



Update on optical research in the GEANT network

400G ZR+, QKD, time/frequency

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CEF11 workshop Prague

18-19 April 2023

Public

- Spectrum and 400G ZR+
- QKD
- Time frequency

Spectrum services and 400G ZR+ Optical pluggables

Long-term Backbone Traffic Growth

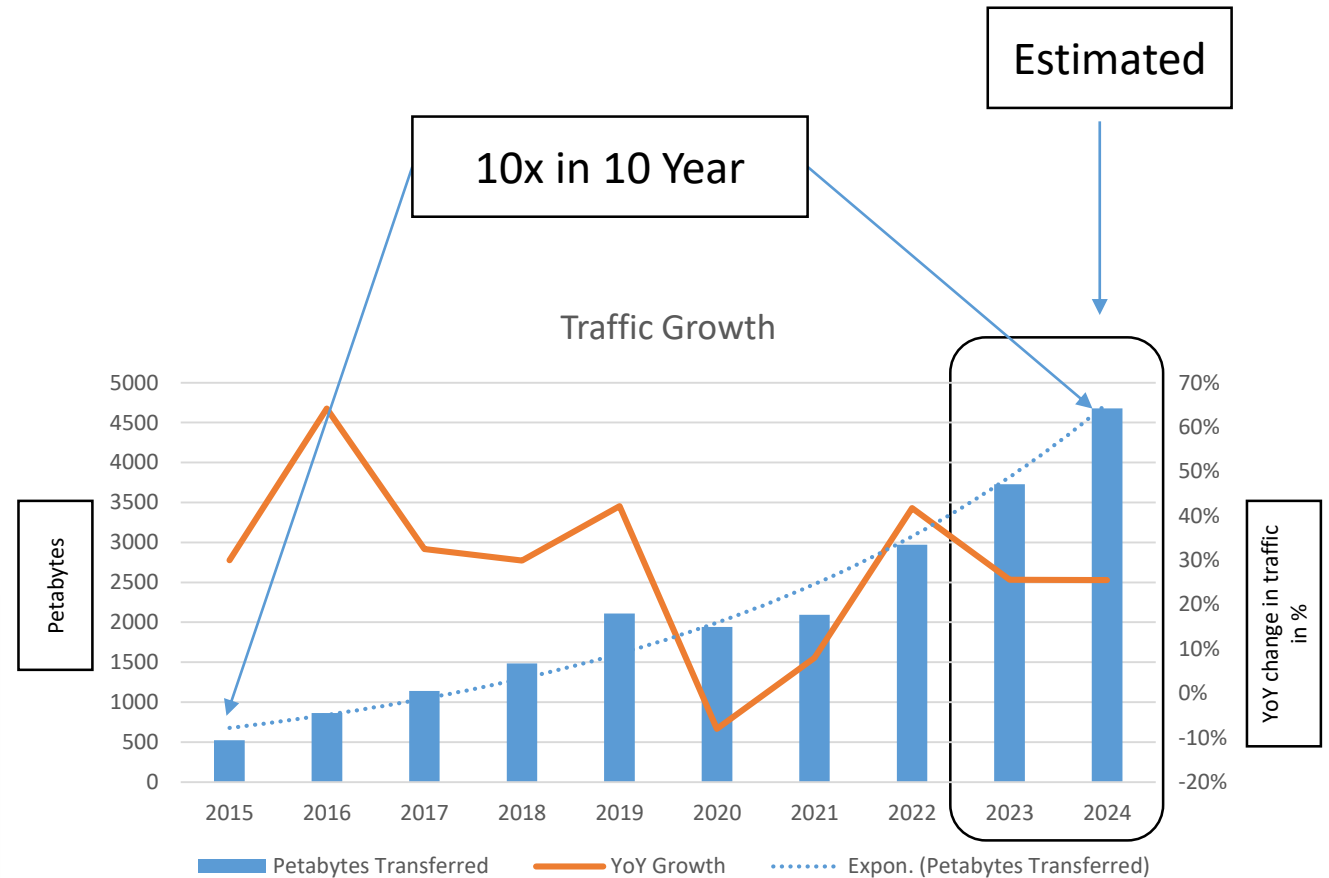
(on GÉANT network driven by scientific instruments)

- **Total: 2010 –2022** growth of over **30% YoY**
- **2015–2019:** Traffic growth of **40% YoY**
- **2015–2022:** Traffic growth of **27% YoY**

Total Backbone Trunk Capacity

February 2019 **2.7 Tbps**

Now 2022 **9.4 Tbps**



Big trends

- Next generation of DCI and pluggable optics increasing fibre capacity
- DCI and pluggable form factors are current trend
- Up to 80Tbps on a fibre pair

