WHERE IS RIGHT SPECTRAL GAP FOR ACCOMMODATION OF EMERGED PHOTONIC SERVICES OF TIME AND FREQUENCY OR QKD?

(APPROACHING 10 YEARS AND PLAN TO MOVE FROM C BAND)

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T/F transfers over shared fibre
T/F infrastructure CESNET
Spectrum Exhaustion
Alternatives
Performance verifications
Clonets
Why T/F transfers over shared fibre? On dedicated it is easier.

Example fibre line length: 1 400 km

Fibres rental annual cost (based on average price*)
  - EUR 420 000

Share T/F infrastructure with data

Core network example – project CLONETS
Examples C band (1530-1565 nm)
- T - lambdas - IPE-BEV/CESNET-ACONET
- T - lambdas - MIKES/CSC/FUNET
- T - lambdas - RISE/SUNET

- F - lambdas - RISE/SUNET
- F - dark channel bidi amplified (ch 44) – LNE-SYRTE/RENATER
- F - dark channel bidi amplified (ch 46-39) – ISI/CESNET
Examples out of C band

- T - dark channel semibidi amplified – VSL-NIKHEF/SURFNET
  - 1470/1490nm
  - 1nm in 1510
  - C band

Under construction

- F - dark channel bidi amplified (1570 nm C/L) – METAS, ETH Zurich/SWITCH

- T - lambdas (C band) – GARR
2011 – alien wave

- Comparison of time scales UTC(TP) and UTC(BEV), Caesium beam 5071A/001 atomic clocks, since Aug 2011
- One way distance 550km/340miles (including 220km/137miles NIL) 137 dB
- C band channel any
2014

- Already C and L DWDM systems
- Amplified 800 GHz channel, One way 306 km, 85 dB, combination of G.652 and G.655 fibres
- 4, later 5 pcs bidi EDFAs with single signal path
Research and Education Network CESNET2

- > 5800 km of dark fibre lines
- T/F transfer
- Fibres shared with data
- Dedicated all-optical channel
- 800/400 GHz,
  - Ch 46-39/46-43

- 700km of lit bidi channels provided as a service
- Projected length 2476 km, transmission 1183 km
Time and Frequency Infrastructure

- Coherent Optical Frequency
- Metro – Fibre
- Long haul – DWDM bidi channel
- 550 km 800 GHz / 520 km 400 GHz
- Operation
  - 840 km ch46 1540.5 nm
  - 250 km ch44 1542.1 nm
Inceased Spectrum Use

Obsolete – 96 ch. per 10 Gbit/s – 0,96 Tbit/s (OOK)
Mature – 96 ch. per 200 Gbit/s – 19,2 Tbit/s (DP16QAM)
Present – 80 ch. per 400 Gbit/s – 32 Tbit/s (60 GHz, DP16QAM)

L band technology available since late 1990 – 90nm

\[ \text{OSNR}_{ASE} = \text{Pout} - \text{NF} - G - 10 \log(N) + 58 \]

source: Pecci P. Alcatel Submarine Networks „Design of Submarine Open Cables“

source: cisco.com
Alternative Bands

- Multiplication of data capacity of single 50 GHz channel capacity with similar reach is no more scaling (Shannon),
- **C** capacity is exhausting (necessary guardbands)
- **L** will have the similar problem soon
- **S** not suitable for long haul (lack of amplification)
- **C/L** typ 4 nm 1566-1570 are skipped because of technological reasons, EDFAs work fine here
## Alternative Bands

<table>
<thead>
<tr>
<th>Coherent Frequency Transmission</th>
<th>Precise Time Transmission</th>
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<tr>
<td><strong>Sources</strong></td>
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<td>C/L</td>
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<td>SOA, Brill only</td>
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<tr>
<td>S</td>
<td>CWDM only</td>
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<td>SOA only</td>
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**Notes:**
- C: Coherent Frequency Transmission
- C/L: C+L Coherent Frequency Transmission
- L: Precise Time Transmission
- S: Spectral Transmission
- CWDM: CWDM only
- SOA: SOA only
- Brill: Brill only
- Coherent Optical Frequency
- Optical clock $^{40}\text{Ca}^+$ ion
- Transfer of second harmonic of 729 nm (1458)
- Requested transfer channels:
  - Classical: C band ch. 46
  - 1570 nm C/L band
  - S band (1458 nm)
Optical clock based on trapped and cooled single ion $^{40}\text{Ca}^+$ Direct output at: 729 nm

Distance: 20 km, 29 dB
Performance Verification of 1570 nm-bidi EDFAs CzechLight

Vojtech J., "Alternative spectral windows for photonic services distribution," Proc. SPIE 11128, Infrared Remote Sensing and Instrumentation XXVII, 1112806 (9 September 2019); https://doi.org/10.1117/12.2529713
Tested WhiteRabbit in 1570 nm band, dark channel (100 km), bidirectionaly amplified channel (200 and 300 km)
- Necessity of significant spectral gap
- Raman energy transfer to lower energies/high wavelengths
- On shared fibres S band looks interesting (no amplifiers necessary)
- 1570 nm to be field tested and deployed soon
- 1458 subject to further tests
- Plans to gradual vacation of channels 44/46 and move to 1570 nm
Thank You very much for Kind Attention!

Questions?

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