Exploiting the Transmission Layer in Logical Topology Design of Flexible-Grid Optical Networks

POLITECNICO DI TORINO

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Outline

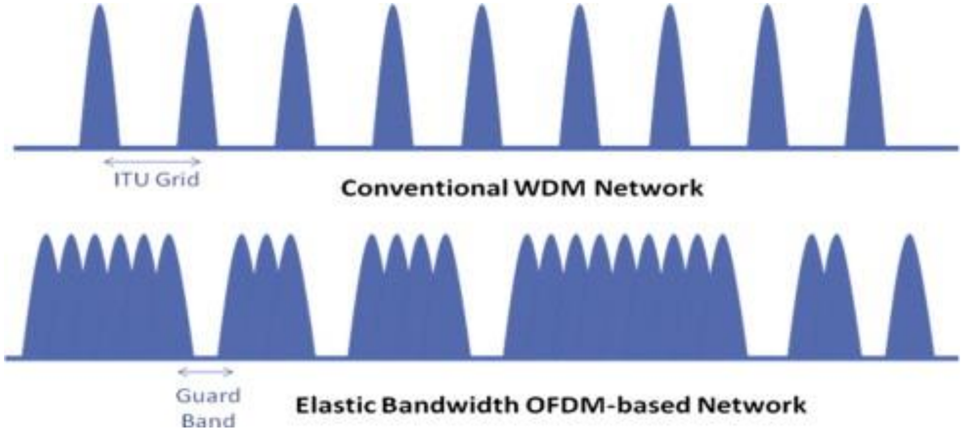
- Introduction
- Physical Layer Model
  - Physical Layer Details
  - Linear Vs. Non-Linear Model.
- Network Layer Model
  - Planning flexible-grid WDM network
  - Design Heuristic & Traffic Ordering Schemes
- Results
  - Importance of Detailed Physical Layer model
  - Hybrid Fiber Amplification
- Conclusions

Introduction

- The world-wide IP traffic is envisioned as ever increasing growth of 30% p.a. during next years [Cisco VNI 2015]
- Optical network being the cornerstone of future internet, must cope with this enormous traffic growth
- Currently, optical backbone network are based on wavelength Division Multiplexing (WDM) systems & they follow ITU fixed grid for wavelength channel allocation
- The advent of Coherent technology with Digital-Signal-Processing (DSP) enabled the use of multilevel-modulation formats
- Demand of operators are towards a maximal exploitation of the network physical – photonics – layer

Fixed-grid Vs. Flexible-grid optical networks

- Fixed-grid
  - ITU fixed spectrum grid
  - Fixed transmission rates
  - Inefficient use of spectral resources
  - Mismatch between provided and required bandwidth
- Flexible-grid
  - Flexible use of spectral resources
  - Adaptability of transmission rates to the traffic requirements
  - High spectral efficiency
  - Better match between provided and required bandwidth



J.L. Vizcaíno et al., Energy efficiency analysis for flexible-grid OFDM-based optical networks, Computer Networks, Volume 56, Issue 10

Motivations and Contributions

- Comparison of simplified and detailed physical layer model in the design of logical topology to answer the following questions;
  - What are we missing by not considering the detailed physical layer model ?
  - Can we appreciate the effect of physical layer phenomena like HFA on network design using a simplified physical layer model ?

- Studying the impact of physical layer's parameters on the network level;
  - Importance of a detailed physical layer level using Gaussian-Noise (GN) model
  - Hybrid-Fiber-Amplification (Raman with EDFA)

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Physical layer details

	Modulation Formats				ΔF (GHz)	Total # slots
	PM-BPSK	PM-QPSK	PM-16QAM	PM-64QAM		
BpS	2	4	8	12	12,5	320
R_b (Gbps/sl)	20	40	80	120		
Max # sl/ch	18	9	5	3		
$R_{b,ch}$ (Gbps/ch)	360	360	360	360		

