Recent Advances in WDM Transmission and Transport Technologies in Brazil - CPqD

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Agenda

- Focus
  - gλif

- High Speed Optical Transmission Research at CPqD
  - Advanced modulation formats and coherent detection

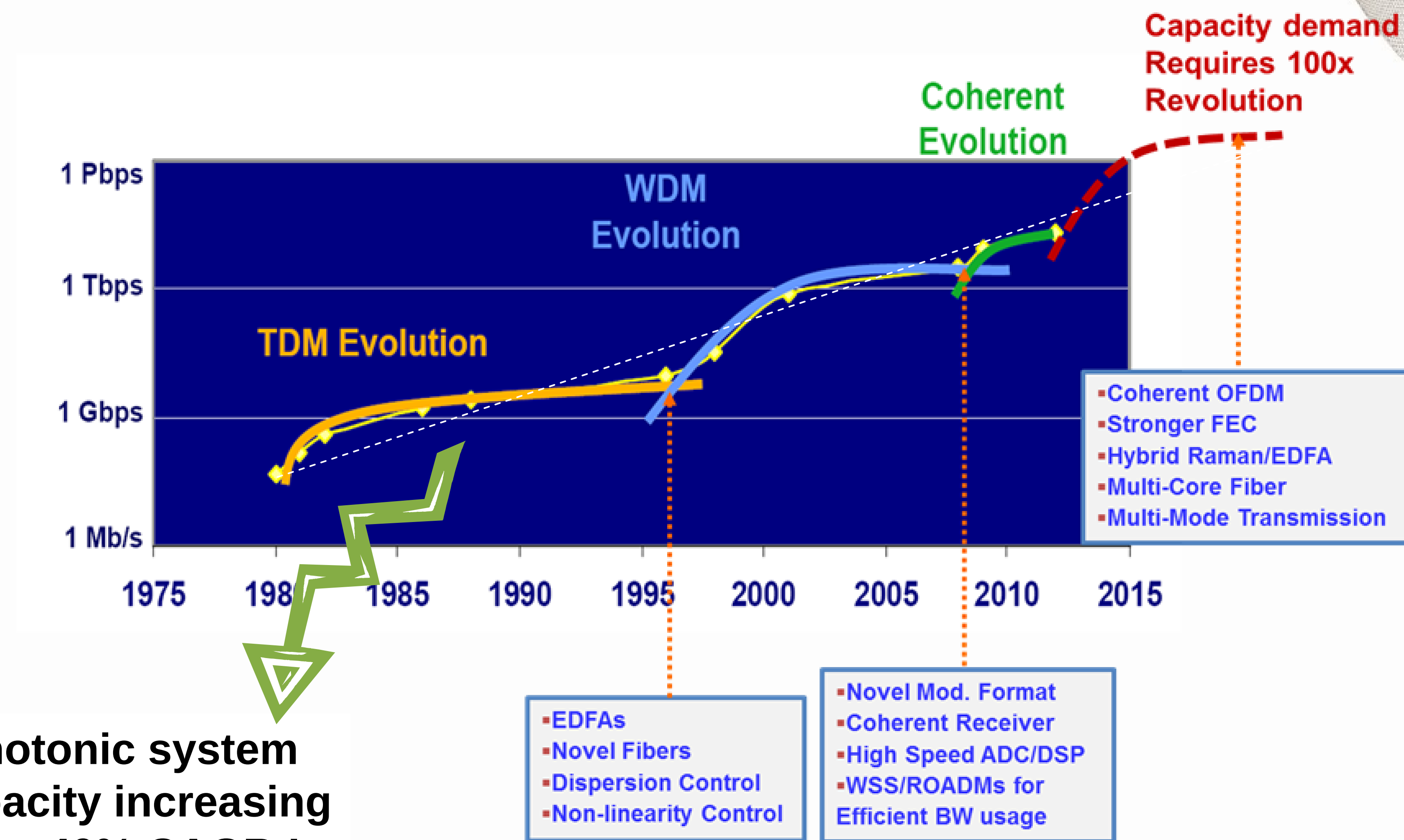
- Optical Transport Networks Technology Research
  - ROADMs (PLC, WSS – Crossconection, Colorless, Gridless, Directionless,…)
  - Optical Amplification (EDFA, Raman, Hybrid Amplification)
  - Autonomic Networks (GMPLs, Monitoring)

IP traffic

- **Global IP traffic has increased eightfold over the past 5 years, and will increase fourfold over the next 5 years.** (Cisco Visual Networking Index: Forecast and Methodology, 2010-2015)

Traffic to increase about **32** times in **10** yrs (~40% CAGR)

Photonic Technology Evolution

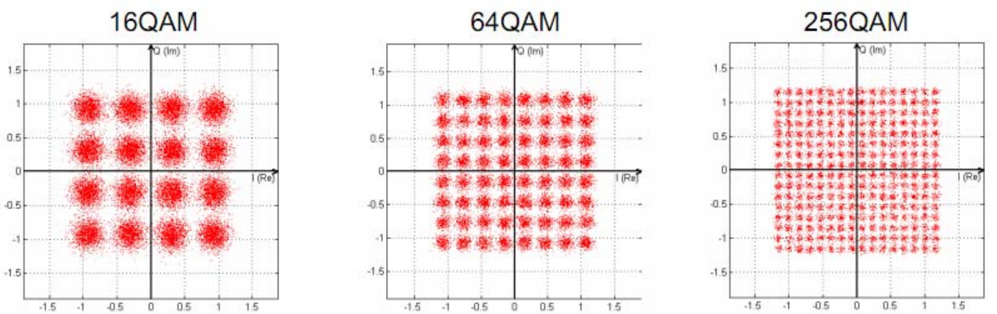


Photonic system capacity increasing at >40% CAGR !

Coherent Evolution

Capacity, Electronics and Reach trade-off

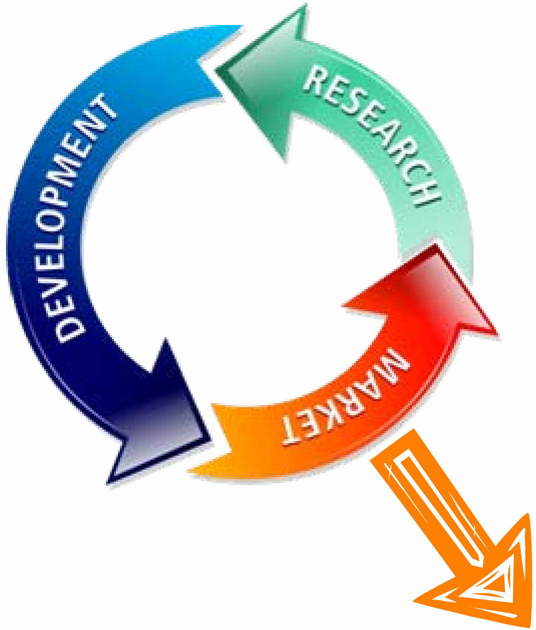
Gbit/s	# Pol.	Gbaud	Grid (GHz)	Bits/ symbol	Modulation	ROSNR (dB) @ $2 \cdot 10^{-3}$
112	2	28	50	2	DP-QPSK	12.6
224	2	28	50	4	DP-16QAM	17.4
448	2	112	200	2	DP-QPSK	18.6
448	2	56	100	4	DP-16QAM	22.4
448	2	37	>50	6	DP-64QAM	26.6
448	2	28	50	8	DP-256QAM	31.9



Source: Fujitsu

Optical Technology at CPqD

Focus on technology R&D driven by industry and operators



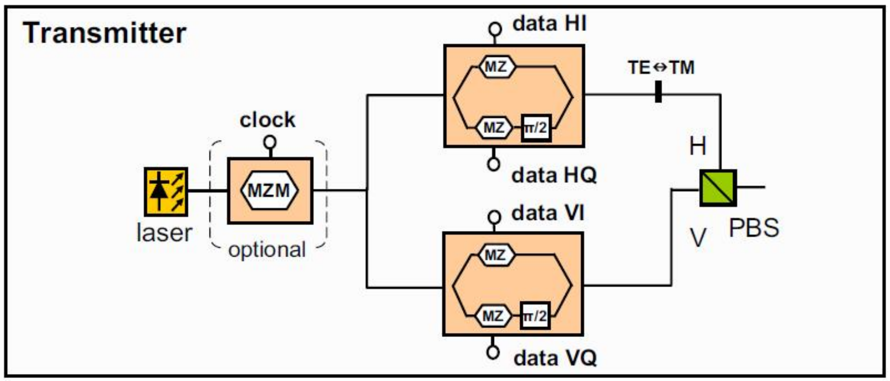
Technology licensing

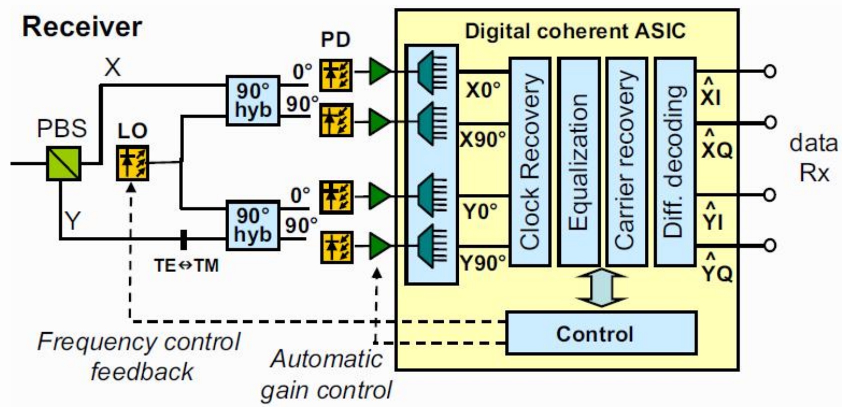
Padtec: created in 2001 with focus on WDM; US$ >100M revenue in 2010; WDM market leader in Brazil, with growing presence in South America and Europe

