

Assessment of Options for Utilizing SNR Margin to Increase Network Data Throughput

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Abstract: When optimizing an optical network should we adapt the SNR to the signal or adapt the signal to the available SNR? We show both approaches give comparable results but have different complexity trade-offs.

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1. Introduction and Motivation

With the ever increasing traffic load on core optical networks it is necessary to maximize the data throughput of a given network with fixed fiber resource and topology. For wavelength routed optical network the different routes will have different transmission impairments such that short routes with high transmitted SNR can utilize high order, high capacity modulation releasing bandwidth for the longer routes with higher signal degradation that support only lower capacity formats [1]. Offline network planning is used to optimize the transmitter parameters, routing and spectral assignment to make full use of the available fiber bandwidth and transmitted SNR.

For a fixed 50 GHz grid if we choose only square PM-mQAM constellations then a client side data granularity of 100GbE can be easily accommodated, but the required SNR increases by ≈ 6 dB for each step up in modulation order. This leads to potentially large margins and wasted SNR. Others have tried to reduce the SNR steps by considering mixed modulation formats [2], set-partitioning optimized 4D formats [3] and variable code rates [4, 5] which all lead to non-standard variable client side data rates.

In this paper we wish to compare the following two possible solutions to maximize the utilization of the available SNR. (1) Adapt the launch power to match the available SNR to the modulation formats required SNR for error free transmission [6], this maintains a 100GbE client side data granularity and (2) Use a constant network wide launch power and adapt the FEC overhead to maximize the error free data transmission given the available SNR [5, 7], which requires a variable client side data granularity. We also consider the effect of ideal SPM compensation on the performance of these two solutions.

2. Signal Transmission Quality and Modulation / FEC Choice

The signal transmission quality is assumed to be degraded by ASE noise and nonlinear interference. The ASE noise is calculated from the accumulation of ASE noise from the EDFAs along the route, ROADMs were assumed ideal and did not contribute to the ASE noise. The nonlinear interference is calculated as the incoherent sum of XPM interference along the route and when included the addition of coherently accumulated SPM. This combination is reasonable as the coherent accumulation factor ϵ in equation (16) of [8] is only significant for SPM ($\epsilon=0.219$) and falls to $\epsilon < 0.006$ for XPM of channels spaced by 50 GHz and more.

We consider ideal hard decision forward error correction, HD FEC, as used in [7] and allow a further 5% overhead for the OTU framing. For the fixed 100GbE client granularity we select a fixed 22% FEC OH and utilize the square QAM modulations (PM-QPSK, PM-16QAM, PM-64QAM...). For the variable FEC overhead, for each transmitted signal SNR we choose the modulation format and FEC overhead that maximizes the error free transmission rate as a multiple of a 10GbE client data rate.

3. Offline Network Optimization

Figure 1 shows the network topologies considered along with the link lengths in km. Each link consists of a SSMF fiber pair in spans with length 80 km, attenuation 0.22 dB.km^{-1} , chromatic dispersion of $16.7 \text{ ps.nm}^{-1}.\text{km}^{-1}$ and nonlinear coefficient $1.3 \text{ W}^{-1}.\text{km}^{-1}$. Each span is ideally compensated by an EDFA with a noise figure of 5 dB. The

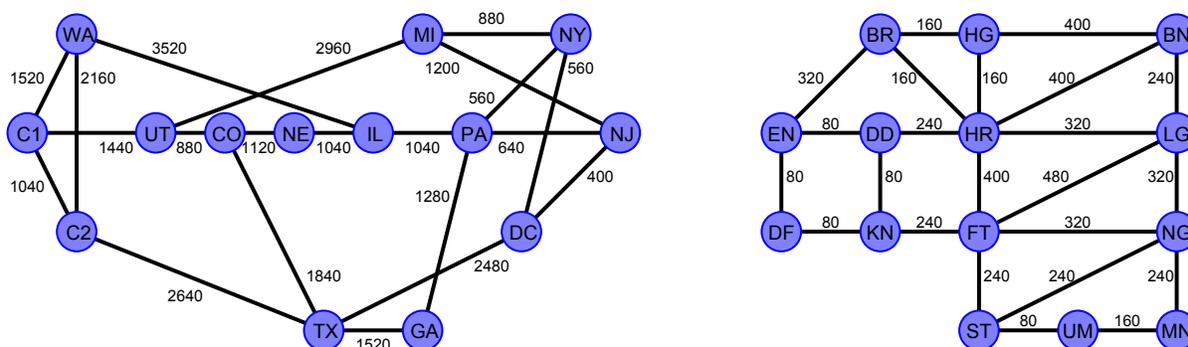


Fig. 1. (left) NSF 14-node, 21-link network topology [9] and (right) 14-node, 23-link DTAG/T-Systems National core network [10]. Both show link lengths in (km).

XPM and SPM efficiency factors were calculated by numerical integration of the GN model. Each fiber supports 80 DWDM channels on a 50 GHz grid at 32 GBaud with Nyquist rectangular spectral shape.