$$SNR = \frac{1}{\sum_{i=1}^{N_{nodes}-1} \frac{1}{SNR_{i,i+1}}}$$

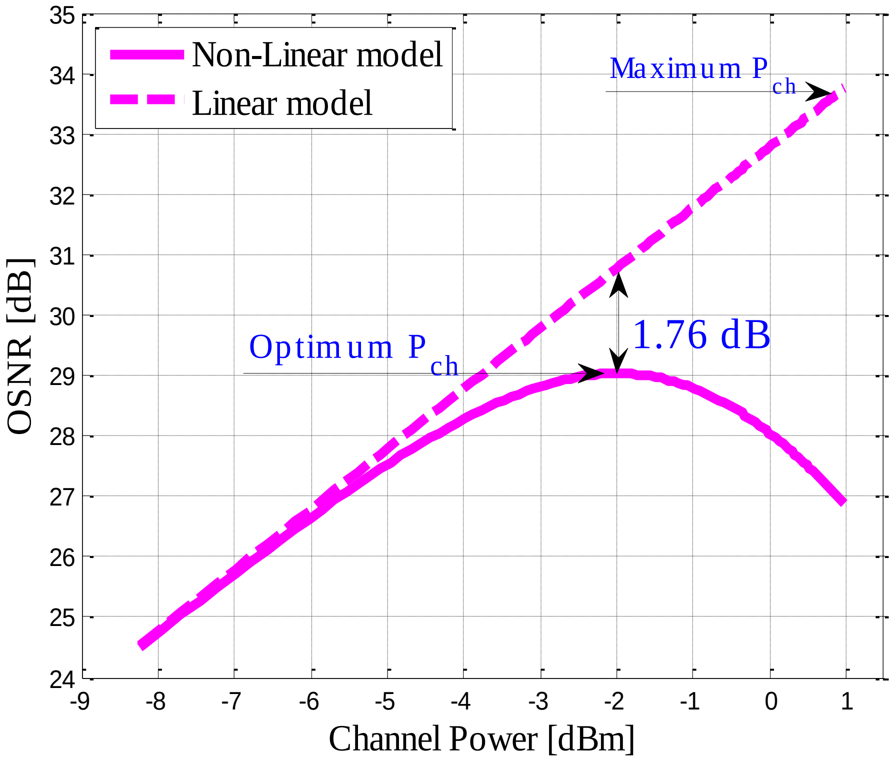
Lighpath Signal-to-noise-ratio (SNR)

$$SNR_{i,j} = \frac{P_{ch}}{N_s \left[P_{ASE} + \eta_{NLI} \cdot P_{ch}^3 \right]}$$

Point-to-point SNR

Linear Vs. Non-linear model physical layer model

- Non-linear model (NLI):
  - Uses Gaussian-Noise (GN)-model: Performance prediction tool for non-linear propagation in dispersion uncompensated Coherent systems
  - Signal **Disturbance** generated by **non-linearity** manifest itself as Additive Gaussian noise (**AGN**)
- Linear Model (LI):
  - Includes Amplified Spontaneous Emission (ASE) accumulated noise due to EDFA amplifier only
  - Ignores Non-linearity



OSNR Vs. Channel Power for linear and non-linear model

A. Carena, et al.: Modeling of the impact of nonlinear propagation effects in uncompensated optical coherent transmission links, Journal of Lightwave Technology..

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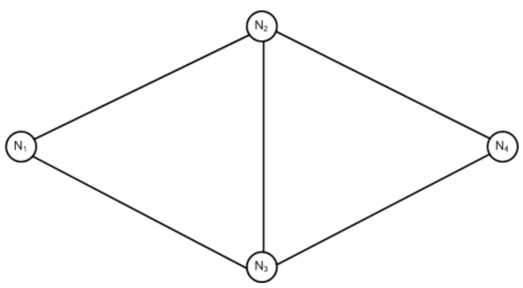
Elastic flexible-grid networks design

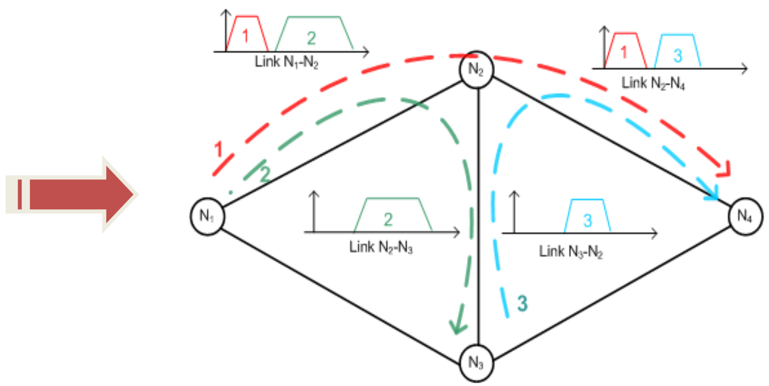
- The design of elastic flexible-grid networks is similar to WDM design
  - Logical Topology Design (LTD):
    - Find the set of lightpaths but decide also which modulation format for each lightpath
  - Routing and Spectrum Assignment (RSA)
    - Route the lightpaths and assign portion of spectrum to each lightpath
    - Spectrum is usually divided in slots, more than one contiguous slots can be assigned to a lightpath
- The sub-problems usually jointly solved
  - RMLSA (Routing, Modulation Level and Spectrum Allocation)
  - The choice of the modulation format depends on the physical length and on the available spectrum
- New design tools are required

