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Simulation analysis of the physical layer in next generation all-optical networks

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Outline

- The evolution of optical networks
- Simulation of all-optical networks: critical issues and incremental approach
- OptSim: a software tool for simulation of physical layer of optical systems
- Example of design: scalability of a wavelength-routed ring network based on RINGO testbed node layout
- Simulation results
- Comments & conclusions

All-optical networks: future perspectives

Static networks → λ–switched networks → packet-switched networks

- Most vendors and carriers agree that:

1) in core networks some switching functions must be moved from the electronic to the photonics domain, to avoid the "bottlenecks" of electronic routers

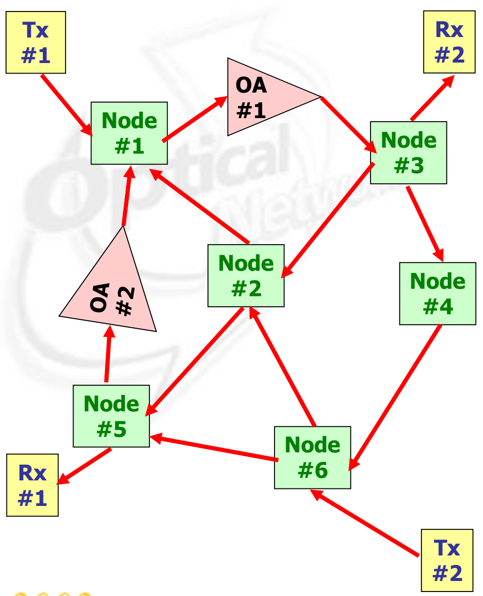
- the technology allows Terabit/s transmission capacity per fiber, but the electronic routers are not able to support it

2) Current optical component technology is (nearly) ready to allow full switching of wavelengths

- it is envisioned that in 1-2 years the first example of optically circuit-lambda switched networks will appear (MPλS - GMPLS - ASON)

3) Optical packet switching will be applied in the "real field". The open question is when (5/7 years?)

Critical issues in the analysis of physical layer



- All-optical networks can be schematically represented by an oriented "meshed" graph
- In general, the analysis of the physical layer is not anymore a set of independent problems (link analyses)
- Propagation of optical field must be studied on the overall graph
- The problem complexity grows exponentially with the graph dimensions, and its rigorous solution is almost impossible
- The analysis of physical layer of re-configurable optical networks must be split in simplified sub-problems

Spectral Analyses

1) Working point of the network

- **Static**: the working point of an all-optical network are the power spectra at each node of the network. In order to define it the most critical components are the amplifier whose behavior depends on the input power spectrum. Before doing any analysis on the network, the static working point of the network must be established.
- **Dynamic**: an all-optical network is an "all-analog" system that "behaves as a mattress". If you add drop channels in one node the working point of each of the nodes starts to oscillate. Evaluation of the transients is therefore needed.

2) Scalability issues

- This step of the network analysis can be carried on on the base of a Spectral Propagation Technique. The final objective is to establish the maximum number of nodes that can be cascaded on the basis of:
  - Accumulation of noise, crosstalk, PDL, etc..
  - Non-ideality of components, e.g., detuning of center frequencies.

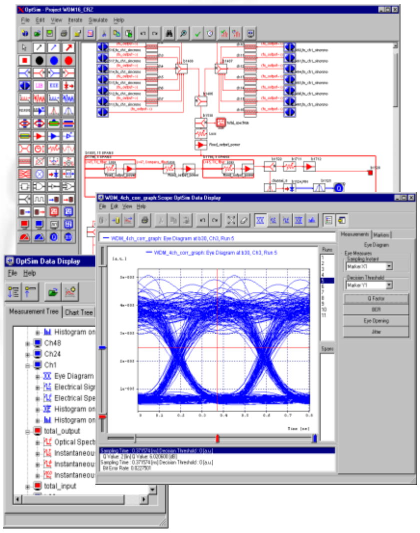
Time-domain Analyses

3) Lightpath identification and linear analysis

- After the definition of the working point of the network the analysis can proceed toward performance estimate for each lightpath
  - First, lightpath identification
  - Second, linear analysis. Considering only linear effects each lightpath can be analyzed independently of the others considering all the noise sources defined at the point 2
  - Third, performance label for each of the lightpaths.

4) Non-linear impairments of fiber propagation (dispersion, SPM, XPM, FWM, SRS)