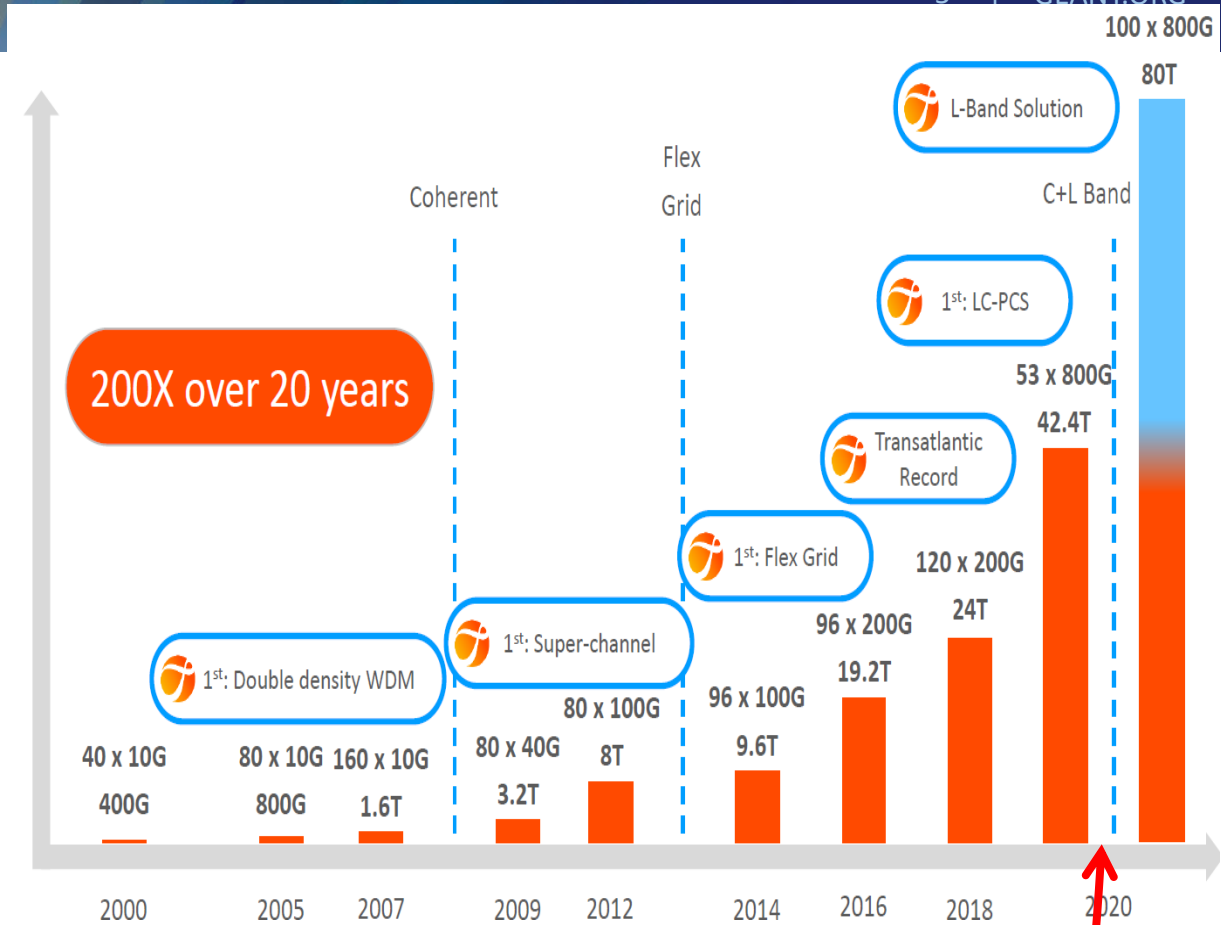


Infinera Groove



400 ZR+ Pluggable

Spectrum: the resource that keeps on giving

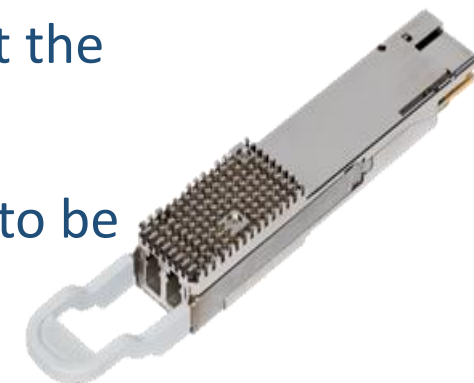


Field Trial 2021:
800G Direct Detect
800G per λ , 42T per
fiber

- Three key 400G ZR+ vendors: Cisco, Coherent, Infinera (also Fujitsu and Huawei)
- Cisco has acquired Acacia to add coherent pluggables to their portfolio
- In 2022, II-VI Inc. acquired Coherent Inc., the merged company is now Coherent Corp
- Infinera are leveraging their integrated photonic circuit technology to build 400G ZR+
- Other vendors include Fujitsu and Huawei

Cisco's purchase of Acacia is of interest as it signal the move towards vertical integration of coherent technology into routing equipment (Packet over Optical)

- The responses to the IP/MPLS procurement will affect the type of optics we use
- The capability of the new packet equipment to support ZR+ optics will affect the way we procure optics
- The reach for ZR+ optics on real-world fibre with good margins is expected to be around **750km with 400G**
- The price of ZR+ 0dBm optics is expected to be in the range of 8k, resulting up to 50% cost reduction over CHM2T



| Specification | Data rate | Modulation | FEC/coding gain | Target reach (fibre dependent) |
|------------------|-----------|------------|-----------------|--------------------------------|
| OIF 400ZR | 400G | DP-16QAM | OFEC/11.6dB | 120km |
| OpenZR+ | 400G | DP-16QAM | OFEC/11.6dB | 1400km |
| | 300G | DP-8QAM | OFEC/11.6dB | 2500km |
| | 200G | DP-QPSK | OFEC/11.6dB | 3000km |
| | 100G | DP-QPSK | OFEC/11.6dB | 8000km |

Table: Max reach of ZR and ZR+ optics from Open ZR+ MSA



- Most routes in GEANT are suitable for ZR+ 0dBm
- Green routes are highly suitable
- Yellow routes are possible, but may be spectral density issues