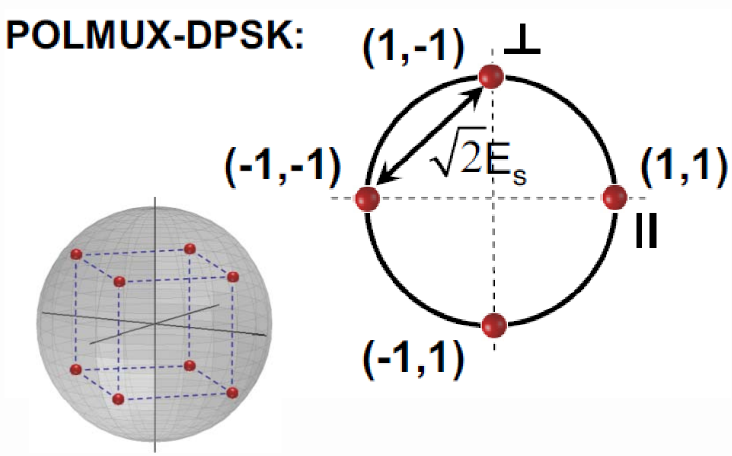
112Gbps Coherent

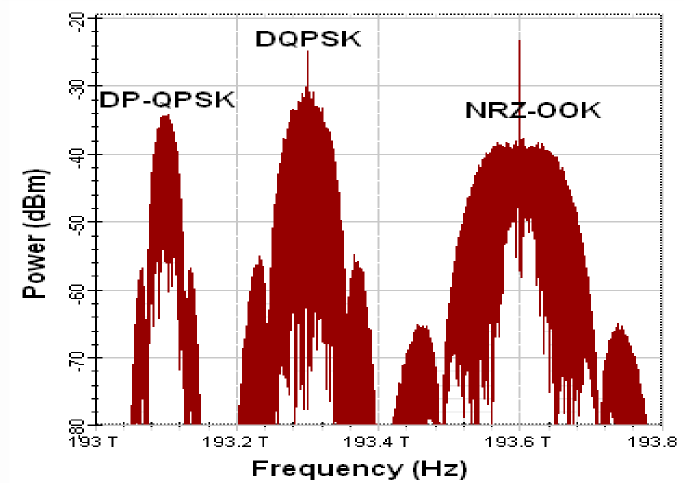
112 Gbps DP-QPSK

- Phase Modulation (QPSK) and Polarization Multiplexing (DP)
- Spectral Efficiency: 2 bits/s/Hz
- 10 Tb/s in the C-band (96 channels at **112** Gb/s)
- Fiber effects compensated with coherent detection and digital processing

