Estimating QoT of Unestablished Lightpaths

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Outline

- Motivation
- Network model and QoT estimation
- Interference Aware QoT estimation
- Results
- Conclusion

Motivation

- In Optical Transport Networks lightpaths accumulate impairments
- Bit error ration (BER)/Quality of Transmission (QoT) metrics determine whether a lightpath is acceptable or not
- Traditional lightpaths provisioning use abundant margins to account for
  - equipment ageing
  - increased interference due to future added lightpaths

☒ High margins require regenerators and/or more robust transceivers

☑ Significant savings can be achieved by lowering the margins

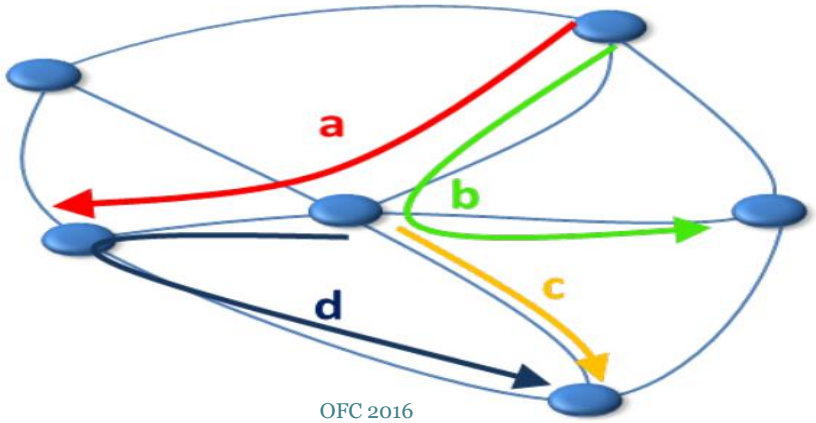
➲ Lowering the margins requires **accurate estimation of the QoT**:

  - before provisioning new lightpaths & to anticipate the QoT problems

➲ Accurate QoT estimation can also be used to optimize dynamic reconfiguration action in emerging dynamic optical networks

Contribution

- We develop a framework that correlates monitoring information from established lightpaths to estimate
  - the QoT (BER) of a new lightpath before it is established
  - the degradation the new lightpath will cause to existing ones
- Our estimation framework
  - takes into account the network utilization state, not assuming worst channel interference (as previous approaches did)
  - targets multi-rate WDM networks and can be expanded to support elastic networks