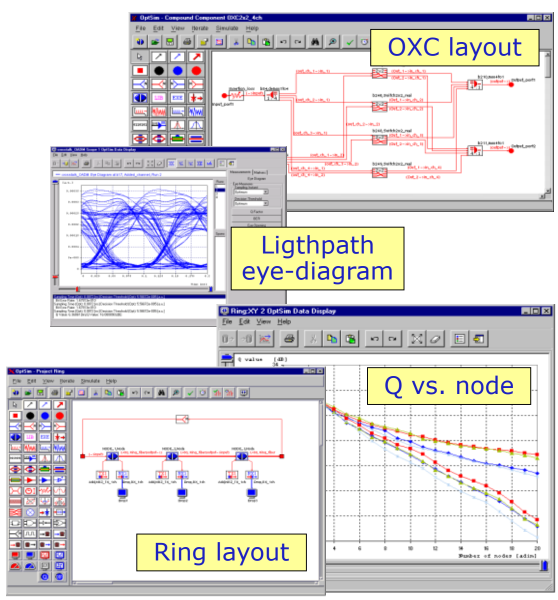
- Rigorously, the non-linear analysis of an all-optical network implies the solution of the NLSE on the overall network: multi-point boundary conditions nonlinear problem $\Rightarrow$ too complex for a system-level analysis
- Our solution is the rigorous analysis over "slices" of the whole used bandwidth considering the effects of the side-bandwidth semi-analytically using the outputs of the previous analysis stages (1,2,3)



- **Physical level simulator:**
  - DWDM/OTDM optical systems
  - Ultra-long haul links
  - All-optical networks
  - CATV/Digital/Analog systems
- **OptSim features:**
  - Accurate models and algorithms
  - Transmission impairment analysis
  - Complete set of measurements
  - Set of virtual instruments for post-processing of results
- **OptSim provides**
  - Fast learning curve & usability
  - Intuitive graphical user interface
  - Data output display & lab-like measurements
  - Reliability with large number of WDM Channels

OptSim: Network Simulation

- Pre-built, customizable network components (OXC, OADM, AWG/Mux/Demux, switch) with use of measured data
- Lightpath propagation over complex networks
- Create sub-system models and re-use them
- Ring simulation and analysis of nodes cascadability



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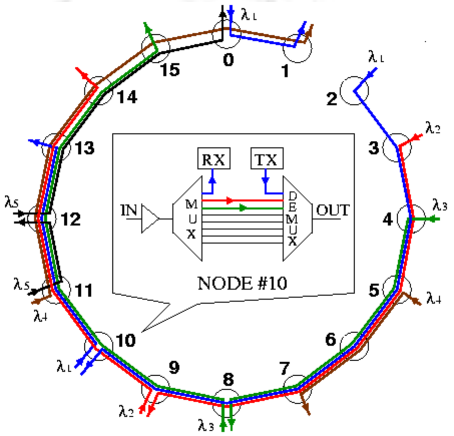
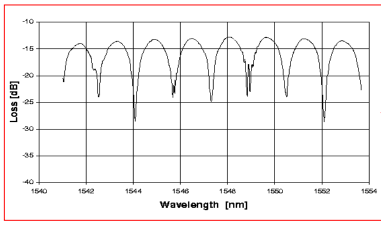
Example: design of a λ-routed ring

First realizations of all-optical networks will likely be based on ring topology



Parameter	Value
Bit Rate	10 Gbit/s
Data Format	NRZ, rising time 10 ps
WDM channel spacing	200 GHz
Length of fiber spans	25 km
Fiber Type	TrueWave® RS
Fiber Dispersion	D = + 5 ps/nm/km
Fiber Attenuation	0.2 dB/km
Passive Losses per node	20 dB
AWG filter shapes	From measurements
Amplifier gain	20 dB
EDFA noise figure	5 dB



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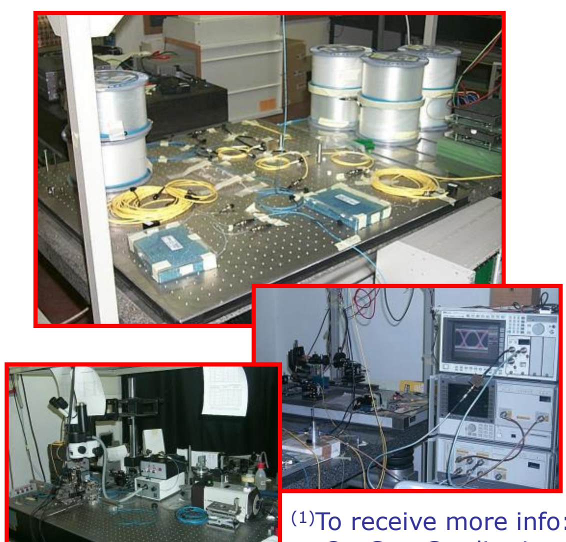
The node layout: RINGO network

- The core of the RINGO[1] project is an experimental testbed
  - Developed in the OCG lab at *Politecnico di Torino* - Italy
  - Focused on experimental demonstration of the physical layer of the proposed networks
  - Several subsystems have been developed and tested
    - Experiments on 3 nodes (see pictures)
    - **Simulations focused on the scalability of the network**



