How Pessimistic is a Worst-Case SNR Degradation as a Link Abstraction Metric?

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Abstract: We consider a fully loaded, worst-case SNR degradation as an abstraction metric for impairment aware link virtualization. For the NSF topology with minimal fully connected load, the power optimized SNR is only 0.6 dB better.

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1. Introduction and Motivation

Network physical layer abstraction is a promising method to simplify the management of complex interconnected networks by describing the properties of network elements in a common, technology agnostic way [1,2]. This will allow physical network infrastructures to be merged and divided into a number of virtual networks for multiple clients [3].

Network virtualization at layer 2 and 3 [4] assumes the links perfectly transfer the digital data between switch ports, with switching occuring in the digital domain. For a wavelength routed optical network the signals are transparently routed in the analogue domain leading to a quality of transmission that degrades with each successive link. The virtualization of an analogue switched network requires the abstraction of the link properties and must expose sufficient physical layer information to allow the client application to make accurate management choices while being simple enough to avoid undue complexity.

One possible impairment abstraction is to assign each network transmission element a SNR degradation [5,6]. That is the transmitter, ROADMs, links and receivers are each assigned an SNR degradation. For polarization multiplexed coherent transmission in the nonlinear regime the SNR degradation due to the transmission through a fiber link depends on the launch power and number of co-propagation signals. Similar to the LOGON [5] approach each link can be assigned a worst-case SNR degradation based on full channel loading with uniform optimum launch power.

The SNR of the end to end data path can be calculated as the inverse sum of the inverse SNR degradation of each element. One useful advantage of the worst-case SNR approach is that this SNR can be achieved even under full network load such that there is no need to recalculate the viability of existing light paths as new light paths are added. The concern is that for a network operating with less than full load this worst-case simplification leads to underutilization of network resources as the actual SNR would be higher. Is this pessimistic use of resources significant?

2. Methodology

As an example network we consider the 14 node, 21 link, NSF network topology with the fiber and EDFA parameters as described in [7]. At start of life to fully connect all node pairs requires a minimal number of DWDM channels which can be calculated from the minimum network cut [8] as 13 for the NSF network. 32 GBd polarization multiplexed transmission with Nyquist rectangular spectral shape on a fixed 50 GHz grid with up to 80 channels was used where each channel is assumed to transport the ideal $2 \times 32 \log_2(1+SNR)$ [Gbps]. The worst-case SNR of the l^{th} link was calculated as

$$SNR_{wc,l} = \frac{p_0}{N_l n_{ASE} + N_l \eta_{wc} p_0^3} \qquad \text{where} \qquad p_0 = \sqrt[3]{\frac{n_{ASE}}{2\eta_{wc}}}, \qquad \eta_{wc} = \frac{1}{74} \sum_{i=-39}^{40} \eta_{74}(|i*50|) \tag{1}$$

where N_l is the number of spans in the l^{th} link, n_{ASE} is the ASE noise generated by each EDFA, η_{wc} is a worst-case nonlinear interference factor for a single span and p_0 is the uniform channel optimum launch power for fully loaded links. To avoid the need to consider the coherence factor in the addition of nonlinear noise sources the worst-case nonlinear interference factor has been calculated from the longest shortest path in the network, a path of 74 spans, where $\eta_{74}(|\Delta\nu|)$ was obtained by numerical integration of the GN model [9] for 74 spans and is the nonlinear interference generated on a signal from an aggressor with a carrier frequency $\Delta\nu$ away.

The routing and DWDM channel assignment, RWA, was made using a route based ILP as outlined in Fig. 1(left) [7]. The actual SNR of each signal was calculated with a partially coherent GN model as outlined in Fig. 1(right). In this model the XCI is accumulated incoherently while the SCI is accumulated using the coherent GN model where the SCI for N spans is $N^{1+\varepsilon}$ times the SCI for a single span. For the fiber and signal parameters used in this work ε was calculated from the ratio of the nonlinear interference from 1 and 74 spans and was found to be 0.22 for SCI but insignificant, less than 0.01 for XCI.