Network model

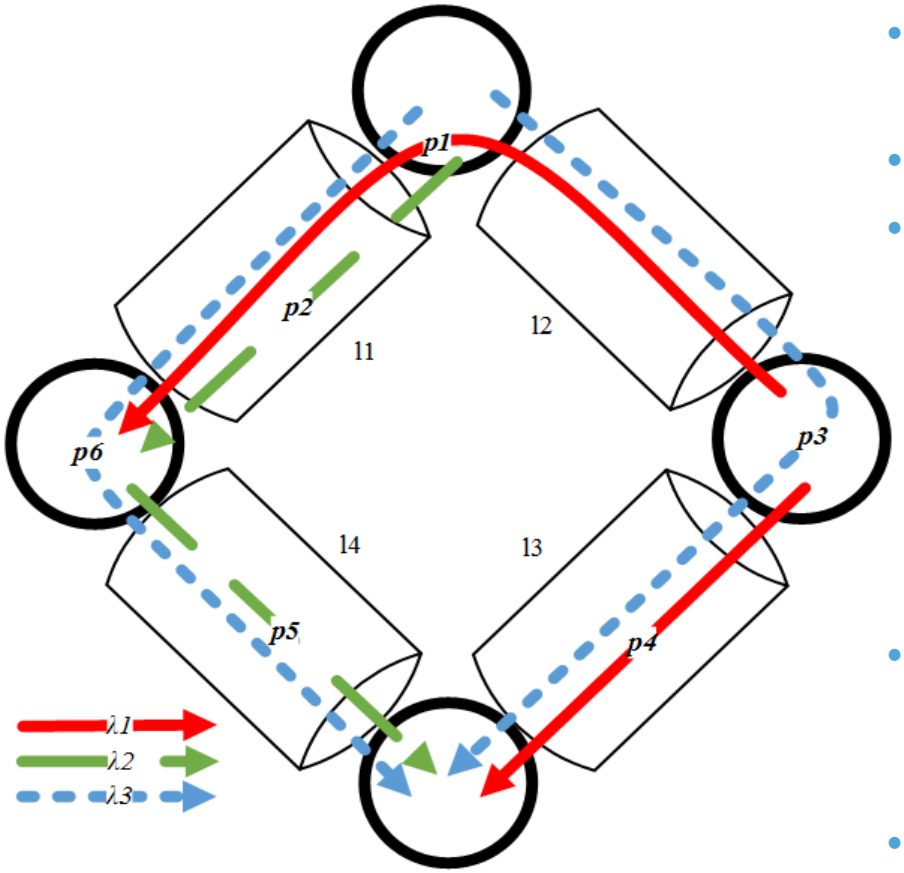
- Optical network
  - Dispersion uncompensated links
  - Coherent receivers that function as Optical Performance Monitors (OPM)
    - OPMs are located at the termination of all or some lightpaths
- OPM provides information about the SNR of the lightpath
  - SNR: accounts for all impairments, such as Amplified Spontaneous Emission (ASE), residual dispersion (Chromatic, Polarization mode), and Non Linear Impairments (NLI)
- The BER can be calculated based on the SNR value

Framework's assumptions

- Assumption: the inverse of SNR is additive per link
  - This assumption is also used in the GN model (*)
- To validate our framework we use the GN model before and after the establishment of a new lightpath:
  - Before: to get measurements of the established lightpaths SNRs
  - After: to check the accuracy of the estimation
- The estimation framework does not depend on the GN model
  - The GN model is used as the ground truth (because it is fast)
  - Real values from OPMs would be used in a real network

* P. Poggiolini, et al, "A detailed analytical derivation of the GN model of non-linear interference in coherent optical transmission systems," arXiv:1209.0394 (2012)

Estimating end-to-end parameters



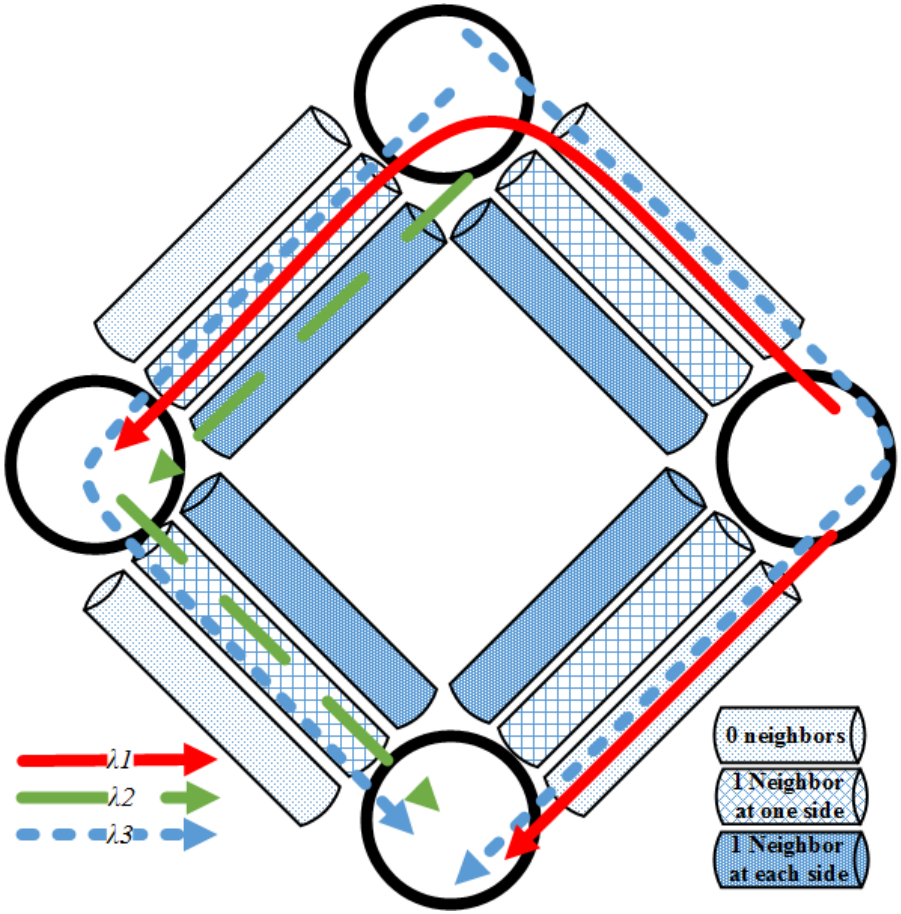
λ1,λ2,λ3: represent adjacent wavelengths