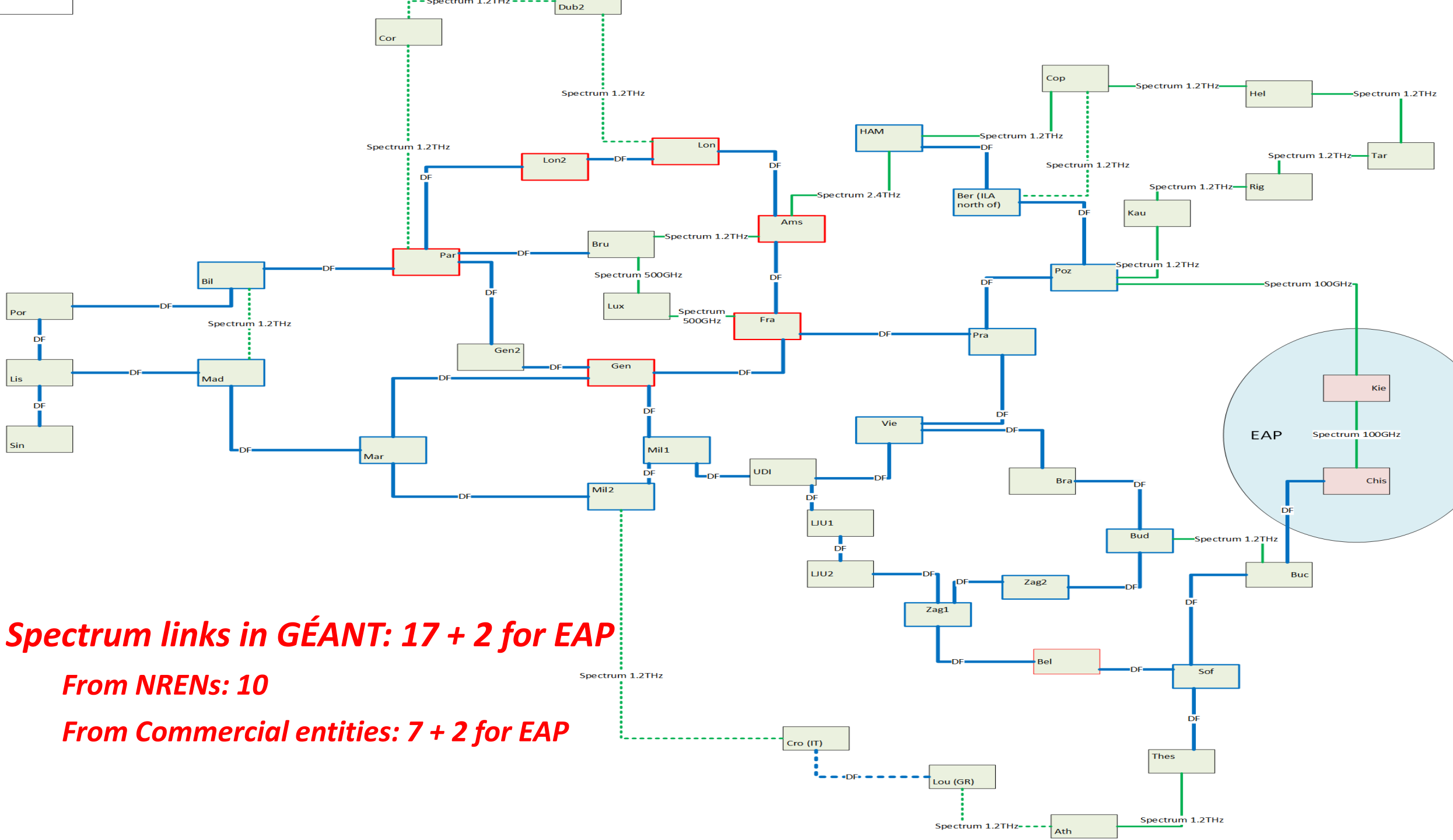
| Route | fibre length (km) | | Route | fibre length (km) | | Route | fibre length (km) |
|-----------|-------------------|--|-----------|-------------------|--|-----------|-------------------|
| AMS-FRA | 672 | | BIL-PAR | 1,120 | | LJU-LJU | 4 |
| AMS-LON1 | 476 | | BIL-POR | 1,067 | | UDI-LJU | 176 |
| FRA-GEN1 | 831 | | LIS-POR | 366 | | RIG-SIA | 150 |
| FRA-PRA | 668 | | LIS-MAD | 897 | | ZAG1-ZAG2 | 10 |
| GEN1-GEN2 | 5 | | HAM-POZ | 692 | | BEL1-BEL2 | 27 |
| GEN1-MIL1 | 714 | | POZ-PRA | 748 | | BUC-SOF | 611 |
| GEN2-MAR | 700 | | BRA-BUD | 249 | | PAR-BRU | 524 |
| GEN2-PAR | 788 | | BRA-VIE | 111 | | LIS-SUN | 172 |
| LON1-LON2 | 70 | | BUD-ZAG | 456 | | | |
| LON2-PAR | 626 | | LJU-MIL1 | 678 | | | |
| MAD-MAR | 1,400 | | LJU-ZAG | 197 | | | |
| MAR-MIL2 | 770 | | BEL-SOF | 458 | | | |
| MIL1-MIL2 | 23 | | BEL-ZAG | 546 | | | |
| MIL2-VIE | 1,080 | | SOF-THES | 512 | | | |
| PRA-VIE | 451 | | DUB1-DUB2 | 24 | | | |

- CIM8: Coherent Interconnect Module 8: 1.2T pluggable coherent solution
- Available now from Acacia, not clear what equipment provider take up will be – first in DCI equipment
- Probabilistic shaping (and Nyquist carriers?)