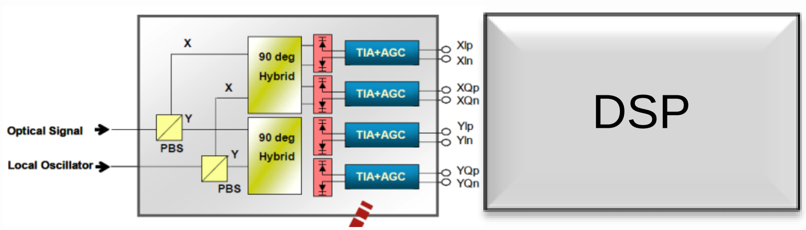






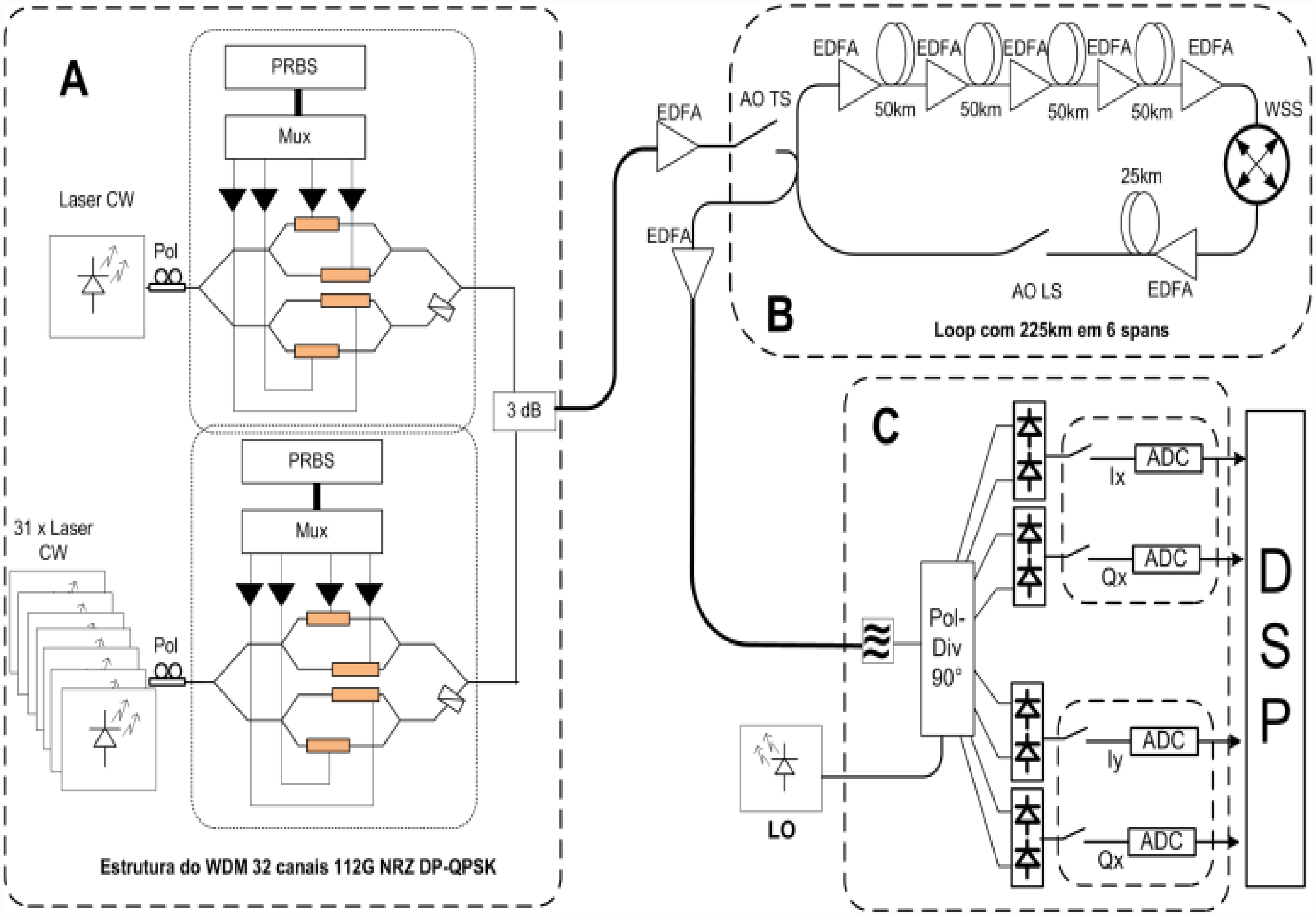


Digital Filtering (DSP) after Receiver

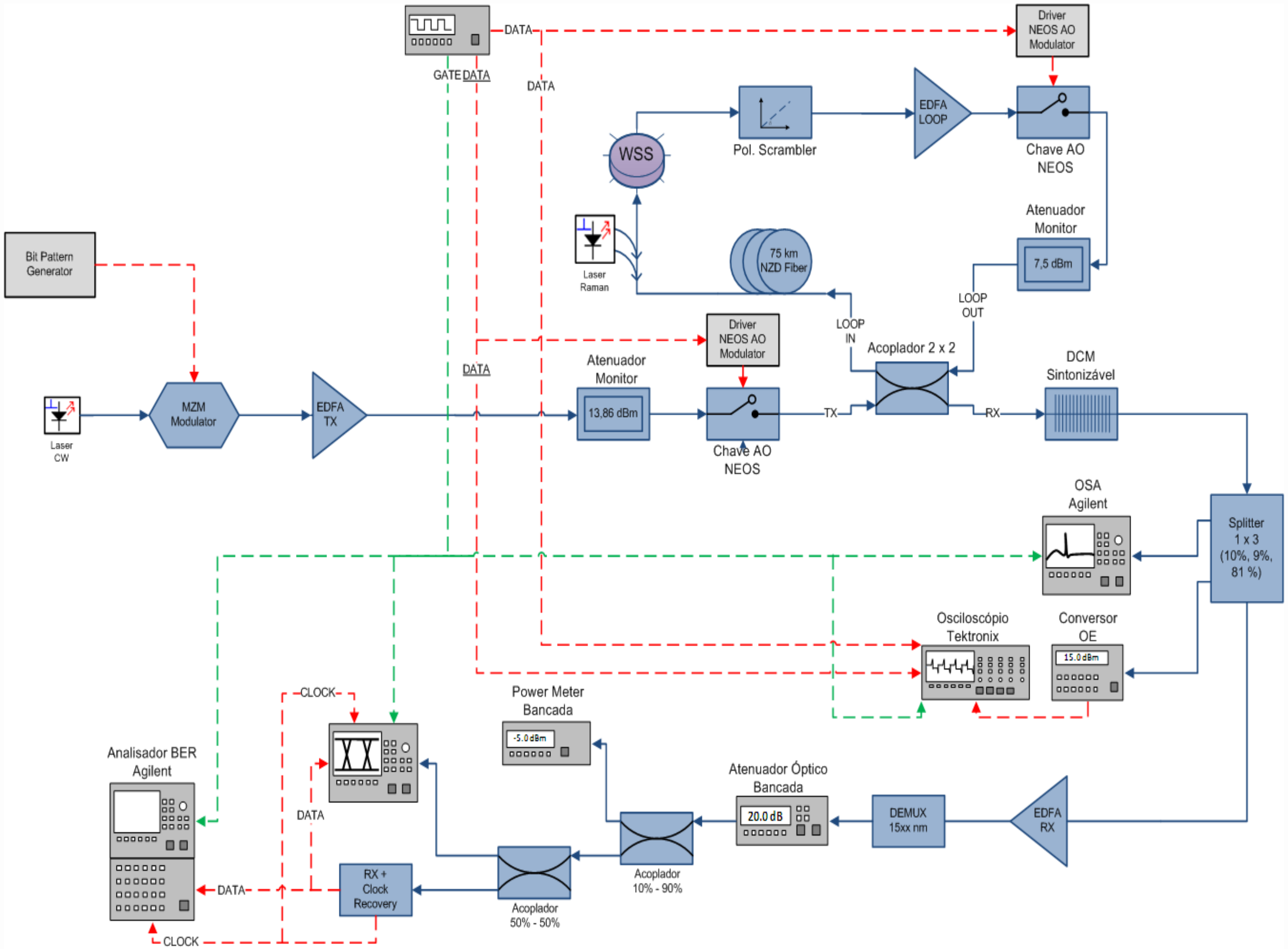


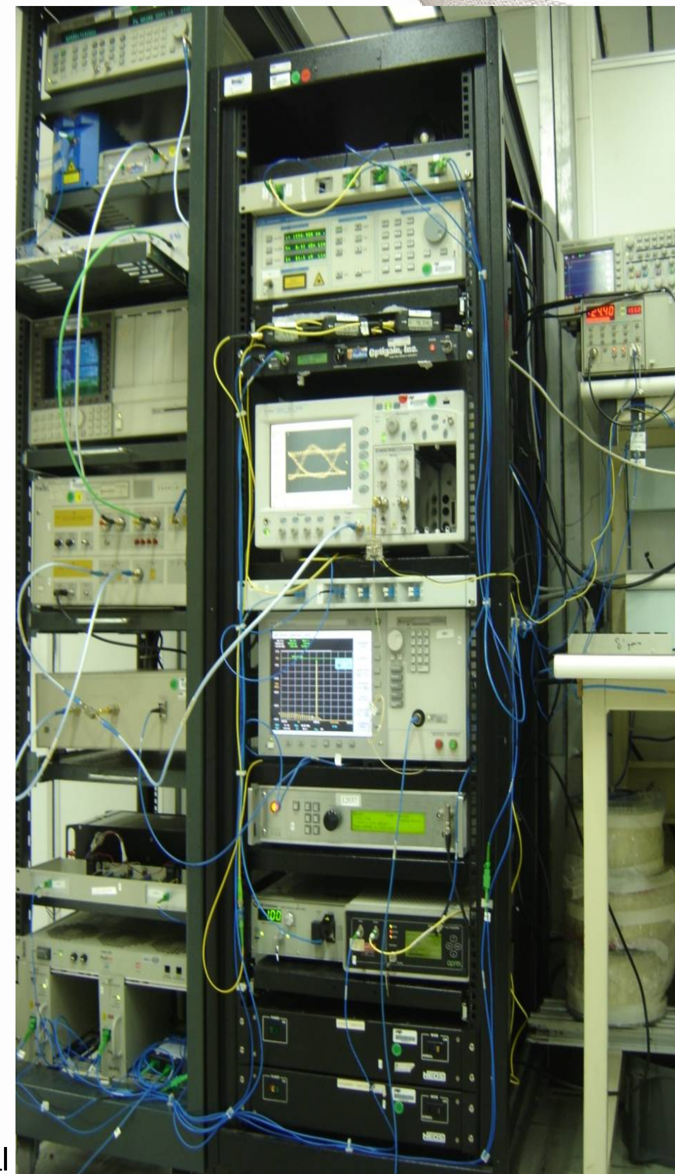
1. De-skew and orthonormalization
2. Static channel equalization
3. Dynamic channel equalization
4. Interpolation and time recovery
5. Frequency estimation
6. Carrier phase estimation
7. Symbol estimation and decoding

32 channel x 112G DP-QPSK WDM (Tx/RX)

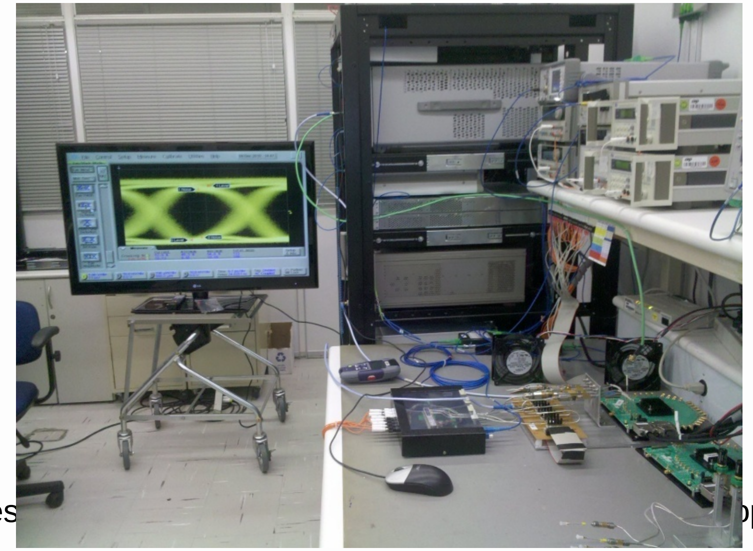


Recirculation loop

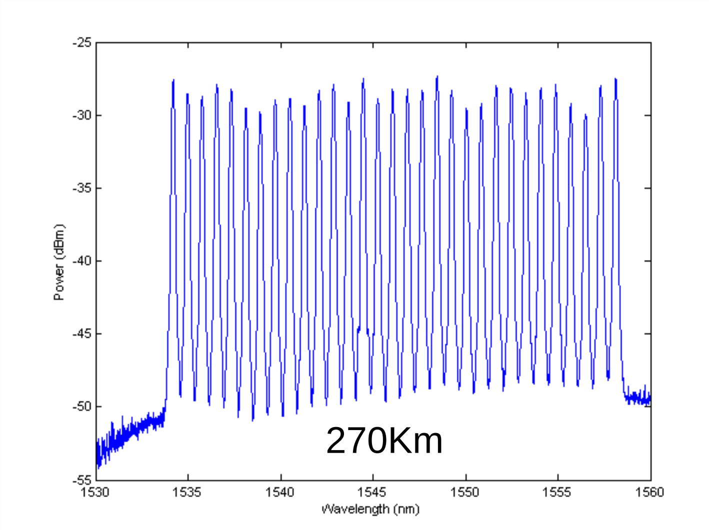


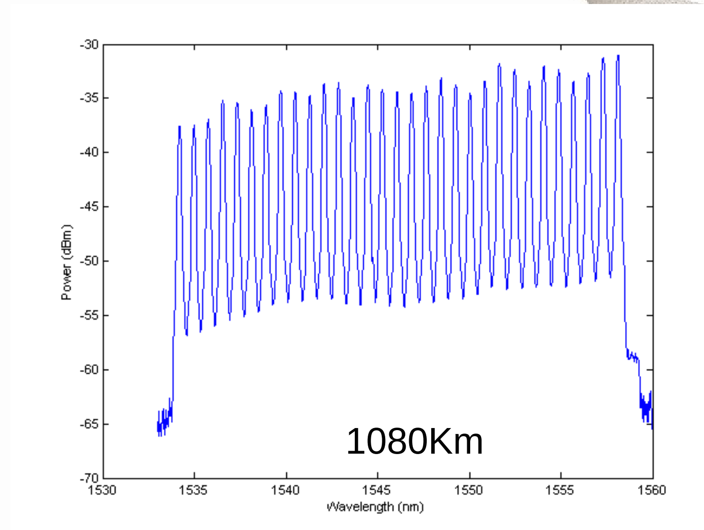


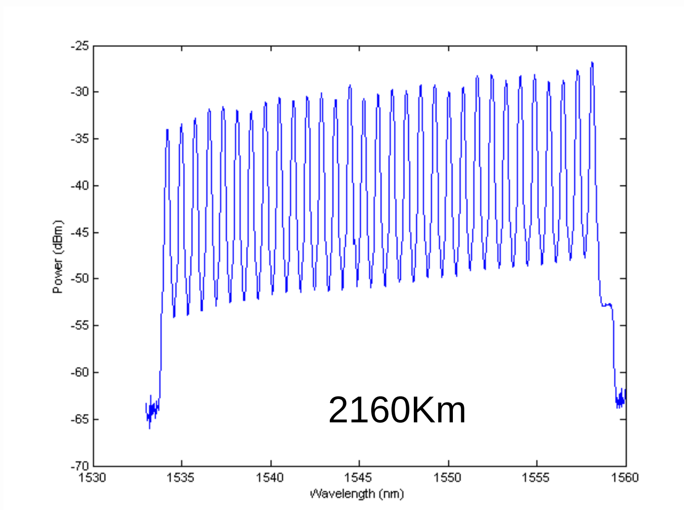
Complete 112G DP-QPSK Experimental Setup

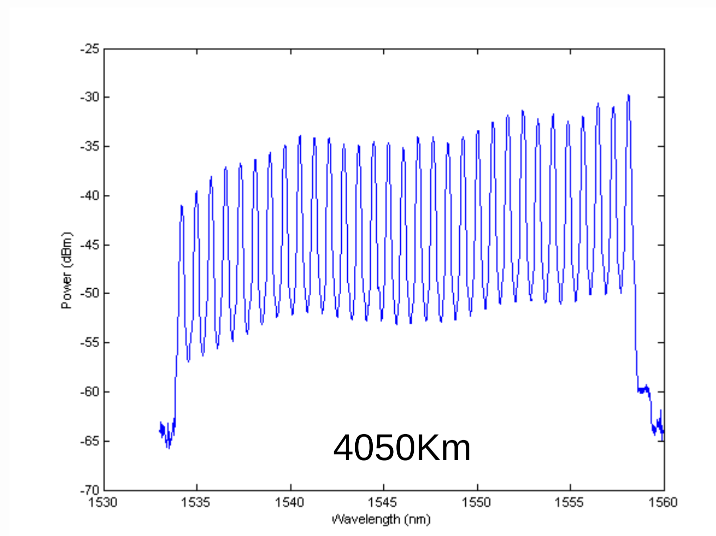


32x112G DP-QPSK WDM (3.2Tb/s)