- G $\{0,1\}^{PxL}$:Routing matrix of lightpaths $G_{p,l}$=1 when lightpath p uses link l
- **x**: vector of *link-level* parameters (unknown)
- **y**: vector of *end-to-end* parameters
  y is a linear combination of **x**

  $$[\mathbf{y'}_m\ \mathbf{y'}_n]=[G'_m\ G'_n]\ \mathbf{x},$$

  where ***m*** represents the lightpaths for which monitoring data is available, and ***n*** the new lightapth(s) whose parameter should be estimated (assuming known routing G_n)
- Estimating the unknown $\mathbf{y'}_n$ can be done using Network Kriging (NK) or Norm Minimization (NM)
- Parameter: 1/SNR

Interference Aware QoT estimation



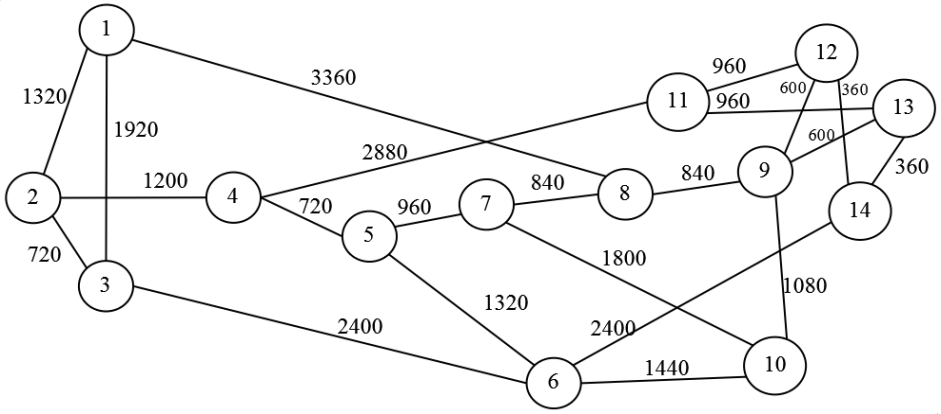
- The previous notation does not take into account the interference
- To do so we construct a new interference aware graph (IA-graph)
- We assume that lightpaths that have the same number and position of neighbors exhibit equal interference
- Every link is replaced by Interference Aware links (IA-links) that represent
  - the number and position of the neighboring channels
  - the baud-rate (in case of multi-baud-rate networks)
- The lightpaths are rerouted depending on their neighbors on each link

Interference Aware QoT estimation

- We run NK or NM on the interference aware (IA)-graph, so that the calculated SNR (and BER afterwards) takes into account interference
- The columns of routing matrix G represent the IA-links, while vector **y** (the end-to-end parameters) is not changed
- We assumed 2 neighbors from each side, since they contribute the most to the interference
- We use a database (DB) to store past measurement data
  - Store the end-to-end values (SNR), along with the IA-links that were used
- Our framework can estimate how the new lightpath affects the previous established ones
  - The insertion of the new lightpath changes the IA-links used by some existing lightpaths
  - We use our estimation framework to calculate the QoT of these lightpaths

