Migration Strategies from C band to C+L Band in Optical Backbone Network

NetLab Group Meeting

Friday, January 31, 2020

14-node NSFnet Network

C band everywhere 5 THz
Incremental Traffic
Worst Case Noise Model

Noise Model

- A lightpath **optical signal-to-noise ratio (OSNR) estimation model** that considers nonlinear interference **(NLI)** due to inter-channel stimulated Raman scattering **(ISRS)** and amplified spontaneous emission **(ASE)** noise generated by in-line amplifiers
- ISRS is a phase-insensitive power transfer that **amplifies** lower-frequency components and **depletes** higher-frequency components
- In C + L band network operation, this process needs to be considered in order to reasonably predict the increase in **network capacity**

OSNR Estimation Model

- Multiple ROADMs, optical links and EDFA
- In line EDFA compensates for previous span loss and ISRS gain
- Amplified spontaneous emission (ASE) : noise from EDFA and ROADM
- NLI: Self-phase modulation + Cross-phase modulation + ISRS gain

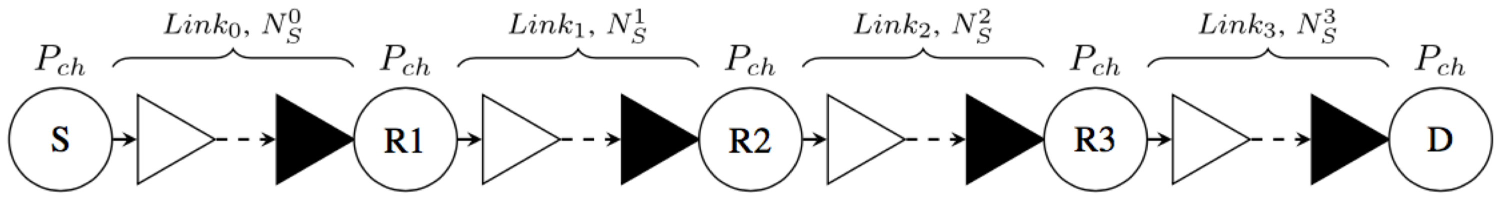


Fig. 1. Multihop path for OSNR estimation.

A. Mitra, D. Semrau, N. Gahlawat, A. Srivastava, P. Bayvel, and A. Lord, "Effect of reduced link margins on C + L band elastic optical networks," *J. Opt. Communication Networks,* vol. 11, no. 10, pp. C86-C93, Sept. 2019.

OSNR Estimation Model

- OSNR of a network lightpath operating at a particular frequency is calculated

$$\frac{1}{\mathrm{OSNR}(f)} = \sum_{i=0}^{N_L-1} \left(\frac{P^i_{\mathrm{ASE}}(f) + P^i_{\mathrm{NLI}}(f)}{P_{\mathrm{ch}}} \right) + \left(\frac{P^R_{\mathrm{ASE}}}{P_{\mathrm{ch}}} \right) N_R. \quad (1)$$

- $P^i_{ASE}(f)$ is the total amplified spontaneous emission (ASE) noise from the in-line EDFAs in the *i*-th optical link
- $P^i_{NLI}(f)$ is the NLI power in the *i*-th optical link (self-phase modulation (SPM) and cross-phase modulation (XPM)
- P^R_{ASE} is the ASE noise generated at the ROADM post ASE amplification
- N_R is the number of intermediate ROADM nodes traversed by a lightpath

A. Mitra, D. Semrau, N. Gahlawat, A. Srivastava, P. Bayvel, and A. Lord, "Effect of reduced link margins on C + L band elastic optical networks," *J. Opt. Communication Networks,* vol. 11, no. 10, pp. C86-C93, Sept. 2019.

Inter-Channel Stimulated Raman Scattering (ISRS)

- *Power transfer between high-frequency optical signal to low-frequency optical signal sharing the same fiber that amplifies low-frequency signals and depletes higher-frequency ones*

ISRS gain at frequency f,

$$\rho(z, f) = \frac{P_{\mathrm{tot}} e^{-\alpha z - P_{\mathrm{tot}} C_r L_{\mathrm{eff}} f}}{\int G_{\mathrm{Tx}}(\nu) e^{-P_{\mathrm{tot}} C_r L_{\mathrm{eff}} \nu} \mathrm{d}\nu}. \qquad \textbf{(2)}$$

P_{tot} is the total signal power, G_{Tx} is the power spectral density, C_r is the Raman gain slope, α is the attenuation, L_{eff} is the effective length of link

A. Mitra, D. Semrau, N. Gahlawat, A. Srivastava, P. Bayvel, and A. Lord, "Effect of reduced link margins on C + L band elastic optical networks," *J. Opt. Communication Networks,* vol. 11, no. 10, pp. C86-C93, Sept. 2019.