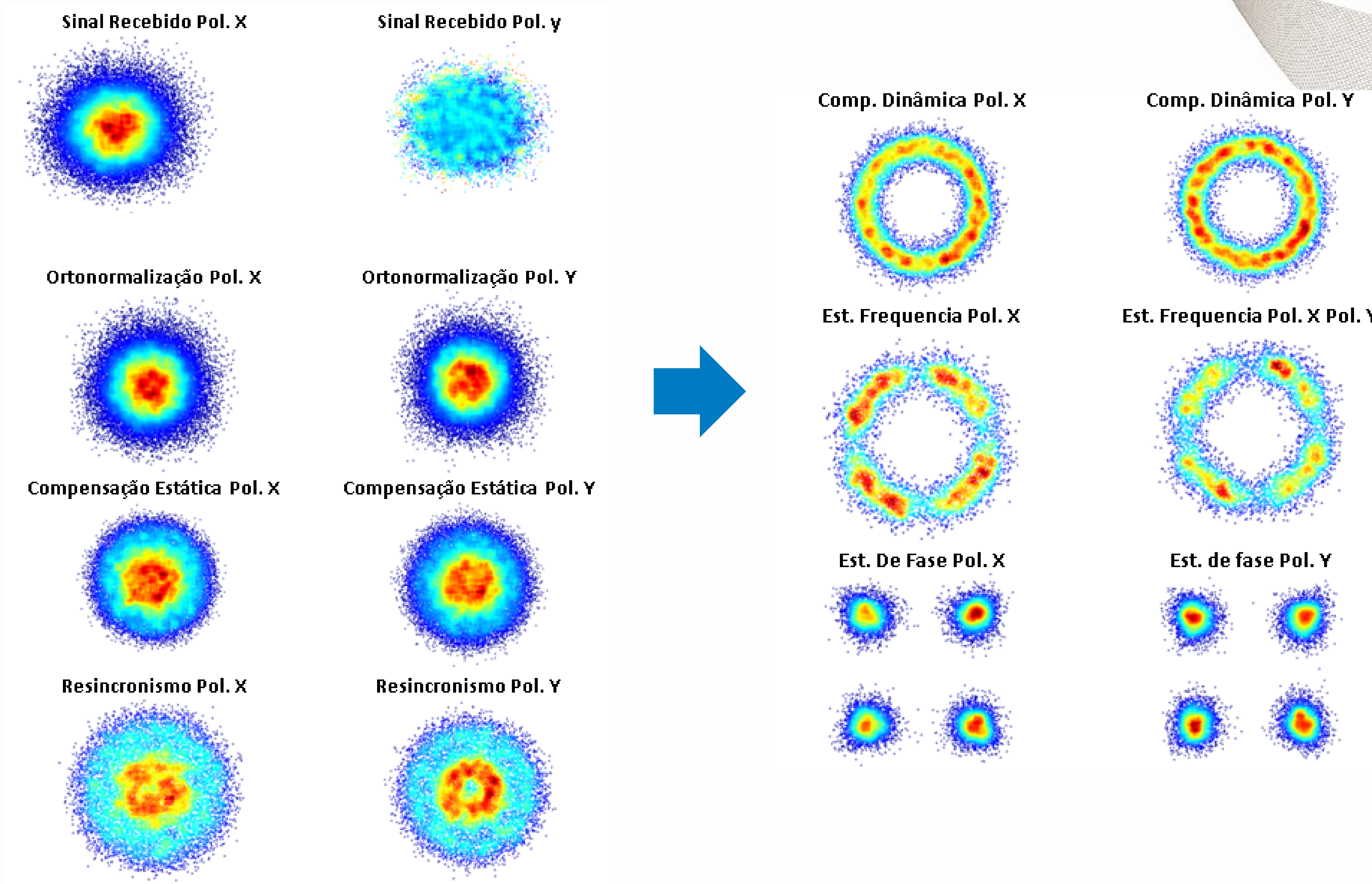




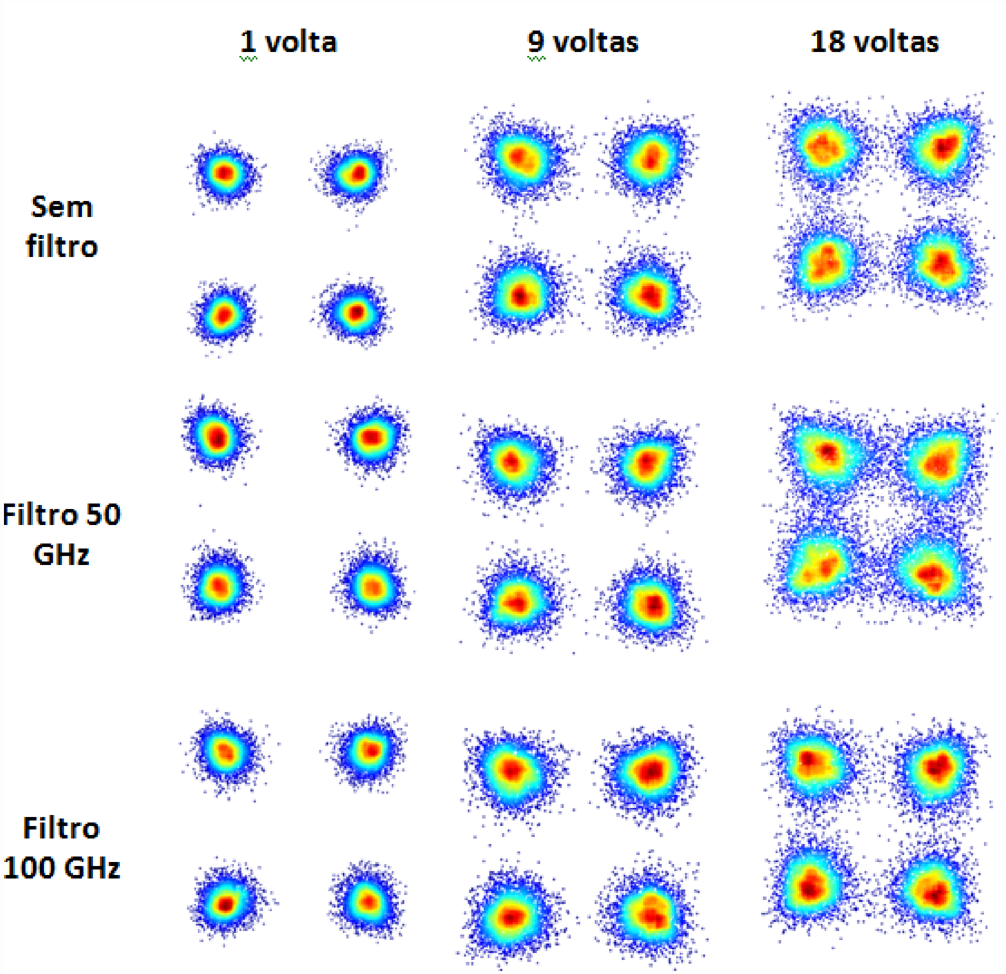


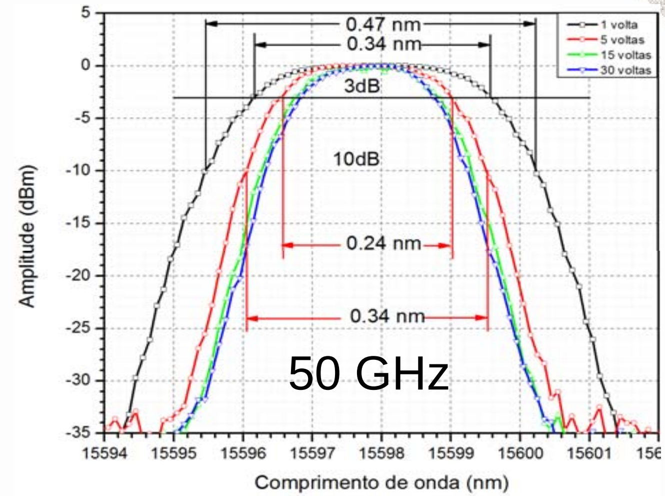


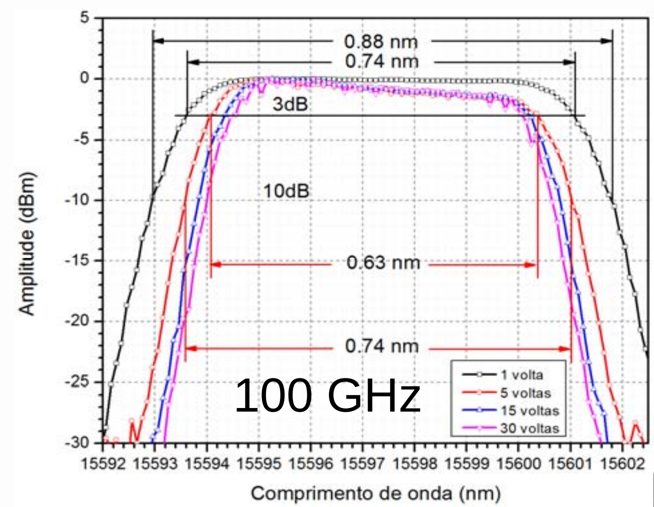
32x112G (3.58Tb/s) NRZ-DP-QPSK 4050 Km



32 x 112G DP-QPSK WDM (Tx/RX)