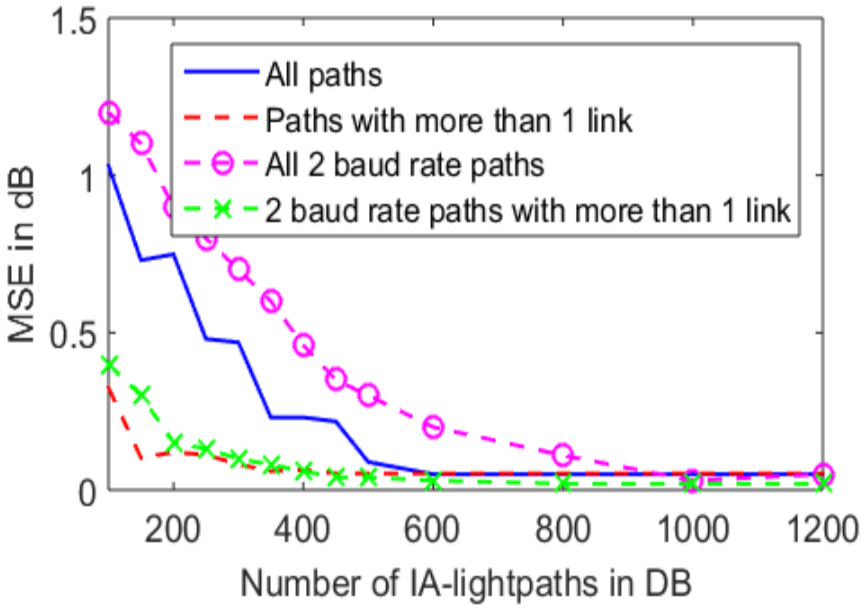
Performance results

- We evaluate the accuracy of the estimation and then we translate that into savings of regenerators
- NSFNET topology
- 100G PM-QPSK with (i) 28 Gbaud and (ii) 28 and 32Gbaud
- Poisson lightpath arrivals with exponential duration
- Database keeps monitored values and is updated when new lightpaths are established
- We obtain the BER estimate for every new lightpath and then compare it to the value that the GN model provides



Estimation accuracy

- Error decreases as DB size increases
- Large errors occur mainly at single link lightpaths, so are negligible
- DB fills very quickly: a single lightpath establishment creates many entries, since it affects the IA-links of many existing lightpaths
  - 600 IA-lightpaths translate to ~170 lightpaths in the original network