Lightpath Allocation

Before allocating a 100 Gbps demand,

- Single shortest path is found
- Network OSNR estimation model is used to predict OSNR of the lightpath
- Modulation formats selected based on calculated OSNR & OSNR threshold
- After new lightpath allocation, OSNRs of active lightpaths sharing same link are updated
- An attempt is made to re-accommodate demands of any degraded lightpath

Table 3. OSNR Threshold

Modulation	Data Rate (Gbps)	OSNR Threshold
PM-BPSK	50	9 dB
PM-QPSK	100	12 dB
PM-8QAM	150	16 dB
PM-16QAM	200	18.6 dB
PM-32QAM	250	21.6 dB
PM-64QAM	300	24.6 dB

PM-QPSK = 25 (symbol/sec) * 2 (bit/symbol) *2 (polarization) = 100 Gbps

PM-16QAM = 25 * 4 * 2 = 200 Gbps

PM-BPSK = 25 * 1 * 2 = 50 Gbps

PM-32QAM = 25 * 5 * 2 = 250 Gbps

PM-64QAM = 25 * 6 * 2 = 300 Gbps

A. Mitra, D. Semrau, N. Gahlawat, A. Srivastava, P. Bayvel, and A. Lord, "Effect of reduced link margins on C + L band elastic optical networks," *J. Opt. Communication Networks*, vol. 11, no. 10, pp. C86-C93, Sept. 2019.

Migration Strategies for C+L Upgradation

Shortest Path, First-fit

1% blocking is experienced

Migration Strategy (1)

- When the 1% blocking is observed for a connection request
- Upgrade the entire path to L band

Migration Strategy (2)

- When the 1% blocking is observed on for a connection request

1. Calculate the **fill factor** of each link on the path
2. Calculate the **fragmentation** of the links on the path
3. Find the congested link/links
4. Avoid those congested link/links and reroute the traffic (maintaining the OSNR)
5. If rerouting is not possible (OSNR degrades), upgrade the path to C+L
6. Route the traffic in L band

Migration Strategy (3)

- When the 1% blocking is observed for a connection request

1. Calculate the **fill factor** of each link on the path
2. Calculate the **fragmentation** of the links on the path
3. Find the congested link/links
4. Avoid those congested link/links and reroute the traffic (maintaining or degrading the OSNR)
5. If rerouting is not possible, upgrade the path to C+L
6. Route the traffic in L band

Mixed C and C+L Links

Now the OSNR Estimations Change (drops)
As the number of C+L band links grows (?)

Migration Strategy

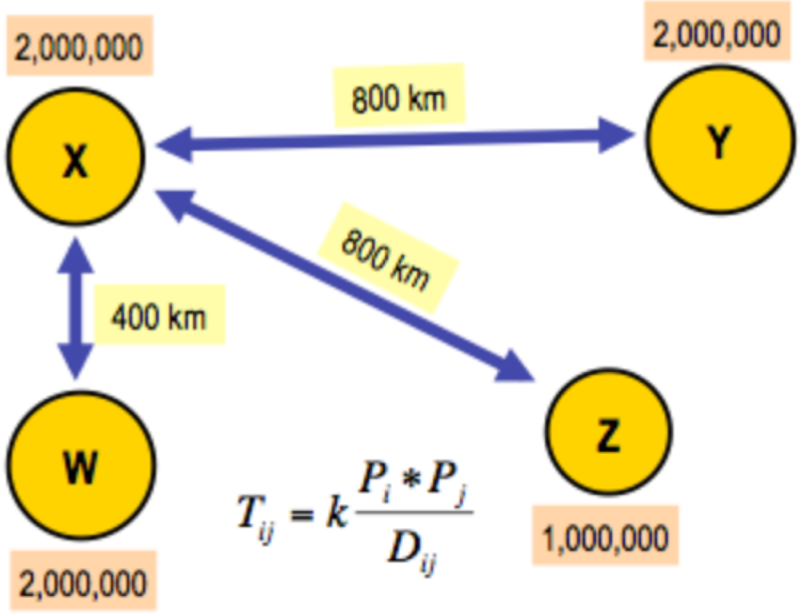
- Continue with previous three migration strategies with new OSNR estimations