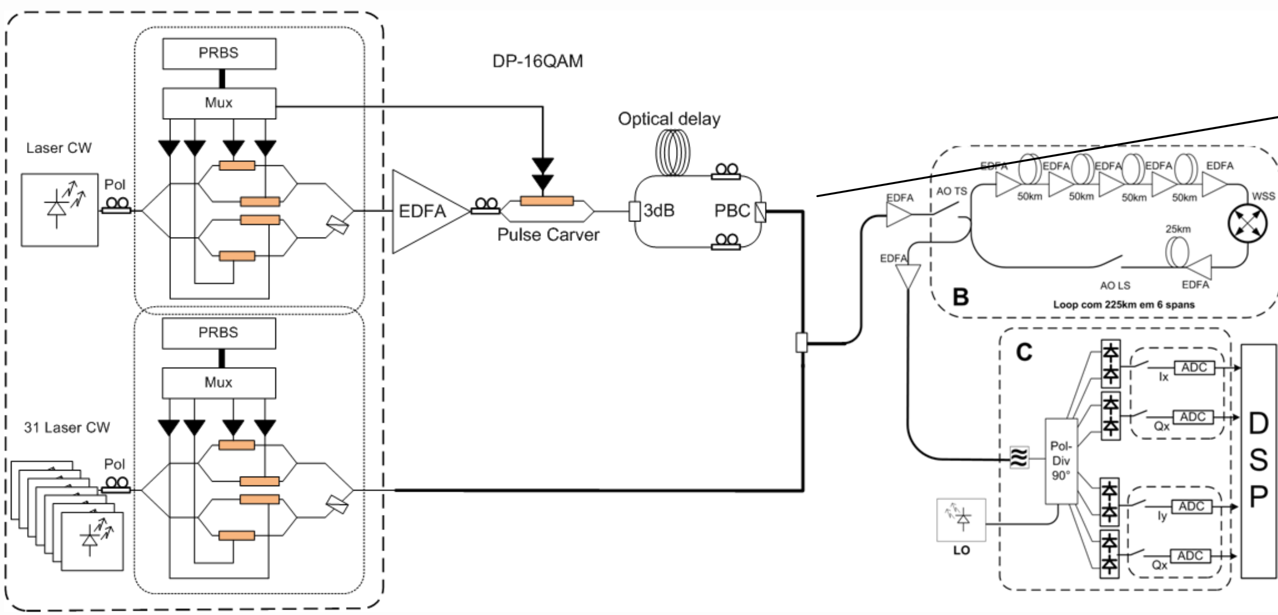


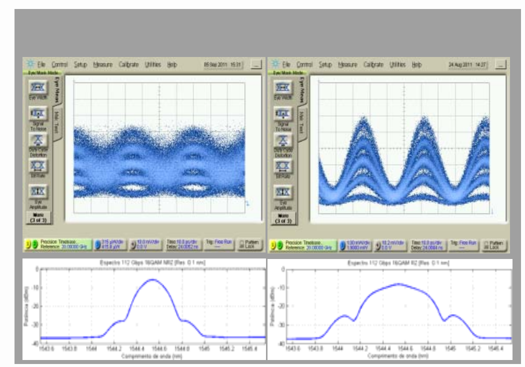


224Gbps Coherent

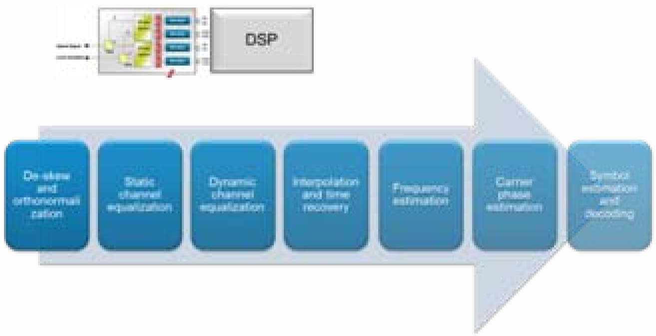
224Gbps DP-16QAM Coherent – TX side

- Phase Modulation and Polarization Multiplexing
- Spectral Efficiency: **4** bits/s/Hz
- 20 Tbps in the C-band (96 channels at **224** Gb/s)
- Fiber linear effects compensated with coherent detection and digital processing