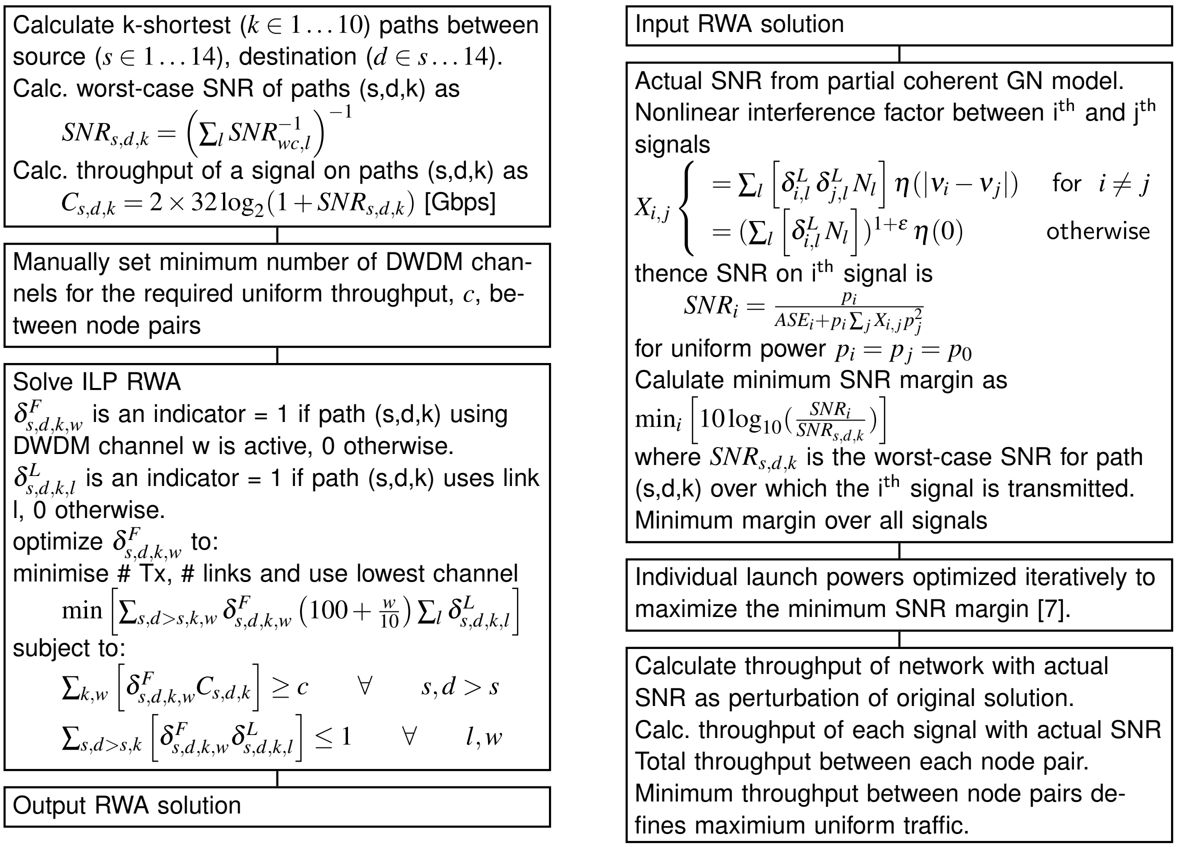

Fig. 1. The algorithms used to solve the routing and wavelength assignment(left) and the calculation of the actual SNR(right).