Results

- In results there will be a notion of time, we track which strategy started the upgradation first, 2nd and 3rd
- Which links needed to be upgraded for all three strategies
- Once the most congested links are located, we can modify the RSA to avoid those links when allocation lightpaths, that would be another migration strategy (4)
- Cost of upgradation needs to calculated. Overall cost for each strategy can be shown

Gravity Model for Biased Traffic

- The network is represented as a graph **G = (V,E)**. The nodes are cities, the edges are roads connecting the cities. Traffic passes through links moving between *origin* and *destination* vertices. Additional information about the nodes and the edges is the population of the cities and the distances between them.



Biased Traffic Matrix

- Probability Mass Functions based on Gravitational Model

	Seattle	Palo Alto	San Diego	Salt Lake City	Boulder	Houston	Lincoln	Champaign	Pittsburgh	Atlanta	Ann Arbor	Ithaca	Princeton	College Pk
Seattle	0	0.1119041	0.1667369	0.1688483	0.07299	0.0571824	0.0387771	0.0202173	0.0173859	0.0168271	0.0150814	0.0128297	0.0112556	0.0090996
Palo Alto	0.0501523	0	0.1228368	0.0215922	0.0081419	0.0086807	0.0042797	0.0020199	0.0017312	0.0018189	0.0014932	0.0012841	0.0011286	0.0011204
San Diego	0.4499745	0.7396726	0	0.4560375	0.2251454	0.2955089	0.0964943	0.0486641	0.041364	0.0548508	0.032564	0.0277	0.0267506	0.0199513
Salt Lake City	0.1453278	0.0414671	0.1454442	0	0.1498184	0.0446563	0.0437538	0.0142163	0.0101714	0.0103808	0.009486	0.0071115	0.0060602	0.0045821
Boulder	0.0310477	0.0077276	0.0354873	0.0740421	0	0.0426997	0.0698774	0.013794	0.008301	0.0092446	0.0083327	0.0054529	0.0046617	0.0036234
Houston	0.2262866	0.0766491	0.4333221	0.2053181	0.3972422	0	0.503979	0.3516066	0.2205135	0.6595924	0.1740787	0.1290303	0.1291979	0.1120006
Lincoln	0.0082568	0.0020333	0.0076134	0.0108243	0.0349789	0.0271176	0	0.0234675	0.0083831	0.0083355	0.0102101	0.0048557	0.0038594	0.0031026
Champaign	0.0101981	0.0022735	0.009096	0.0083317	0.0163577	0.0448185	0.0555941	0	0.0651589	0.0409409	0.0931172	0.0224431	0.0196852	0.0178543
Pittsburgh	0.0259945	0.0057754	0.0229166	0.017669	0.0291775	0.0833148	0.0588642	0.1931349	0	0.125633	0.497588	0.4941719	0.4099824	0.5464622
Atlanta	0.0347024	0.00837	0.0419158	0.0248731	0.0448202	0.34374	0.0807326	0.1673833	0.1732891	0	0.1168517	0.083452	0.0992755	0.1091033
Ann Arbor	0.0116129	0.0025654	0.0092914	0.0084865	0.0150841	0.0338725	0.0369226	0.1421449	0.256262	0.0436297	0	0.0730482	0.0459805	0.0443776
Ithaca	0.0021865	0.0004883	0.0017493	0.0014082	0.0021848	0.0055569	0.0038865	0.0075828	0.0563294	0.0068965	0.0161679	0	0.0920536	0.0312159
Princeton	0.0018979	0.0004246	0.0016714	0.0011872	0.0018479	0.005505	0.0030562	0.0065803	0.0462362	0.0081169	0.0100688	0.0910754	0	0.0975067
College Pk	0.0023621	0.000649	0.0019191	0.0013819	0.0022112	0.0073468	0.0037823	0.009188	0.0948744	0.0137328	0.0149602	0.0475453	0.1501088	0