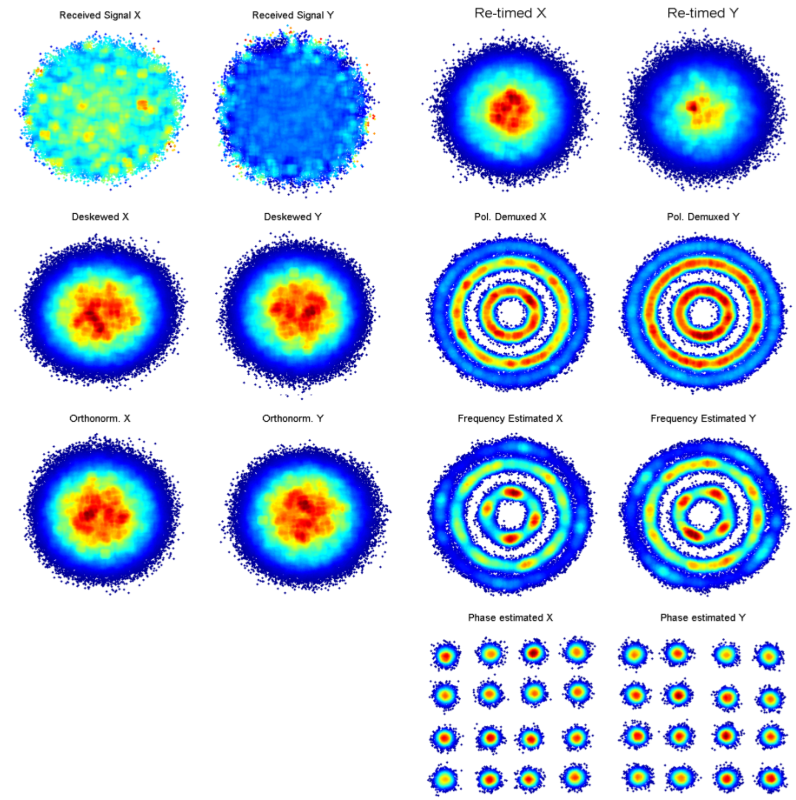




224Gbps DP-16QAM Coherent – RX side



After 1,200 km propagation



BER_{est} = 4.1075e-006

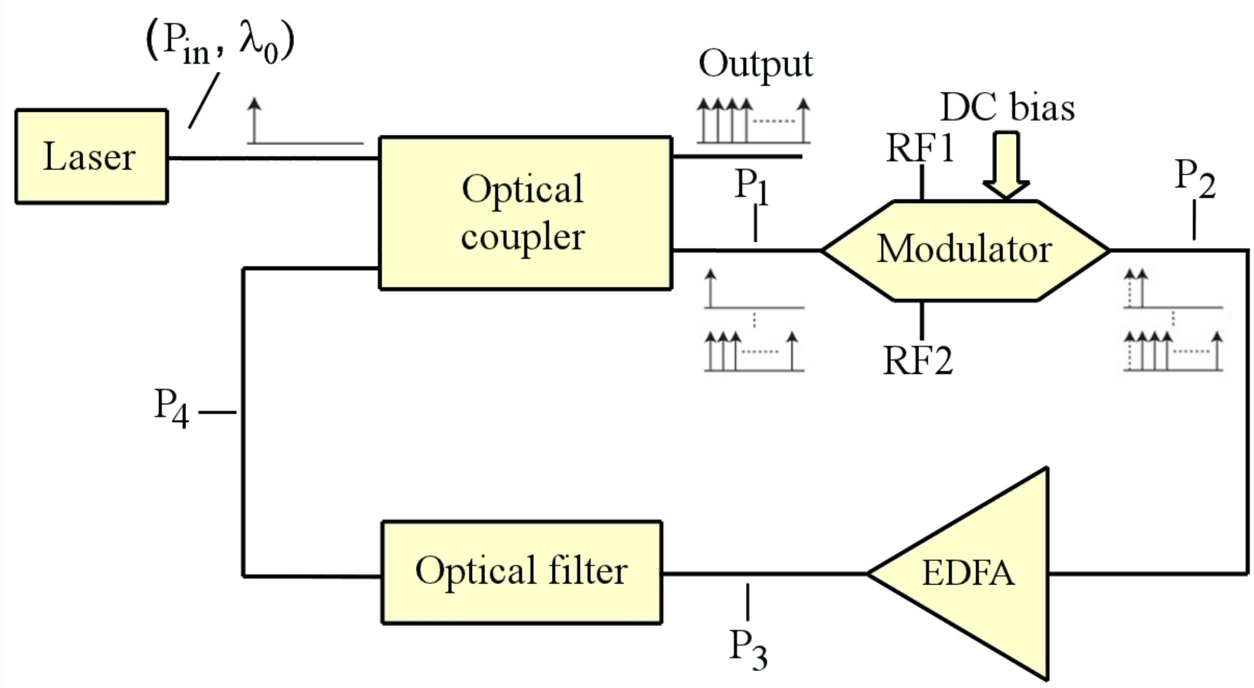
BER_{cont} = 0

Distinct information

Towards 1Tbps per channel

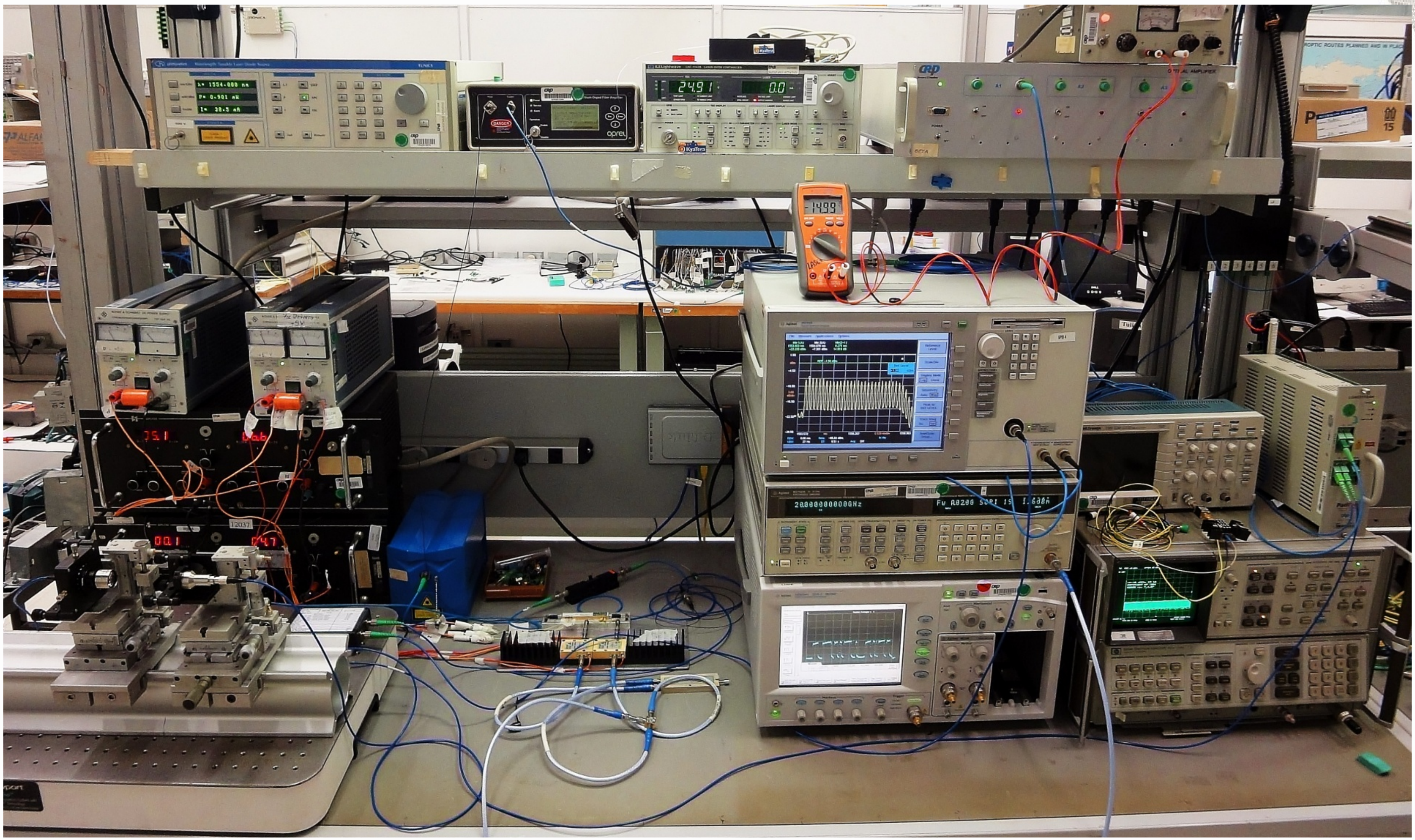
Co-OFDM – Terabit Superchannel

Diagram for superchannel generation

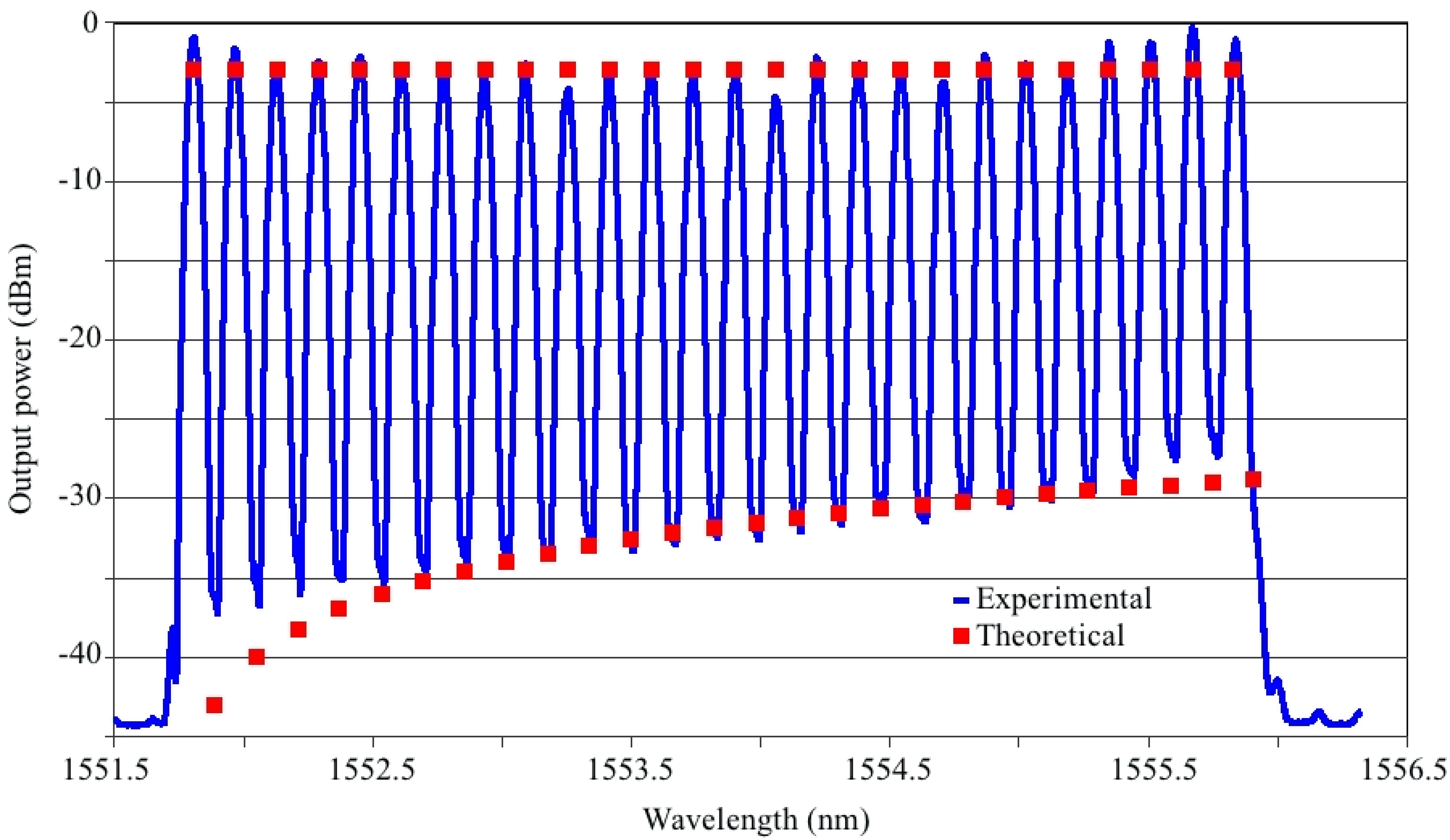


$$OSNR(n) = \frac{2 \cdot P_A \cdot \lambda^5 \cdot f_m}{(m+1)\left(\lambda_f - \lambda_0\right)\left[\left(NF \cdot \alpha_F \cdot \alpha_{ac} \cdot \alpha_m\right) - 1\right] \cdot h \cdot c^3 \cdot r}$$

Experimental Setup



Results



Output power (dBm)
0
-10
-20
-30
-40
Experimental
Theoretical
1551.5
1552.5
1553.5
1554.5
1555.5
1556.5
Wavelength (nm)

Amplification

Next Generation Optical Amplifiers

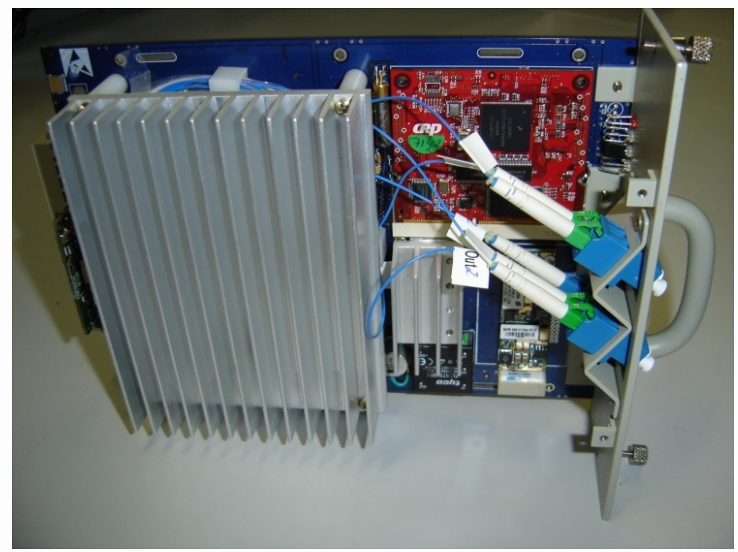
New Features for Operation at Reconfigurable Optical Networks:

i) Gain Control
ii) Transient Suppresion (us)
iii) Extended Dynamic Gain Range
iv) Gain Flatness
v) Dynamic Compensation (SHB)
vi) <u>Boosted performance to support coherent dual-polarization technologies</u>

EDFA technology quite is mature today, but not enough performance for >100Gbps systems

➔

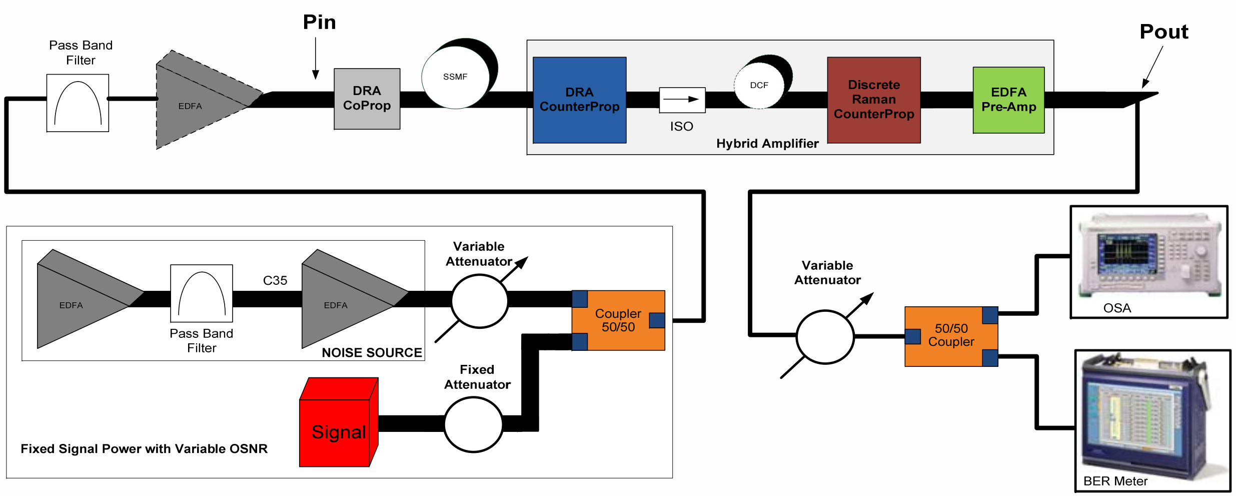
EDFA + Raman



Hybrid Optical Amplifier Research Program

- Evaluation of several technologies to compose the hybrid optical amplifier for several spans lengths;
- Several scenarios were evaluated to obtain the best topologies for:
  - BER X OSNR and BER X Equivalent Noise Figure @ 10Gbps NRZ OOK link;
  - Span of 100, 150, 200, 250 and 300 km without use of Remote EDFA;
  - Complete compensation of chromatic dispersion and residual compensation of chromatic dispersion;