- 800G ZR+ is in the process of being standardized
- Form factor unknown, but target of compatibility with 400G ZR+ is being targeted
- 400G XR optics are similar performance to ZR+, but with multipoint capabilities





Spectrum links in GÉANT: 17 + 2 for EAP

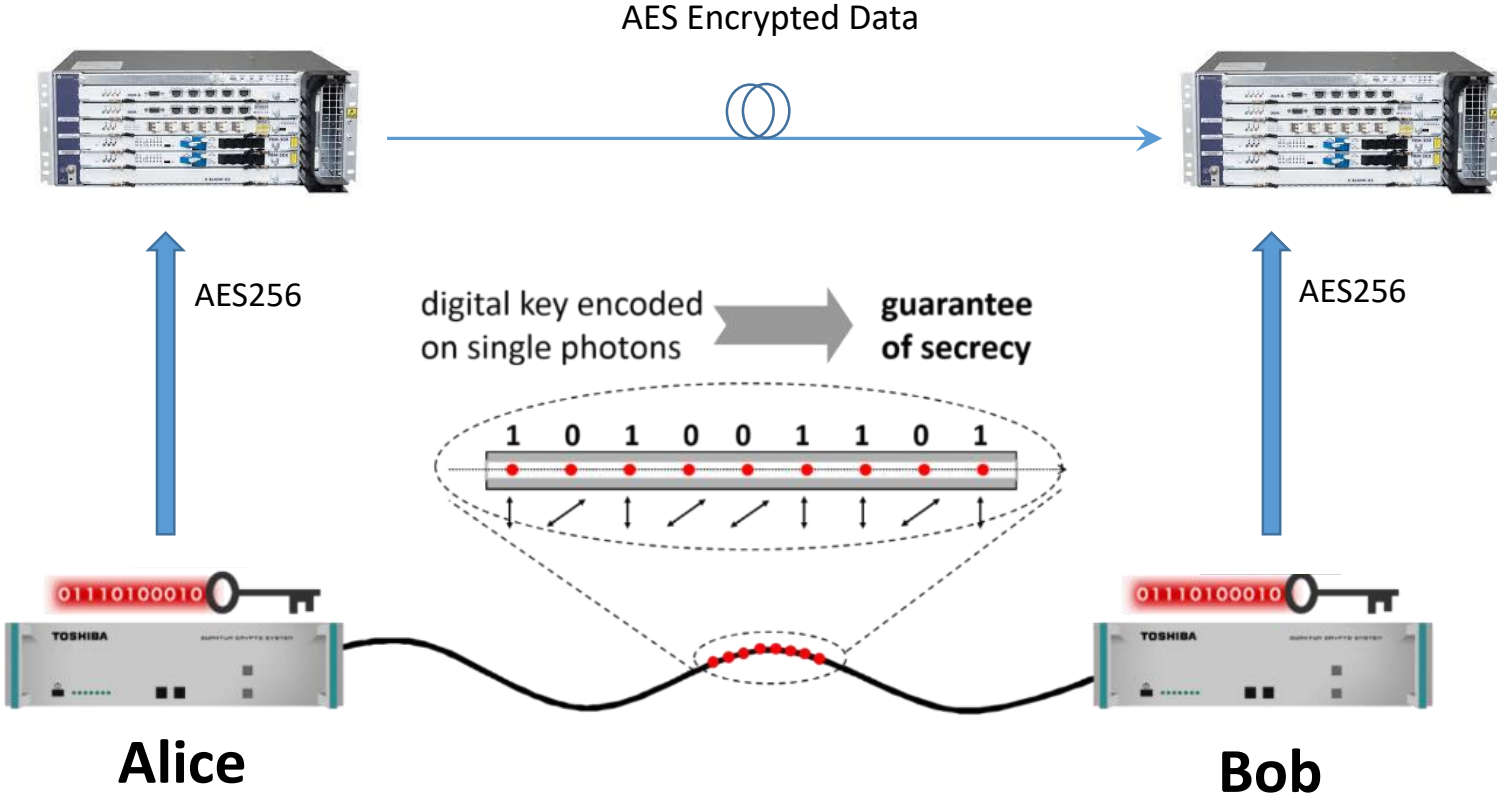
From NRENs: 10

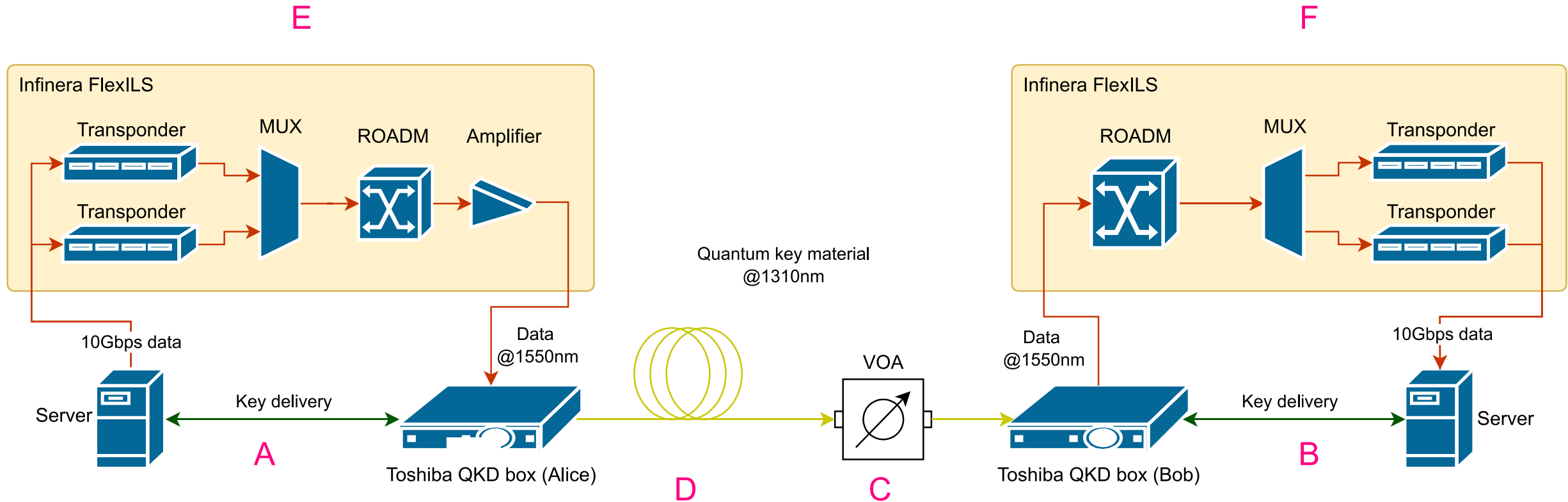
From Commercial entities: 7 + 2 for EAP

