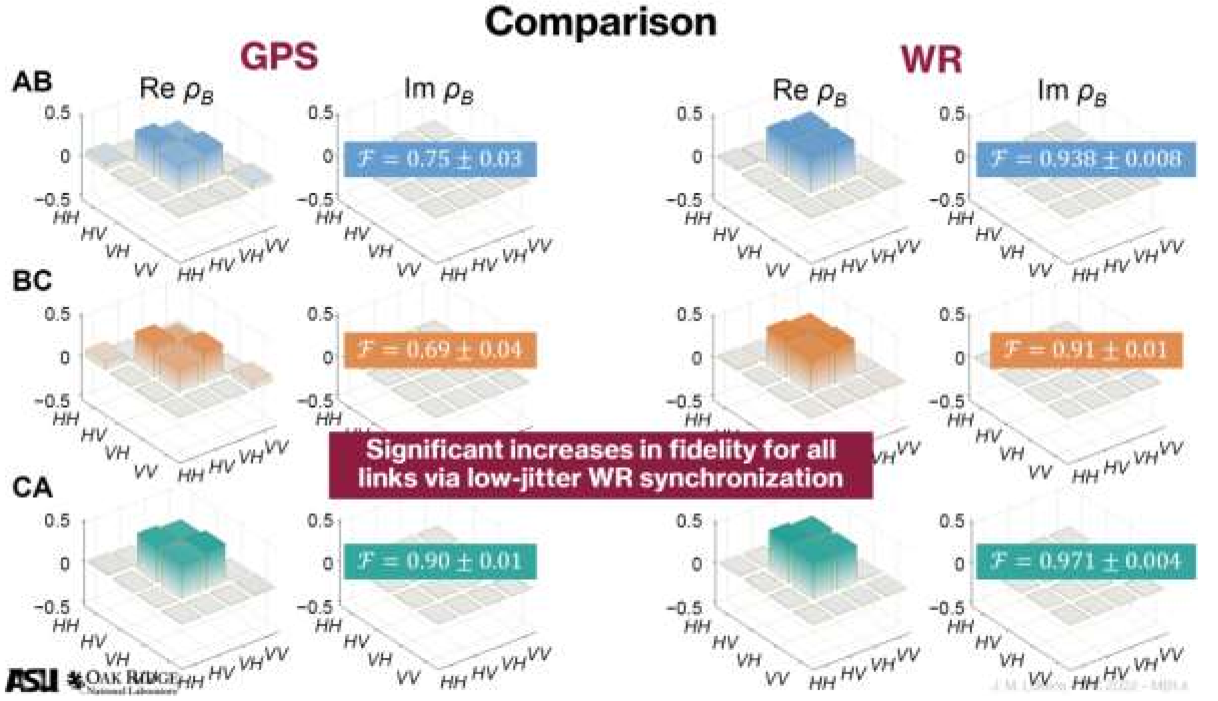
Discrete variable QKD - precise timing is must (transition from APDs to Super-conducting Nanowires SP detectors (improvement in jitter). GPS is no more enough.



« Discrete » vs « continuous » Light

Light is :	Discrete Photons	Continuous Wave
We want to know :	their Number & Coherence	its Amplitude & Phase (polar) its Quadratures X & P (cartesian)
We describe it with :	Density matrix $\rho_{n,m}$	Wigner function W(X,P)
We measure it by :	Counting: APD, VLPC, TES...	Demodulating : Homodyne Detection Local Oscillator, θ, Quantum State, V_1, V_2 $V_1 - V_2 \propto X_\theta = X\cos\theta + P\sin\theta$
« Simple » States	Fock States	Gaussian States

Credit: Grangier P.,http://gdriqfa.unice.fr/IMG/pdf/Grangier.pdf



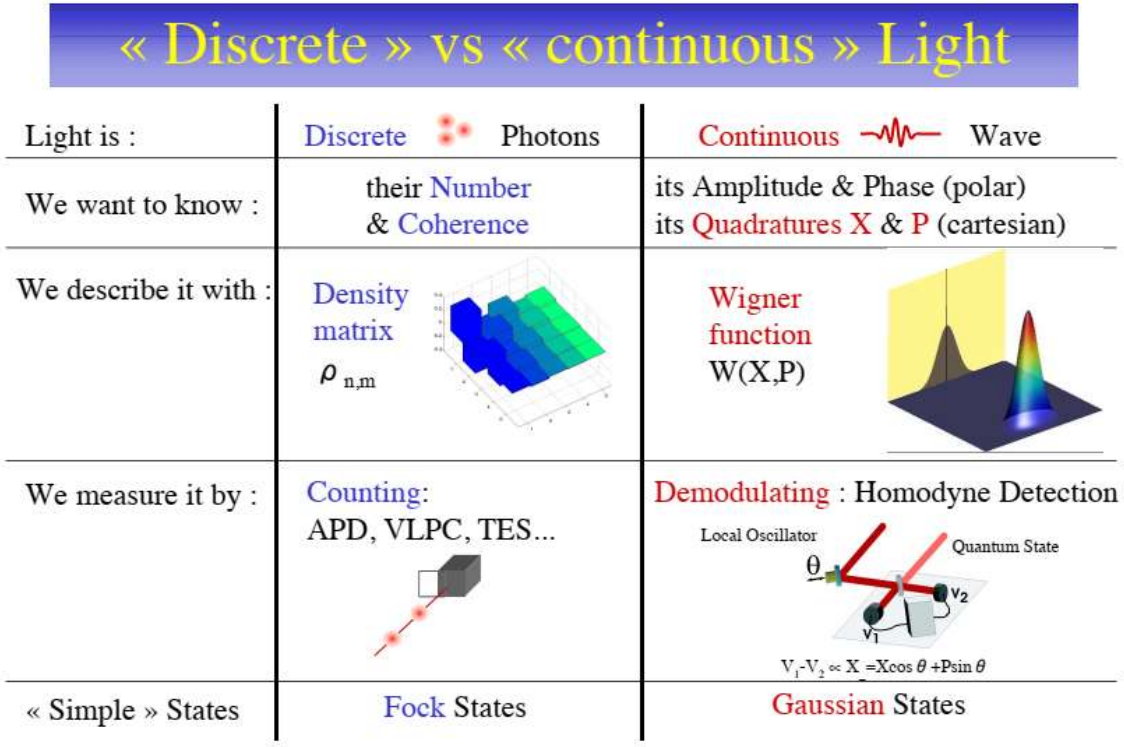
Credit: Lukens. J. et al. ***Scalable and secure architecture for quantum networks, IPC 2022, MB1.4***