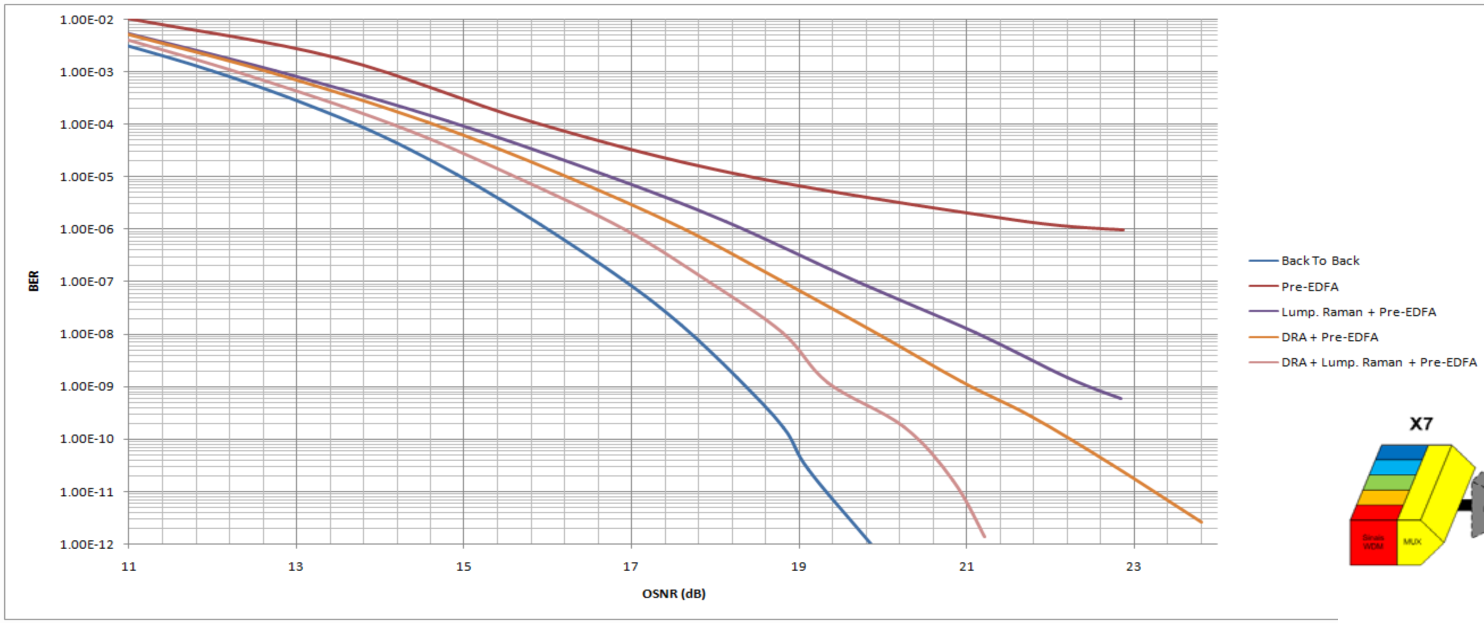
EXPERIMENTAL STATIC ANALYSIS: Hybrid Amplifier

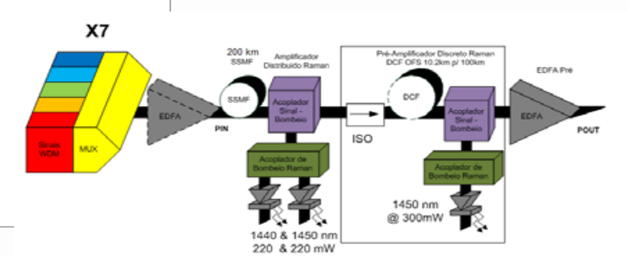


Pin Mono Channel (1549.2 nm; C35 Grid ITU) = 10 dBm; SSMF = 100/300 km; DCF OFS for 100km of SSMF

Hybrid Optical Amplifier Research Program

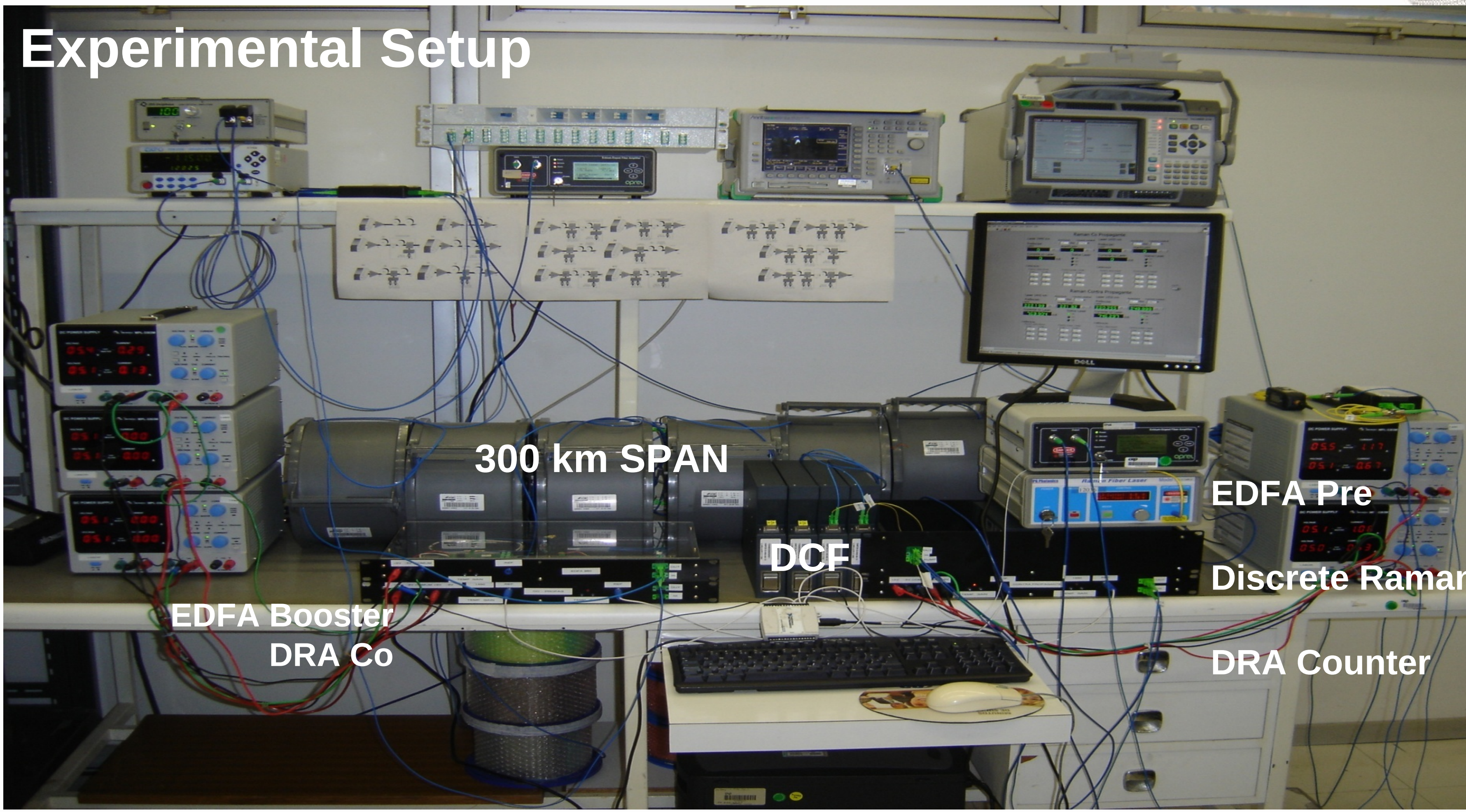
- Further steps:
  - For the best topologies for each span lenghts, find the number of spans supported using our recirculation loop;
  - Dynamic hybrid optical amplifiers analysis;
  - Evaluate the static and dynamic study of hybrid amplifiers topology for 100Gbps coherent channels comparing:
    - The best topologies for each span lenghts;
    - The best trade-of about the dispersion compensation by DCF and Digital Signal Processing DC;
    - Find the 100Gbps transmission reach using the best hybrid amplifier topology for it;





BER X OSNR for 200 km span (10G NRZ OOK)

Hybrid Optical Amplifier Research Program

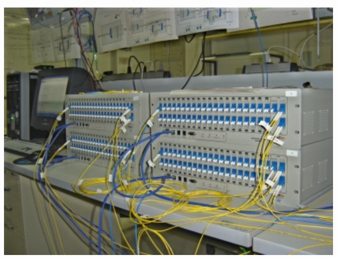


WDM Optical Transport

Optical WDM Networking – From Ring to Mesh...