Quantum Key Distribution – Karel van Klink MSc project GEANT

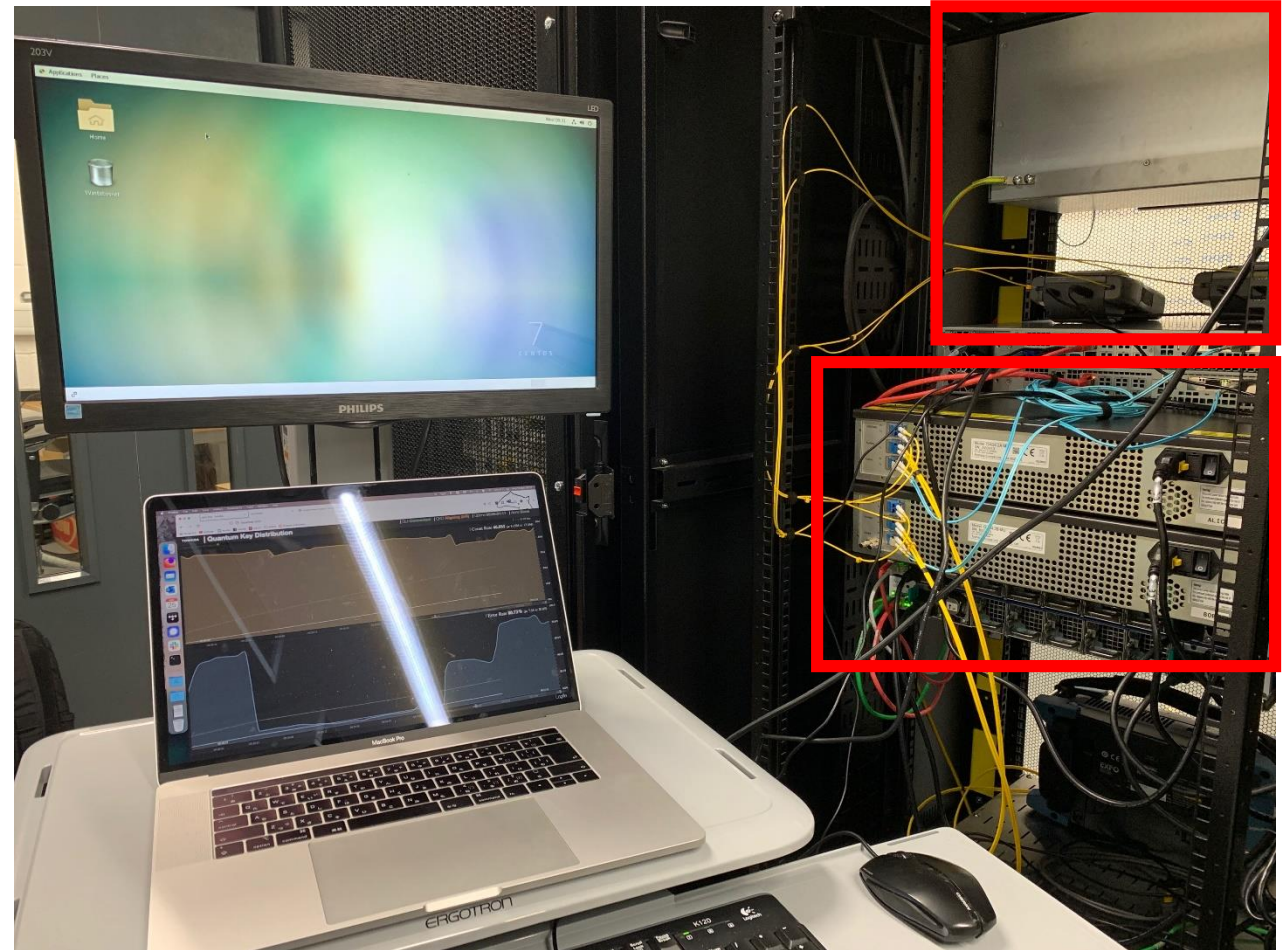
- Lab testing of Toshiba QKD equipment
- Uses T12 Protocol, an optimization based on BB84 protocol
- Two bases (rather than one basis) of polarization increases effective throughput
- Also uses decoy states
- Two variants: dedicated fibre (QKD in C-band 1550nm) /multiplexed with data (QKD in O-band)
- Performance subject to laser/detector grade