Planning flexible-grid networks

- Input: Network topology, traffic matrix, physical layer models
  - Proposed approach: describe TxRx feasible configurations with (reach-rate-spectrum-guard band) tuples
- Output: Routes and spectrum allocation RSA (and also the modulation-level used - RMLSA)
  - Minimize utilized spectrum and/or number of transponders, and/or…
  - Satisfy physical layer constraints



$$+ \begin{bmatrix} 0 & 1 & 2 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 2 & 0 \\ 2 & 1 & 0 & 1 & 0 & 1 \\ 0 & 2 & 1 & 1 & 1 & 0 \end{bmatrix}$$



Courtesy: E. Varvargios, OFC 2013

Network Design Heuristic

- Simple heuristic chosen because the focus of the work is to discuss the influence of physical layer parameters on network performance metrics, with no major emphasis on resource allocation policies
- IP-Grooming Heuristic (IGH)
  - Each traffic demand is fulfilled by either of the two following options;
    - Establishing a new dedicated lightpath
    - Using a sequence of already established lightpaths
  - This involves changing the modulation format and/or the number of spectrum slots used, also known as SEC (Spectrum Expansion/Contraction)
  - Electronic traffic grooming among consecutive lightpaths is required
  - Incorporation of detailed physical layer model ensures the a realistic adaptation of modulation format based on lightpath OSNR

IGH with different traffic ordering policies

- We explore the impact that serving demands in different orders has on network performance.
- Six different orderings are defined using 2 parameters: The **traffic capacity $T_{i,j}$** and the **physical length $D_{i,j}$** of the ligthpath:

  I. Traffic Based Ordering
     a. Ascending order of $T_{i,j}$ **(IT).**
     b. Descending order of $T_{i,j}$ **(DT).**

  II. Lightpath Physical Path Based Ordering
     a. Ascending order of $D_{i,j}$ **(IL).**
     b. Descending order of $D_{i,j}$ **(DL).**

  III. Hybrid Ordering: Extension of IT. The ordering of the traffic demands that have $T_{i,j} = C_{max}$, which is done in ascending order of their $T_{i,j}$ **(IT-IL).**

  IV. Random Ordering **(RAN)**

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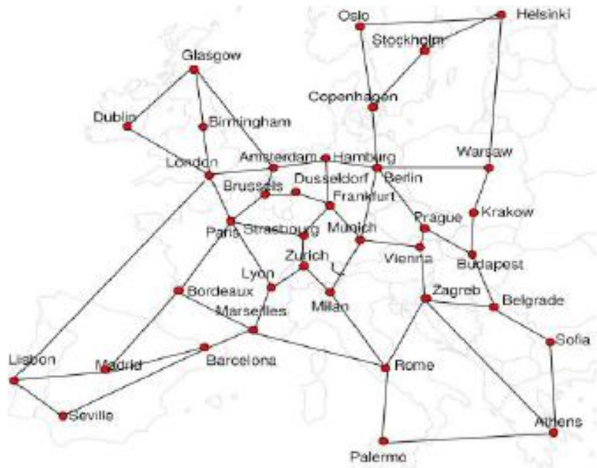
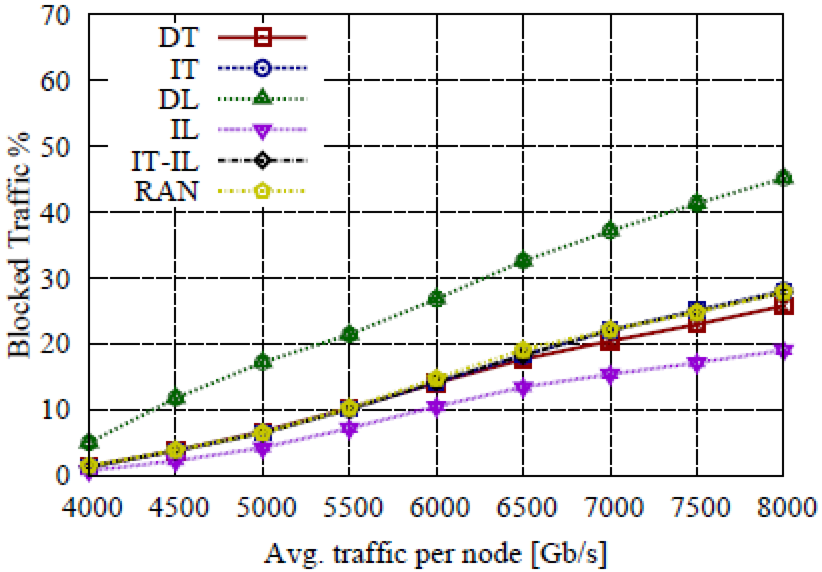
Simulation Scenario