3. Results and Discussion

Fig. 2(left) shows the calculated actual SNR margin above the fully loaded worst-case SNR as a function of the number of active DWDM channels and network load. The continuous line shows the minimum SNR margin achieved for a fractionally fully loaded network upto the number of DWDM channels. The squares show the minimum calculated SNR margin for the RWA solution for a given network load where each signal has an equal full load optimized launch power, while the circles show the minimum calculated SNR margin where the individual launch powers have been optimized. The minimum calculated SNR margin for the RWA solution with uniform launch power closely follows the SNR margin for fractional full loading. This is expected since the RWA solution has approximately $\frac{3}{4}$ of the active link-DWDM channel slots filled for all the throughputs considered and as such at least one transmission will experience a fractional fully loaded path. Optimising individual launch powers allows a redistribution of margin from those transmission on lightly loaded paths to those on fractional fully loaded paths giving an SNR gain of up to 0.2 dB.

Fig. 2(right) shows the gain in data throughput that could be achieved if the actual SNR margin is utilized to transport more data, as a function of the number of active DWDM channels. The absolute gain in data throughput, Gbps per node pair, is approximately constant with the number of active DWDM channels while the fractional gain in data throughput reduces as the number of active DWDM channels reaches full load.

It is anticipated that networks with different diameters will show similar results to first order as the majority of

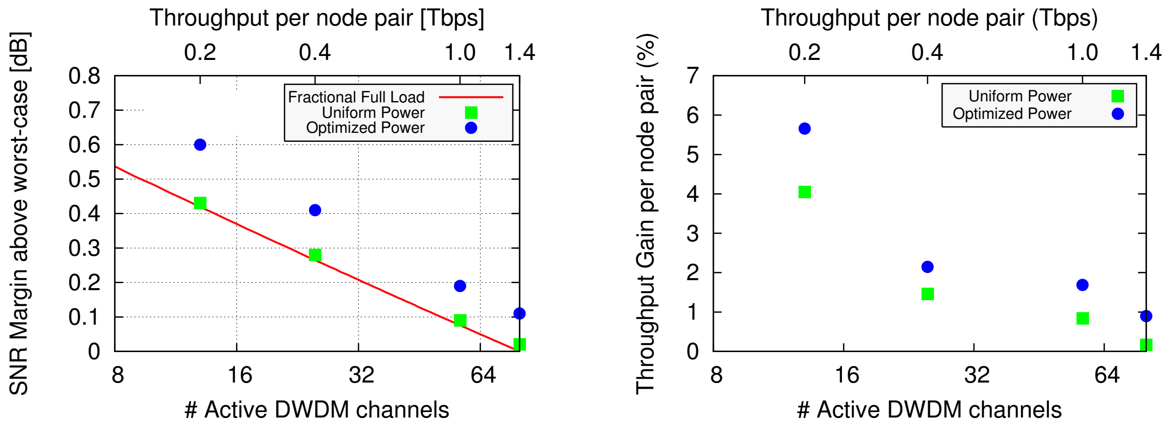

Fig. 2. (left)Actual SNR margin above worst-case SNR and (right) Throughput gain per node pair versus number of active DWDM channels.

nonlinearity accumulates incoherently such that the worst-case SNR and actual SNR will scale linearly with number of spans. If at the network design stage certain links can be guaranteed to be lightly loaded then the worst-case SNR degradation of those links could be estimated based on a lighter load, however the load on these links is then restricted to be less than or equal to this lighter design load. The SNR margin shown in Fig. 2(left) suggests that estimating the worst-case SNR for a fully loaded network should be possible from measurements of a fractionally loaded network.

4. Conclusions

We have considered the use of a worst-case SNR as a metric to describe transmission impairments for link abstraction. We show that even for minimal connectivity between all node pairs the actual calculated SNR by optimising individual launch powers only gives a small ≈0.6 dB SNR margin for the NSF network. Under the simpler uniform launch power assumption this margin is reduced to ≈0.4 dB. The SNR margin could be used to increase the uniform data throughput by just 18 Gbps per node pair. Thus the use of a worst-case SNR for each link does not significantly reduce the data transport of this network but does allow considerable simplification of the management complexity.

Acknowledgments

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