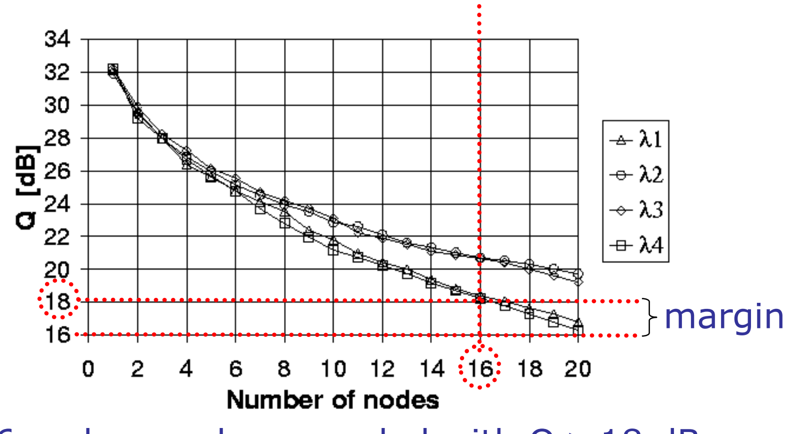
(1)To receive more info: OptCom@polito.it

Simulation-assisted design

- Problem is less complex than the analysis of a general all-optical network
  - Fixed topology with re-circulating periodic structure
  - Local-area: negligible propagation effects
- Point 1 static and point 2 can be carried on unrolling the ring
- On the basis of the results of point 1 and 2, light path analysis can be easily obtained for all the network configurations
- Whenever a lab prototype is set-up, the most important analysis is the scalability of the network
  - Use of measured data to simulate components
  - Previously described incremental analysis also scaling the network dimension (number of nodes of the ring)

Results: scalability

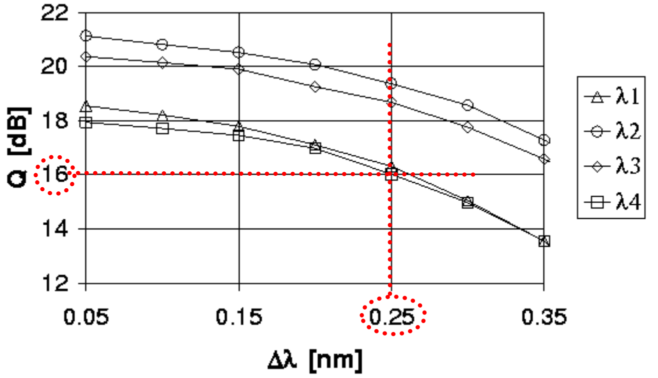
Scalability analysis taking into account self-filtering due to AWGs and ASE noise accumulation



16 nodes can be cascaded with Q ≥ 18 dB
(2 dB design margin)

Results: AWG detuning

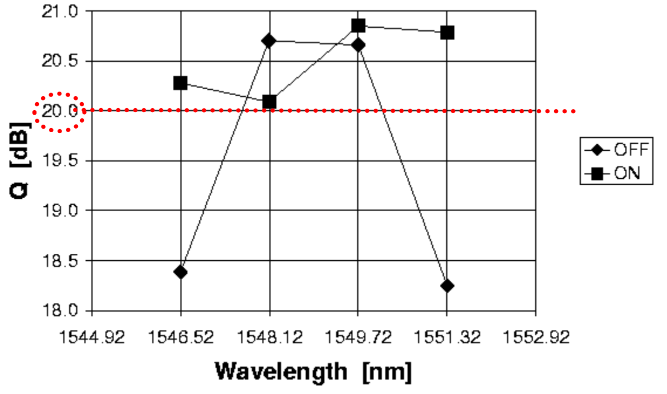
Propagation over 16 nodes: the effect of random detuning of AWGs. Results obtained using a Monte-Carlo analysis. $\Delta\lambda$ means maximum detuning



At $\Delta\lambda$=0.25 nm the 2 dB margin is all absorbed by the detuning

Results: power equalization

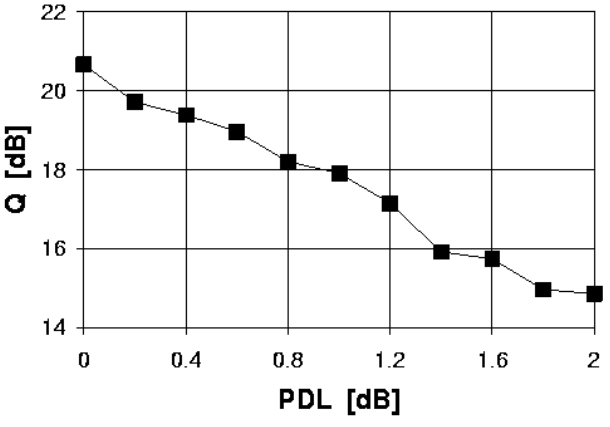
Propagation over 16 nodes with and without power equalization



Power equalization allows to operate with Q ≥ 20 dB (4 dB design margin)

Results: PDL effects

Propagation over 16 nodes: the effect of random PDL on channel at λ_2. Monte-Carlo analysis with respect to PDL



Conclusions

- The analysis of physical layer of re-configurable all-optical networks is an extremely complex problem
- It is necessary to decompose the problem: incremental approach
- OptSim can assist the designer for each of the proposed stages of the analysis
- Analysis of a λ-switched ring-network has been described. Node set-up is the one of the RINGO project
- Simulations define the scalability of the network because the prototype can be scaled up to few nodes.
- Results show the tolerance to self-filtering, AWG detuning, EDFA power equalization and PDL.