- Performance parameters:
  - Percentage of blocked traffic, Spectrum occupancy
- Network topologies used:
  - 20 node random topology
  - Pan-European (Pan-Eu) network
- Average traffic per node :
  - Low load regime 300 to 4000 Gb/s per node(Gbn)
  - High load regime 6000 to 10000 Gb/s per node(Gbn)
- Physical Layer Models:
  - NLI
  - LI

	Pan-European			Random		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**
Distance (km)	**648**	218	1977	**1000**	93	1886
Node Degree	3,08	2	5	3	3	5



Blocked traffic for Pan-EU: NLI vs. LI



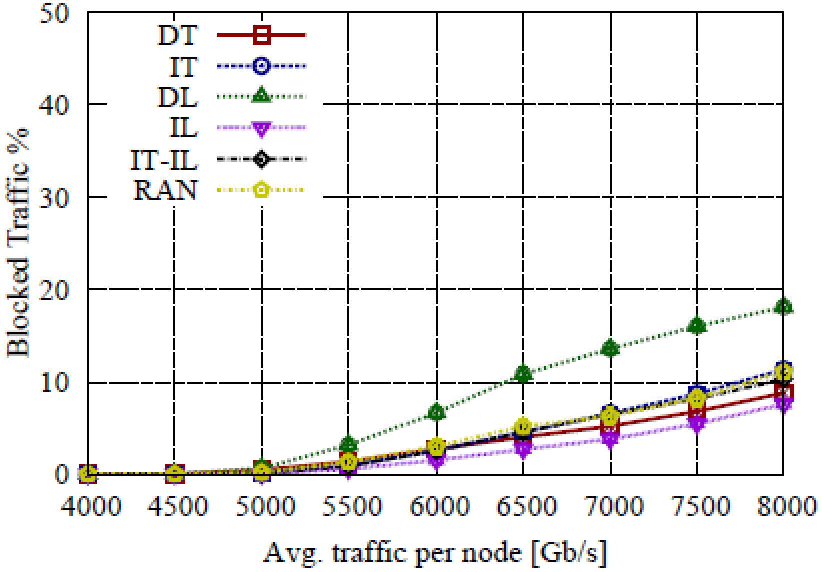


Figure: Blocked traffic vs Average traffic/node for Pan-Eu topology with NLI (Left) and LI (Right).

LI case shows a smaller percentage of blocked traffic if compared to the NLI case due to the over estimation of the SNR value.

IL clearly outperforms other ordering techniques in the NLI case, while in the LI case it performs slightly better than the others.