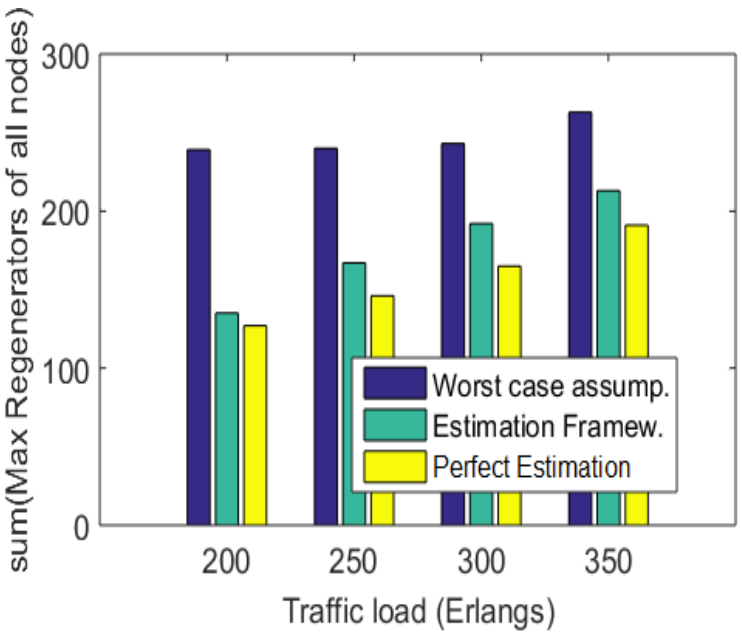


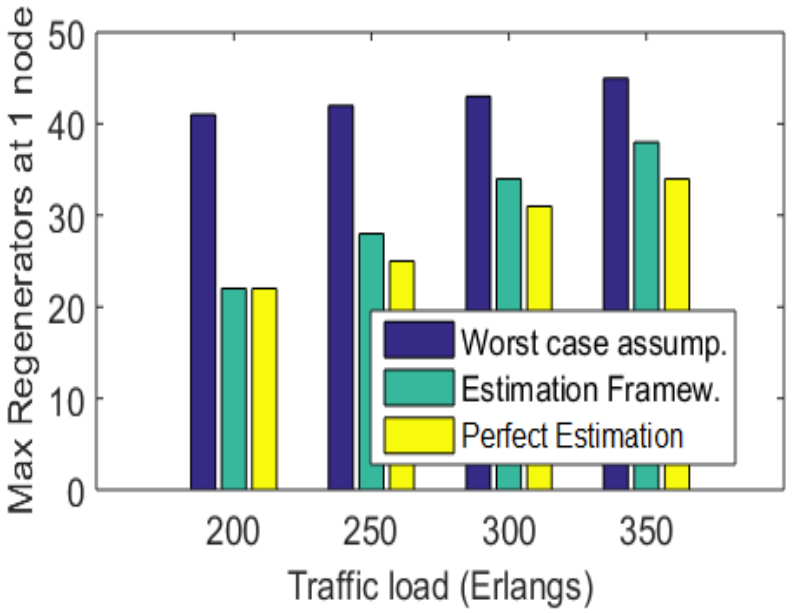
- Maximum underestimation: 0.1dB (1000 IA-lightpaths & 1 baud-rate)
- Maximum underestimation is used as a margin

Regenerators savings (1/2)

- Regenerator savings: the following scenarios are compared
  - Estimation framework: use the framework to estimate the QoT and provision lightpaths with actual margins
  - Perfect estimation: establish lightpaths, measure the QoT and then install regens
  - Worst case assumption: provision lightpaths with worst case interference margins
- A regenerator is placed whenever the BER is larger than the predefined threshold (10^{-2} before FEC)
- Our estimation framework can provide up to 4.10^{-2} (1.4 dB) lower BER estimations when compared to the worst case assumption (taking into account the 0.1dB margin used for the estimation error)

Regenerators savings (2/2)





- Our estimation framework requires
  - up to 47% less regenerators than the worst case scenario,
  - only up to 5% more than the perfect estimation case
- As the network load increases, more lightpaths are concurrently active and thus interference increases and QoT becomes equal to the worst case scenario

Conclusion

- We presented a novel framework that takes into account the interference of neighboring channels to provide an accurate QoT estimation for the establishment of new lightpaths
- The framework was shown to provide quite accurate QoT estimations
- Accurate estimation can increase the network efficiency, enabling network operation with reduced margins, closer to current conditions, and can also enable optimized dynamic reconfiguration actions
  - We showed that using the estimations can lead to significant regeneration savings compared to provisioning under worst case assumptions
- Future work includes the support for elastic networks and the estimation under measurement uncertainties

Questions?

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Backup slides

Network scenario

- New lightpath (or a batch of lightpaths) to be established
- RWA: shortest path and first available wavelength
- For a candidate path-wavelength we use the framework
  - To estimate the QoT before it is established under current network conditions (ageing & interference)
  - To estimate the interference effect to established lightpaths
  - If the QoT of the candidate path-wavelength is infeasible or using that turns infeasible some established lightpath
    - we examine the next free wavelength
    - If there is no more free wavelength, a regenerator is placed at an intermediate node