Synergy with QKD

Continuous variable QKD clearly benefits from providing ultrastable reference and coherent optical frequency transfer as source of phase noise correction (via line stabilization for optical frequency transfer)

Clivati, C., Meda, A., Donadello, S. et al. Coherent phase transfer for real-world twin-field quantum key distribution. Nat Commun 13, 157 (2022). https://doi.org/10.1038/s41467-021-27808-1

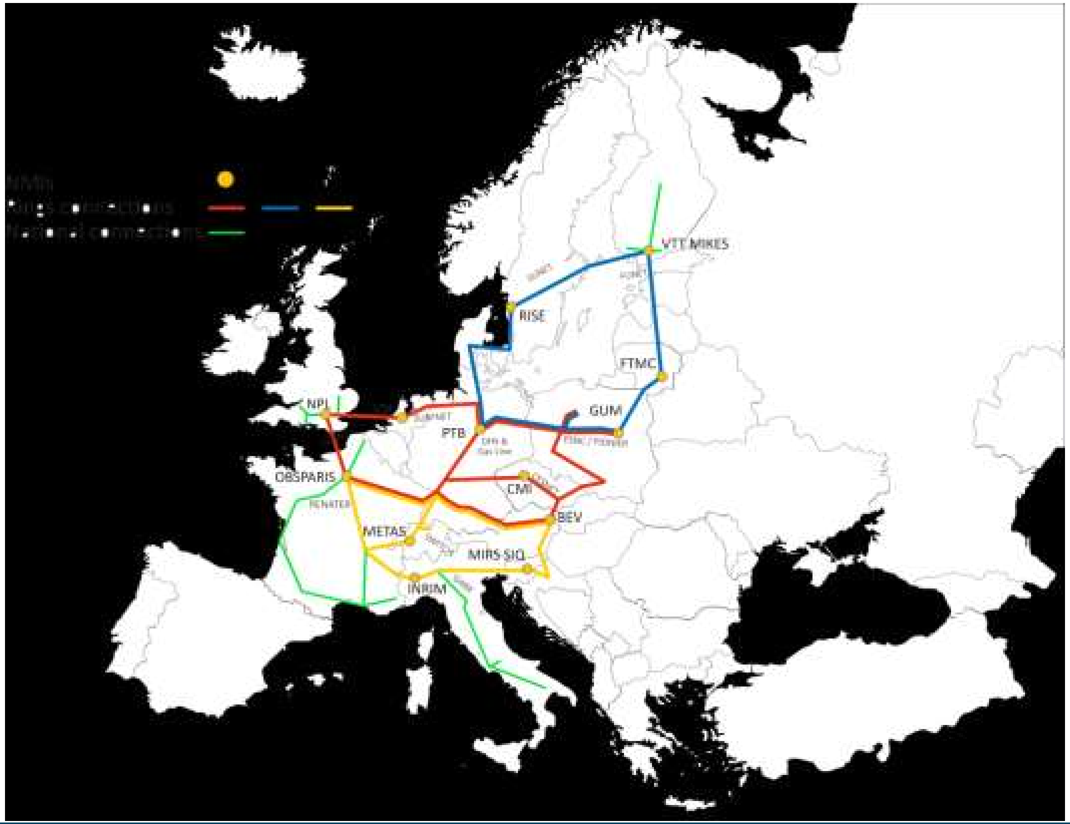
Meda et al., "QKD and frequency distribution cooperation: the Twin-field QKD case," 2022 IEEE 15th Workshop on Low Temperature Electronics (WOLTE), 2022, pp. 1-4, doi: 10.1109/WOLTE55422.2022.9882601.



Credit: Philippe Grangier - http://gdriqfa.unice.fr/IMG/pdf/Grangier.pdf

Optical Time & Frequency Activities – GN5

- Cross border challenges
  - Once CLONET-DS results become available (Apr 2023), infoshare is planned to discuss CLONET-DS results and what this will mean for NRENs



Conclusions

Optical Time Frequency transfers shifted from pionier application in to regular services in many RENs

Monitoring and support necessary

Transfer means are heterogeneous, but final services should be E2E

Huge synergy with quantum applications is expected

Acknowledgement

- Ivana Golub, Tim Chown, Pavle Vuletic

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Thank you very much for kind attention

Any questions?

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