➔Fiber nonlinear impairments have a deeper impact for longer optical distances

Blocked traffic for Random topology with NLI vs LI

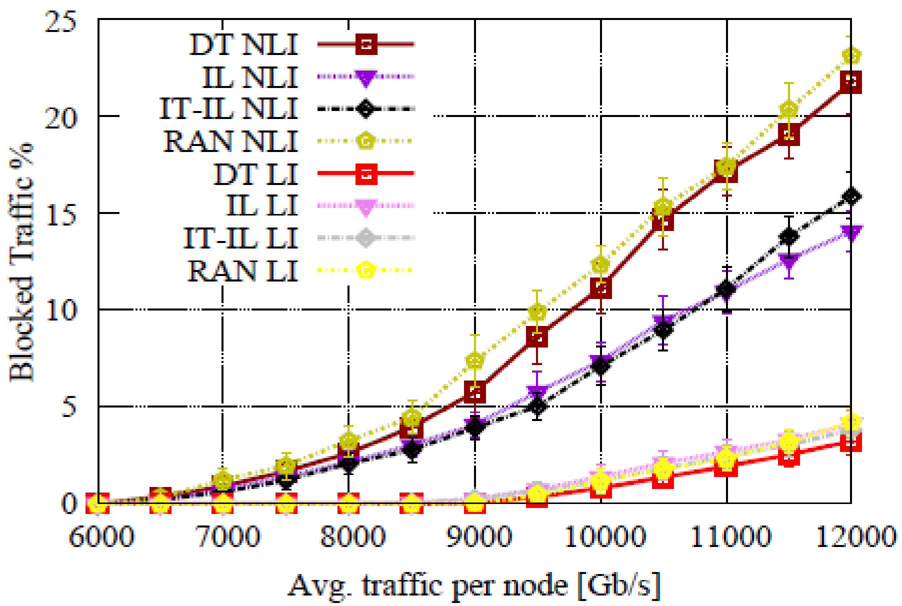


Figure: Blocked traffic vs Average traffic/node for Random 20 nodes topology

Considered Traffic Ordering Schemes:
IL, IT-IL, DT and RAN

IT-IL is more effective here as compared to Pan-Eu network

➔ A small network has more traffic demands equal to C_{max} for the same values of traffic.

➔ The IL part of IT-IL has a significant role to play, particularly at high load regime.

The advantage obtained by IL and IT-IL diminishes in the LI case

Hybrid Fiber Amplification

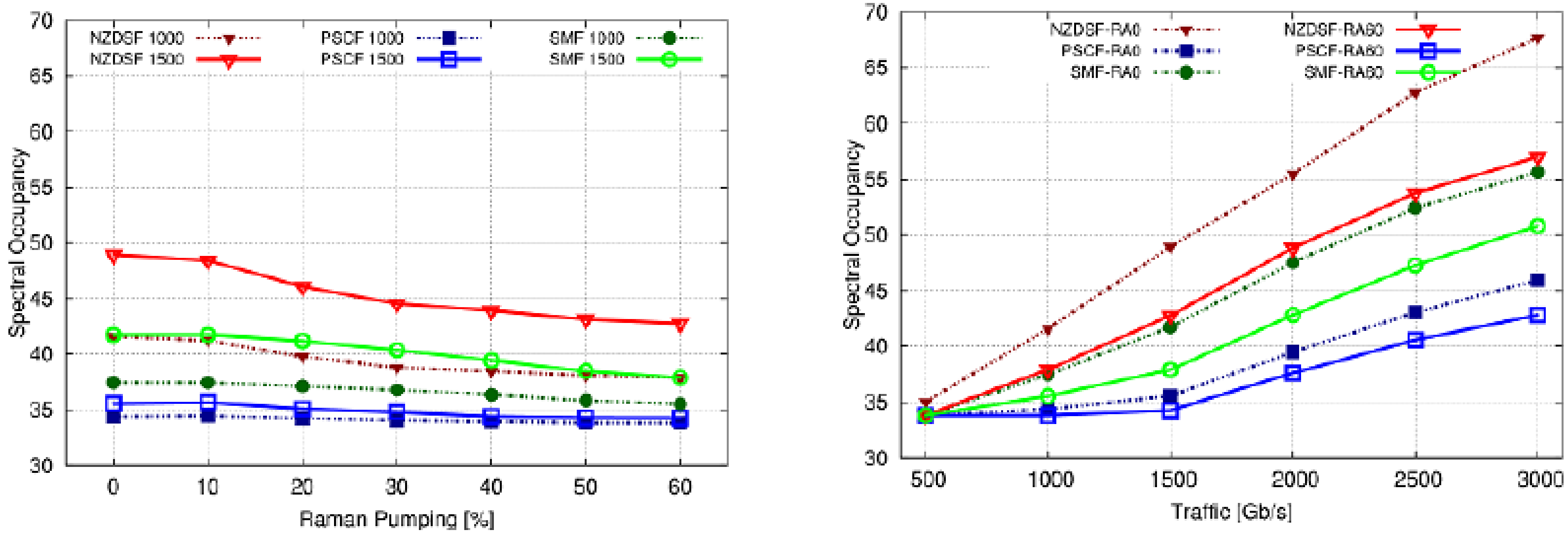


Figure: SO vs (RPL)Raman pumping level (Left) and Average traffic/node (Right)

➔ (Left) With the increase in RPL, SO decreases but advantage varies over different fibers

➔ (Right) Two levels of RPL - RA0 (EDFA only) & RA60 (HFA with 60 % Raman pumping), Again NZDSF shows highest relative SO reduction

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Conclusions

- Incorporation of a detailed transmission layer model is important to have reliability in results.
- IL is the best performing ordering policy both in terms of spectral occupancy and percentage of blocked traffic.
- The advantage of IL over other ordering policies reduces if fiber non-linear impairments are not considered.

Thank you!

Any question?

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