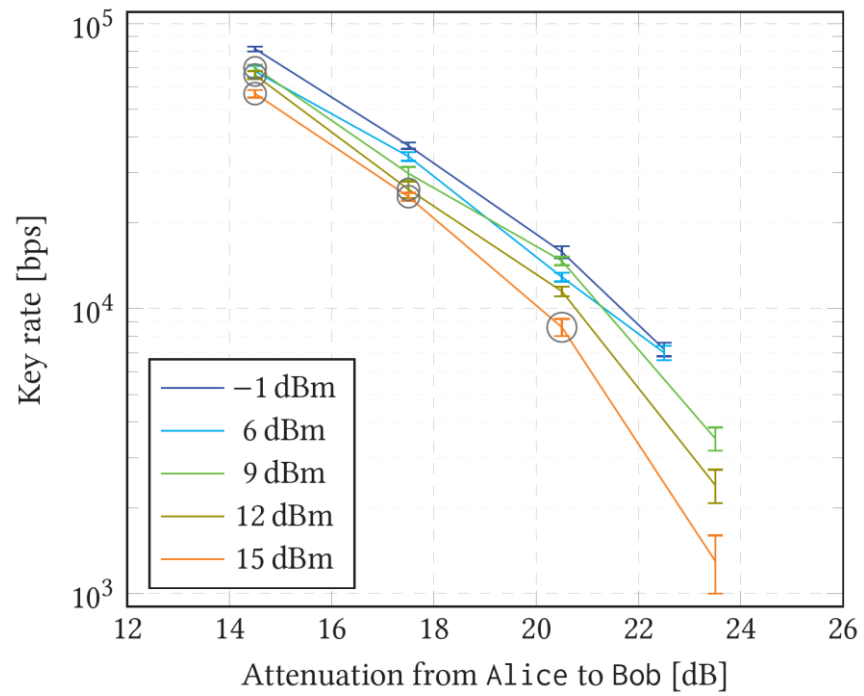




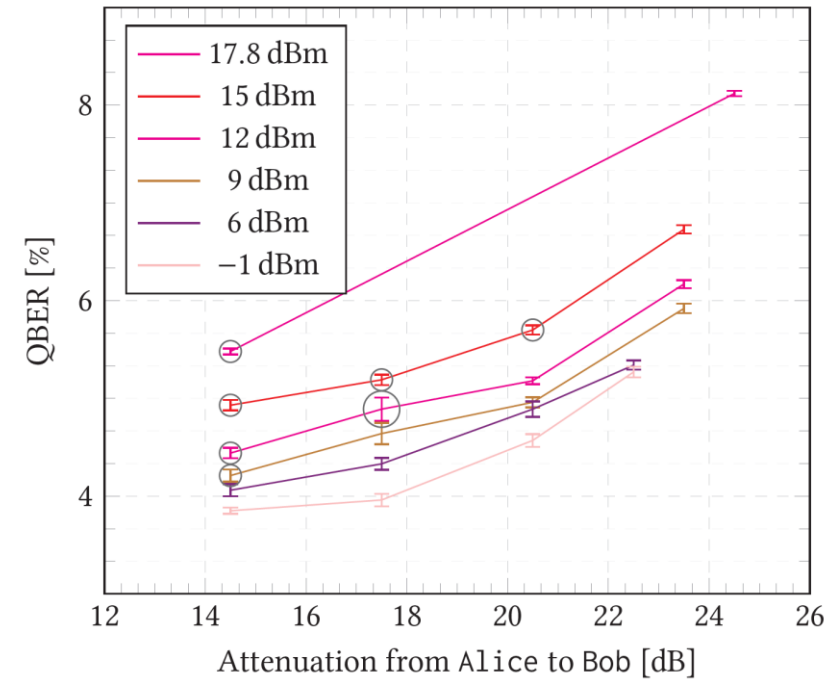
- QKD in O-band, data in C-band
- Multiplex data at multiple power levels
 - Secret Key Rate
 - QBER
- Maximum sustainable attenuation
 - Which link spans could we cover?