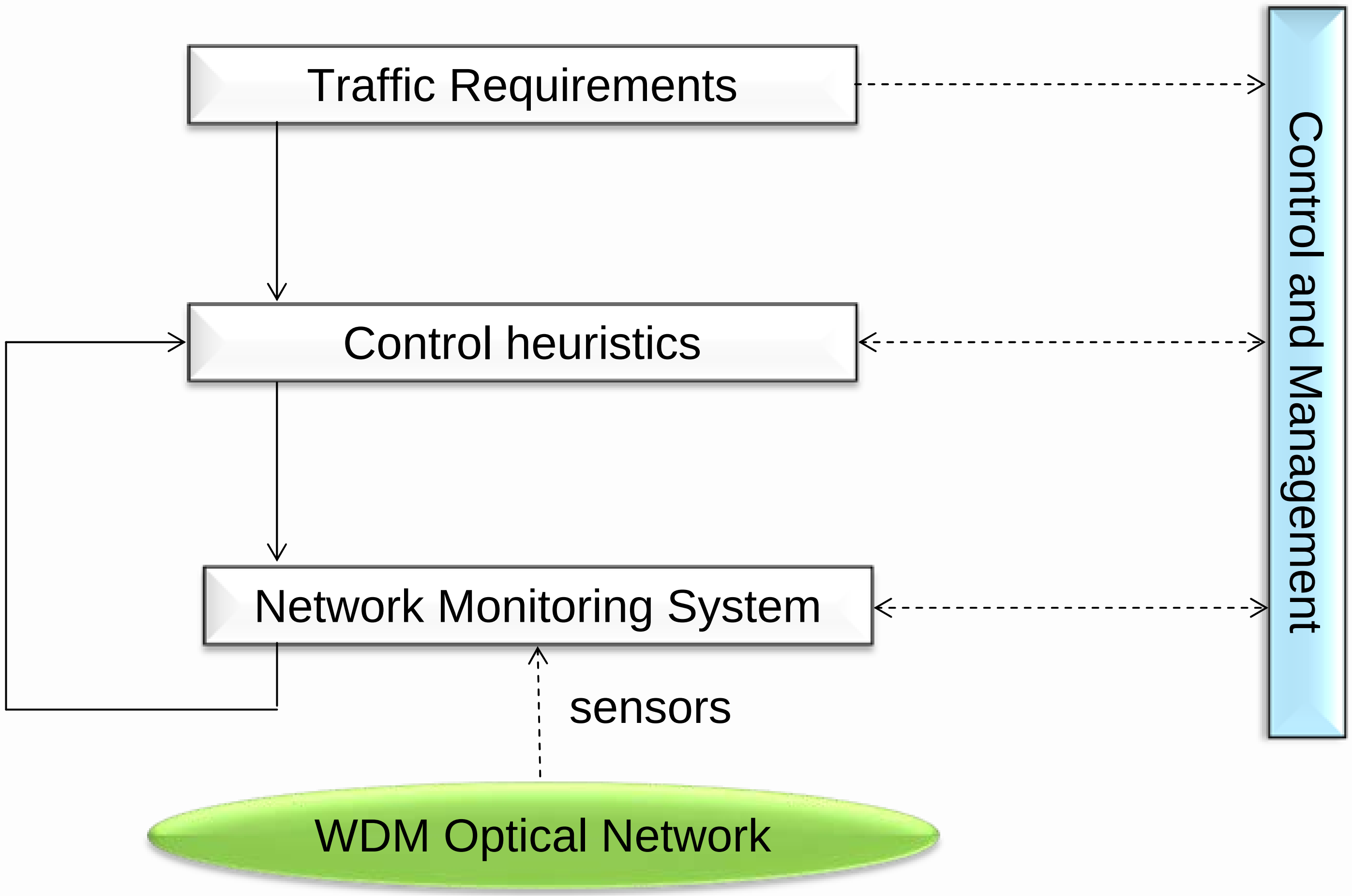
***R**econfigurable **O**ptical **A**DD/ **D**rop **M**ultiplexers*

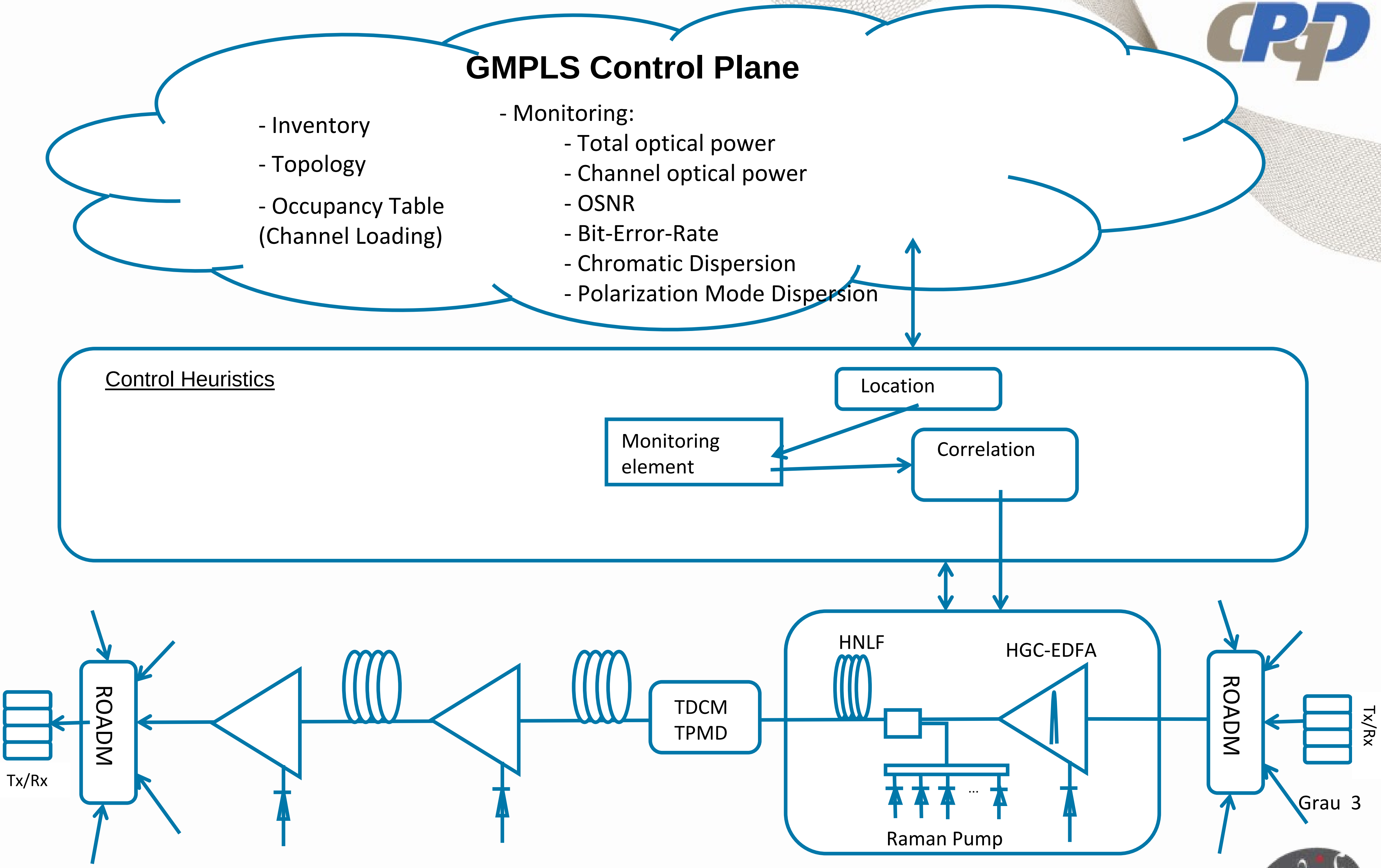
Routing without O-E-O conversion



Source: S. Matsuoka et at., NTT Technical Review August 2011

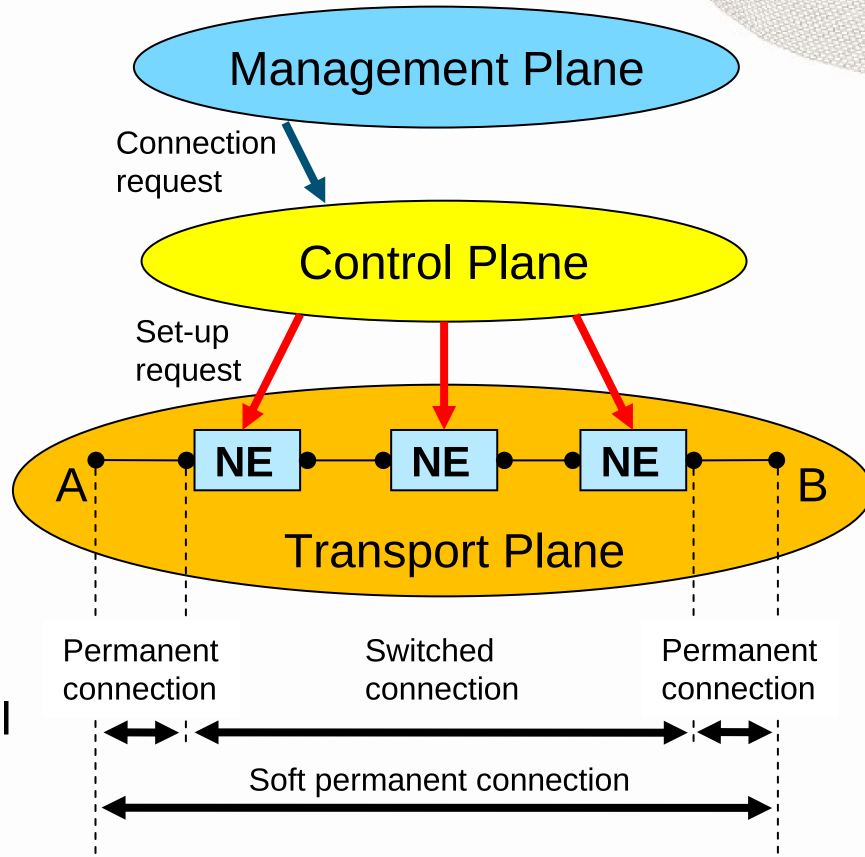
Research target




GMPLS Control Plane
- Inventory
- Topology
- Occupancy Table
(Channel Loading)
- Monitoring:
- Total optical power
- Channel optical power
- OSNR
- Bit-Error-Rate
- Chromatic Dispersion
- Polarization Mode Dispersion
Control Heuristics
Location
Monitoring
element
Correlation
Tx/Rx
ROADM
TDCM
TPMD
HNLF
HGC-EDFA
...
Raman Pump
ROADM
Tx/Rx
Grau 3

CPqD - ASON/GMPLS Control Plane

- **Multiple Switching Technologies supported**
    - Packet, container and wavelength
- **Automated Protection and Restoration**
- **Automated End-to-End Provisioning**
    - Automated LSP Setup
    - **Product Suite**
    - Excellent coverage of RFCs and Drafts
    - RWA, OSPF-TE, RVSP-TE, LMP, UNI/NNI



Source: ITU-T Rec. G. 8080

RWA

- Deterministic (based on Dijkstra's algorithm)
- Topology pre-analysis
  - Resources that don't meet certain requirements are not used
- Route post-analysis
  - Physical-impairment computations to check whether a path is feasible
- The algorithm is able to consider:
  - Transmitters availability
  - Connection restrictions (connectivity matrix)
  - Transmitter bandwidth capacity and its wavelength.

RWA – Next steps

- Use heuristic approaches
- Predict topology conditions after LSP setup
- Consider signal regeneration
  - If no path was found (using only transparent nodes), the algorithm could "prefer" some regeneration nodes.
- Consider sub-wavelength paths (for gridless networks)
  - Hierarchical LSPs
- Network reoptimization
  - Devices configuration (amplifiers, dispersion compensators, etc.)
  - Routes

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