The routing, spectral assignment and transmitter optimization was solved as described in [6]. The primary aim of the network optimization was to maximize the data throughput assuming a uniform traffic matrix with equal data flow between all node pairs. In outline the network optimization was carried out as follows: find the k^{th} shortest paths between each node pair, calculate the transmitted SNR of each path based on fully loaded DWDM channels with a fixed optimal launch power, find the modulation format and FEC overhead that maximizes the error free data throughput on each route, solve using ILP the allocation of transmitters to paths and spectrum to maximize the throughput, re-solve the ILP (constrained by the maximum throughput) to spectrally group transmitters likely to cause nonlinear interference, separate these interfering DWDM channels and calculate the optimal launch power on a per transmitter basis that maximizes the SNR margin on all the transmitted signals. Where there was a large SNR margin the network was re-solved allowing a temporary reduction in the required SNR for error free data transmission in the anticipation that after solving and optimizing the launch powers an error free SNR margin will be regained.

For each network we maximize the network throughput for six scenarios, three each where only linear transmission impairments have been compensated in the receiver and the full nonlinear interference noise applies and three where SPM has also been ideally compensated. The three solutions include a fixed modulation, fixed FEC overhead with $m \times 100\text{GbE}$ client data that can be transmitted between all node pairs as a baseline throughput. Then we have a solution utilizing adapted modulation with a fixed FEC OH giving $m \times 100\text{GbE}$ client data where the individual launch powers have been adjusted to bring the transmitted SNR in line with that required for error free transmission. Finally we have a solution utilizing adapted modulation, and adapted FEC OH giving $m \times 10\text{GbE}$ client data to maximize the use of the available transmitted SNR but keeping the launch power fixed.

Figure 2 shows the throughput results for the 14-node 21-link NSF network topology and the 14-node 23-link DTAG/T-Systems national core network topology. Also shown is the achievable SNR margin with launch power optimization in each case, this serves to highlight the finer differences between CD only compensation and full CD and SPM compensation. The largest network throughput was achieved using the finer granularity $m \times 10\text{GbE}$ transmission rates with SPM compensation for the NSF network and using launch power adaptation for the DTAG network giving an overall increase in network throughput of 87% and 50% from the baseline for the two networks considered. Where SPM is compensated launch power adaptation can allow $m \times 100\text{GbE}$ fixed clients to give a comparable network throughput to that using variable client rates in both networks. When using adapted modulation with adapted FEC OH the effect of compensating SPM increases the network throughput by just 7% and 3% for the two networks.

4. Conclusions

We show that by optimizing the network routing, spectral assignment and transmitter parameters the network throughput can be increased by 87% and 50% for the two networks shown. It appears that SPM compensation has only limited benefit in small diameter networks but in the larger network was necessary to make better use of launch power optimization.

There appears to be a choice of approaches that both give broadly similar gains in network throughput. Use a $m \times 100\text{GbE}$ client rate with launch power adaptation a more complex routing and spectral assignment to minimize

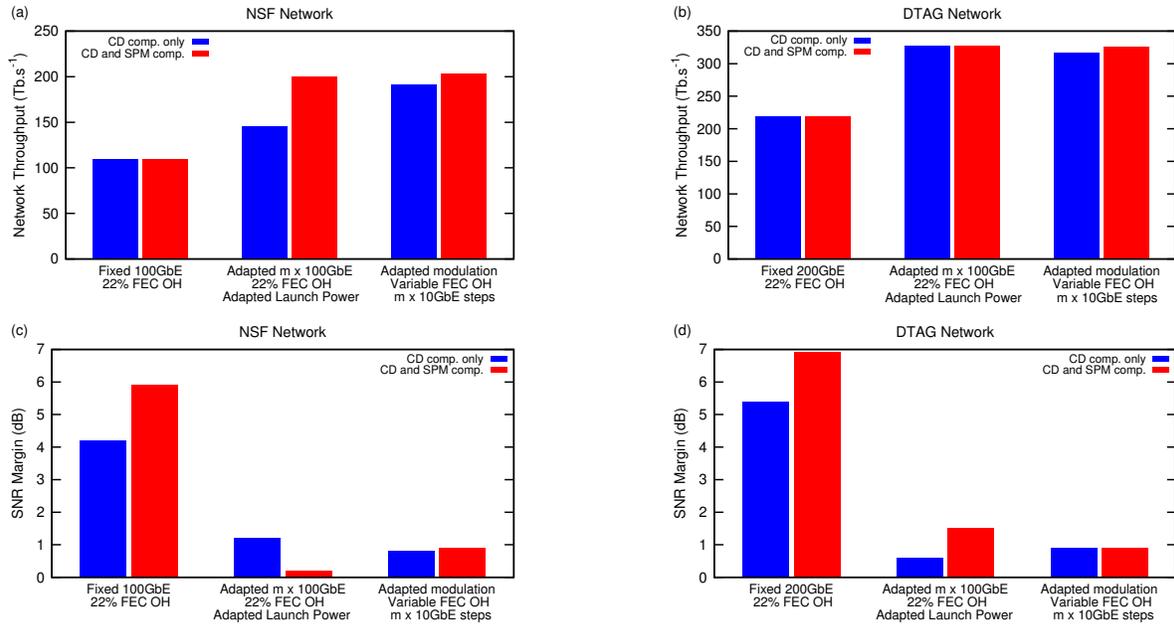


Fig. 2. Network throughput solutions for (a) NSF network, (b) DTAG/T-Systems network and achievable SNR margin for (c) NSF network and (d) DTAG/T-Systems network.

nonlinear interference and perhaps SPM compensation or use a $m \times 10\text{GbE}$ variable client rate with a more complex FEC algorithm. The choice between these solutions will depend on the clients preference for a fixed 100GbE data rate versus a variable client data rate weighed against the complexity of implementing more complex routing and spectral assignment, SPM compensation and adapted FEC.

Acknowledgments

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