DATA-RATE FIGURE OF MERIT FOR PHYSICAL LAYER IN FIXED-GRID RECONFIGURABLE OPTICAL NETWORKS

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PRESENTATION OUTLINE

- Research Context and Motivation
- The Statistical Network Assessment Process (SNAP)
- Example of application
- Results
  - Flex Rate Transceivers comparison
  - NLI impact evaluation
  - NLI models comparison
- Conclusions
TWO GENERIC QUESTIONS

Can we estimate the performance of this **uncompensated link** operated with **coherent transponders**, given the physical layer technologies adopted in it?

Can we estimate the performance of this **optical network** made of **uncompensated links** operated with **coherent transponders**, given the physical layer technologies adopted in it?
TWO POSSIBLE ANSWERS

- Figure of merit: **Optical Signal to Noise Ratio (OSNR)**
- Computed through simulation or Non-Linear Interference (NLI) models

- Figure of merit: ...
- Computed through ...

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INTRODUCING THE STATISTICAL NETWORK ASSESSMENT PROCESS (SNAP)

Lightpath (LP) Demand Set

Routing and Wavelength Assignment (RWA)

Transmission Technique

Topology and Physical (PHY) layer details

Monte Carlo Simulation Engine

Statistical Assessment of Network Performance

SNAP - AN EXAMPLE OF APPLICATION

DATA-RATE FIGURE OF MERIT FOR PHYSICAL LAYER OF OPTICAL NETWORKS

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TARGET ANALYSIS

Network performance figure of merit: **Average BitRate per LightPath** $R_{b,\lambda}$

SNAP based analysis: **Monte Carlo** random loading of transparent optical network

**Network load test**: network loaded up to saturation
ALGORITHM - SINGLE MONTE CARLO RUN

Repeat until the network is fully saturated or allocation fails $N_m$ consecutive times

1. Draw nodes’ pair from uniform distribution
2. QoT routing and first fit WA
3. Assign a bitrate for each allocated LP given its OSNR and the adopted transmission technology
PHYSCIAL NETWORK MODEL AND ROUTING METRIC

LOGO
Locally Optimized Globally Optimized (LOGO) Strategy – Each link operates at optimal power

OSNR
Graph metric: Optical Signal-to-Noise Ratio (OSNR)

IGN
OSNR of LPs computed through the Incoherent Gaussian Noise (IGN) model
TRANSMISSION TECHNIQUES

OSNR vs Spectral Efficiency

- PM-BPSK
- PM-QPSK
- PM-M-QAM
- PM-16QAM
- PM-64QAM

- TDHMF Modulation Format 1
- TDHMF Modulation Format 2

Spectral Efficiency [Bbps]

Quality of Transmission - OSNR [dB]

Time
SCENARIO – PAN EUROPEAN TOPOLOGY

- 49 Nodes
- 68 Bidirectional Links
- Standard Single Mode Fiber (SSMF)
  - $\alpha_{\text{dB}}=0.2 \text{ dB/km}$
  - $A_{\text{eff}} = 80 \text{ um}^2$
  - $n_2=2.50\times10^{-20} \text{ m}^2/\text{W}$
  - $\gamma = 1.27 \text{ 1/W/km}$
  - $D = 16.67 \text{ ps/nm/km}$
- Node Loss = 10 dB
- 80 DWDM channels at 32 GBaud gross (25GBaud net) symbol rate

Link Length [km]
Average Value Convergence

Average $R_{b,\lambda}$ [Gbps] - TDHMF

Number of consecutive missed allocations

Average Value
Probability Density Function Convergence

- 100k Realizations
- 1M Realizations
- Gaussian Fit

Average BitRate per Lightpath - $R_{b,\lambda}$ [Gbps]
SYSTEM RESULTS

![Graph showing the relationship between average R_{b,\lambda} [Gbps] and displacement from optimal power [dB].]

- **PM-64QAM**
  - PM-M-QAM - W/ NLI
  - TDHMF - W/ NLI
  - PM-M-QAM - W/O NLI
  - TDHMF - W/O NLI

- **PM-16QAM**

**Key Points**

- **12% Gain**
- **8% Performance Estimation Error**
- **20% Performance Estimation Error**
- **Power Selection Error**

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**Performance Metrics**

- **Average R_{b,\lambda} [Gbps]**
- **Displacement from Optimal Power [dB]**

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**Graphical Elements**

- **OptCOM**
- **Gain**
- **Performance Error**
# NLI MODELS COMPARISON

## Incoherent Gaussian Noise (IGN) Model


## Coherent Gaussian Noise (GN) Model


## Enhanced Gaussian Noise (EGN) Model

P. Poggiolini “Recent Advances in Non-linear Fiber Propagation Modeling” OFC 2016 – Session W3I.4 - Invited Tutorial
SYSTEM RESULTS – NLI MODELING

Average Bitrate per Lightpath - PM-M-QAM - [Gbps]

- IGN: 224.2 Gbps
- GN: 222.1 Gbps
- EGN: 224.4 Gbps

Comparison: EGN is 0.2% higher than IGN, GN is 2% lower than IGN.

Computational Time for the evaluation of 100 realizations - [hours]

- IGN: 25 hours
- GN: 40 dB
- EGN: 30 hours

Comparison: EGN is 5 hours longer than IGN, GN shows a 40 dB decrease.
CONCLUSIONS

- A **new algorithm for optical networks benchmarking** was also proposed.
- **TDHMF outperforms PM-M-QAM of 12%** at optimal launch power.
  - Better continuity and granularity in BpS vs OSNR
- **8% NLI penalty** in terms of average bitrate per channel is demonstrated at network level.
- **IGN model** should be the **non-linear modeling option of choice** in reconfigurable optical networks scenarios, as its **performance** are extremely **similar to** the one obtained with the more precise, yet more computationally expensive, **EGN model**.
THANK YOU!

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NLI COMPARISON

Consider the set of allocated LPs of each realization (route and assigned modulation).

Recompute each OSNR using the GN model (integration of GN reference formula). Considering the modulation assigned when using IGN, compute the EGN correction factor.

Assign a new bitrate for each allocated LP given its OSNR and the adopted transmission technology.
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