Average bit-rate against attenuation

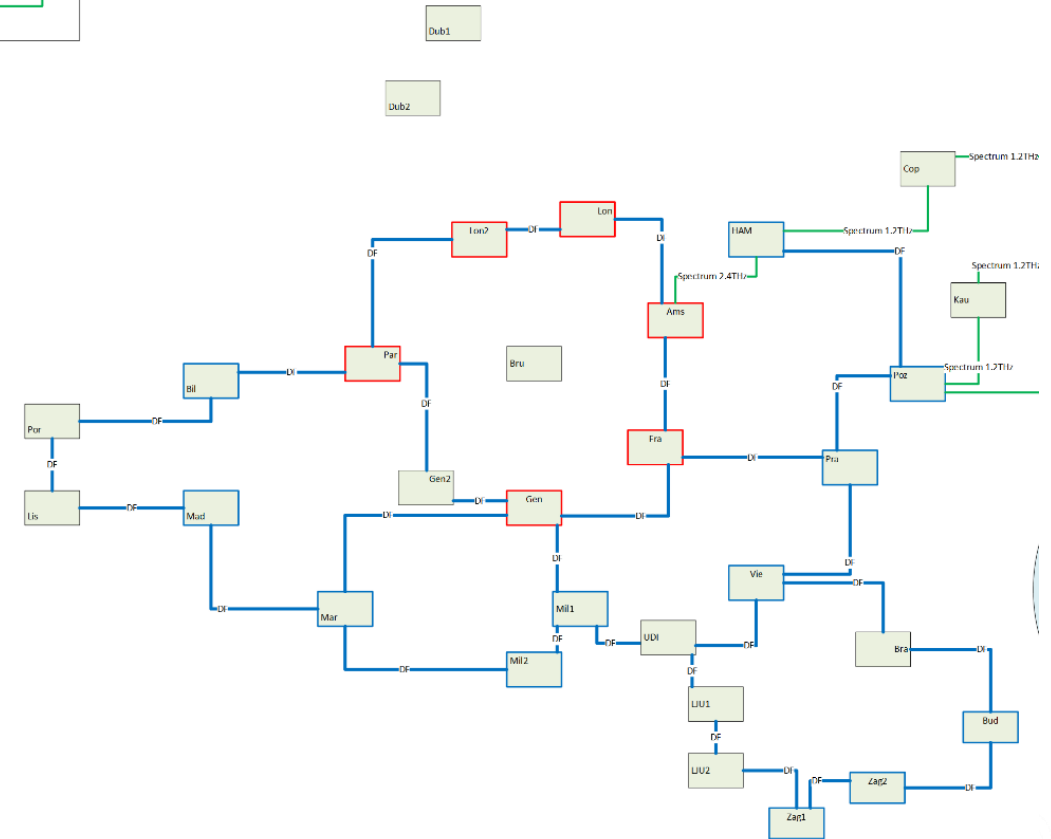
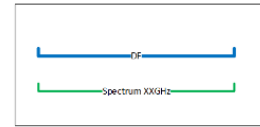


Average QBER against attenuation

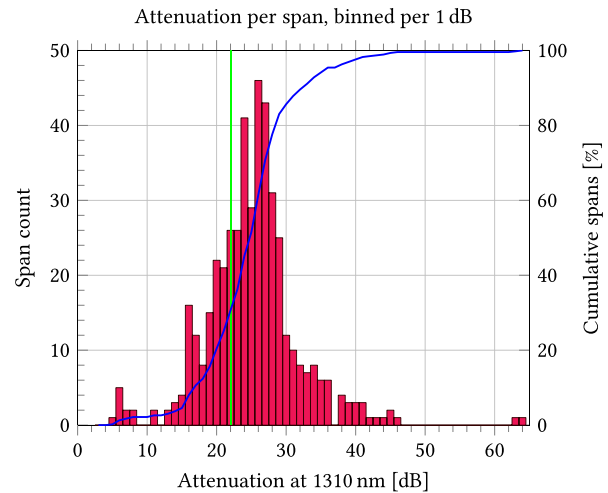


- For every +3dBm increase in power:
 - SKR goes down by ~15%
 - QBER goes up by ~6%
- Maximum sustainable attenuation found to be 23.5dB
 - Estimated to be 22dB with a filled C-band
- Core of GEANT network is L-band enabled

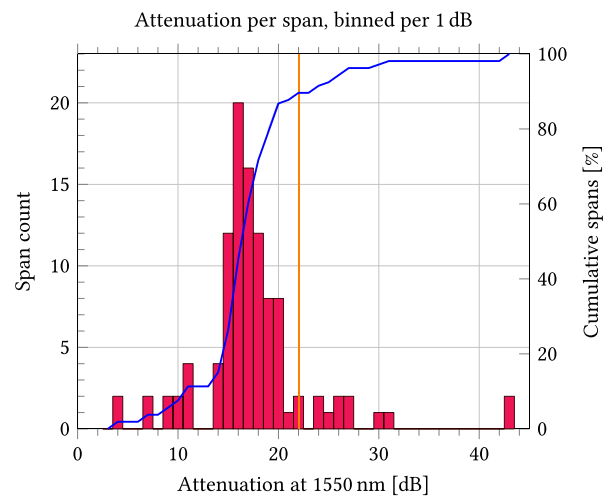
Substrate GN4-3N



- GÉANT network:
 - ~30% @1310nm



- ~90% @1550nm



- Hardware support is largely present
- Standardisation is lacking at the moment
- Available software is not up to the task

- Recommended next steps:
 - Implement a field trial link
 - Real-world performance
 - Long-term reliability
 - Track ongoing standardisation efforts



Time-Frequency in GEANT

- GÉANT would like to support the emerging T/F requirements in Europe.
- If funding is available this would be best served using dedicated dark fibre, but dedicated fibre may be too expensive.
- GÉANT's new network will be completed in 2023
- GÉANT has enabled L-band on the core network links for future capacity expansion.



GÉANT footprint has significant overlaps with Metrology requirements as identified in CLONETS study – could we leverage this?



Two options are being evaluated in GÉANT for supporting CLONETS: dedicated fibre and shared fibre

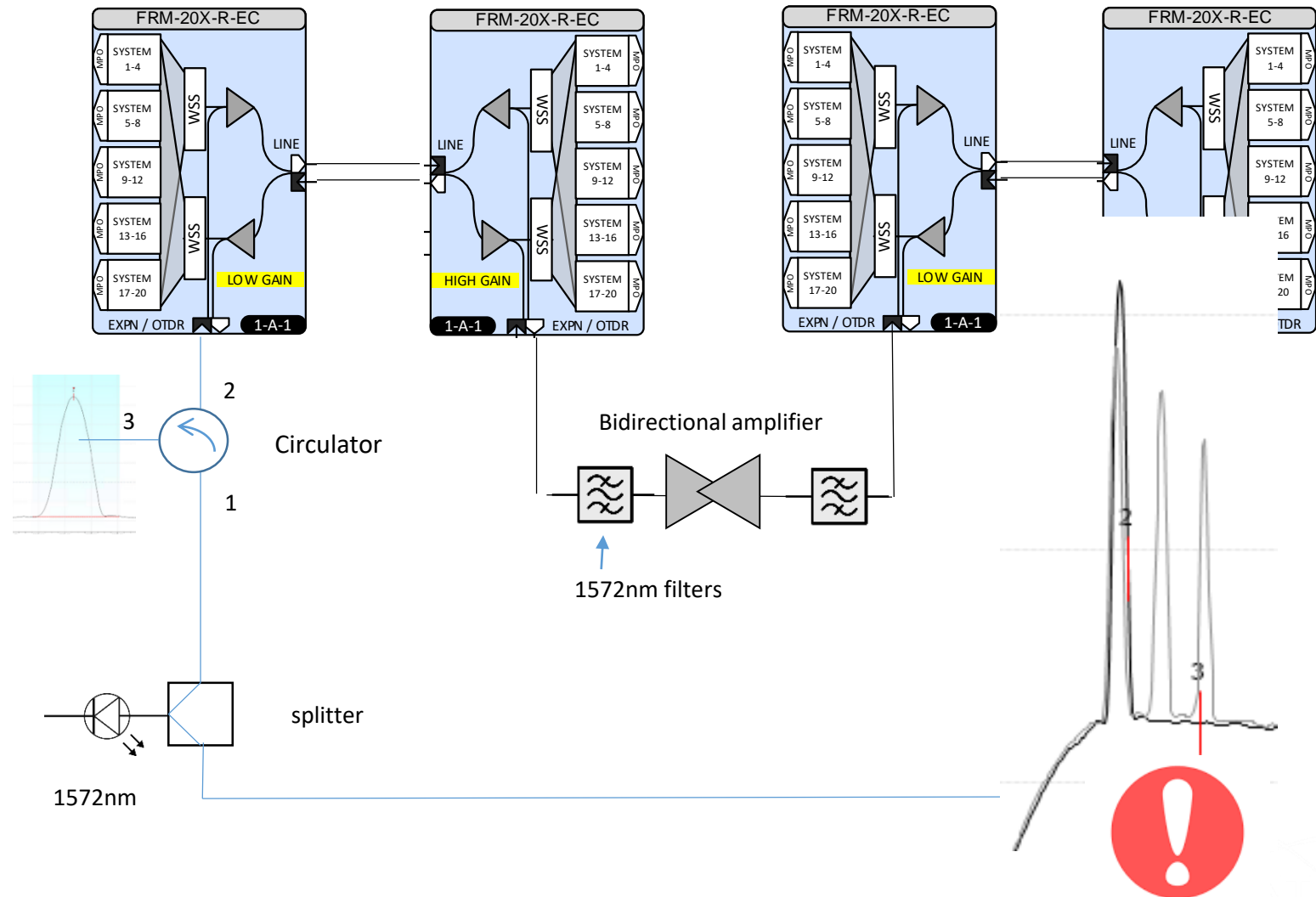
Dedicated fibre:

- In this option GÉANT procures dark fibre that is dedicated for time/frequency use.
- The whole C-band is available for CLONETS.
- GÉANT can also procure and install optical regenerator laser stations (RLS).

Shared fibre:

- In this option existing GÉANT dark fibre for Internet access is shared with time/frequency.
- CLONETS is provided access to a spectral band on GEANT fibre
- GÉANT would also procure and install and operate optical regenerator laser stations (RLS).

- Infinera FlexILS equipment tested in GEANT lab
- Bidirectional amplifiers connected to the EXPN port
- Detailed testing of power level to understand lasing risk
- Lab testing has shown that time/frequency signals can be injected as a bi-directional signal on the L-band using these ports.



Risk of feedback lasing!

CLONETS-DS

- CLONETS-DS identified requirements, services, and delivery models
- Community needs to maintain momentum from CLONETS-DS work
- Incubator proposal has been submitted as a bridge for building European time-frequency infrastructure

Incubator Objectives

- Clear path forward for GÉANT needed by end Q4 2023 to enable planning for GN5-2
- Need for business case and sustainability model to meet Commission's funding requirements
- If successful, consider initiating development in 2024, subject to funding availability



400G ZR+

- Is very promising new technology
- Estimate cost is one third of using Transponder/DCI equipment
- Could work on up to 65% of GEANT routes

QKD

- Mixing QKD and internet traffic is technically feasible
- Crosstalk does not unduly limit QKD in lab tests
- Better reach would be possible if QKD could be deployed on L-band

Time/Frequency

- An incubator has been launched to find ways of continuing the vision set out in CLONETS-DS



Thank You

Any questions?

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