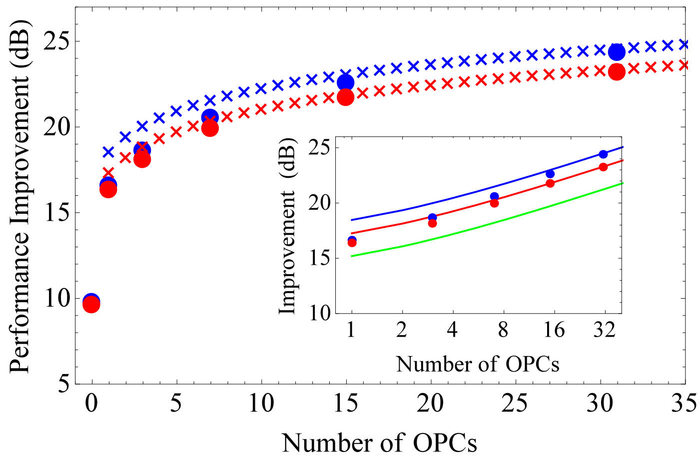

Fig. 6. Performance improvement observed for a variable number of OPC devices considering Eq. (11)(crosses) and a numerically simulated single channel transmission system (filled disks) for single channel (blue), and for 3 channel (red) and full C band (green) WDM systems propagated over a 32x80km of ideal Raman amplified link. Inset shows same data with OPC count shown on a logarithmic scale.

A difference of approximately 2.8 dB between the measured performance/Q-factor and the electrical signal to noise was observed, reflecting the common implementation penalty for 16-QAM Nyquist signals processed at 2 samples per bit. Figure 6 compares the performance of the numerically simulated system with the theoretical prediction of Eq. (11), where a single fitting parameter (SNR_0 for the 3 channel system) was used for all curves. For Raman amplified links, we only consider the bandwidth dependent contributions to the nonlinear noise, since $f_W \to 0$ as $\alpha \to 0$ increasing the dominance of this term. Introduction of NLC results in a 7dB performance improvement and the prediction that increasing the number of OPCs enhances the optimum SNR by $\sqrt[2]{N_{OPC}+1}$ hold well for 3 channels, and for large numbers of OPCs. This rate of increase is readily observed in the inset to Fig. 6 which plots the data on a log-log scale revealing a straight line whose slope (1/2) may be clearly observed indicating the anticipated power law dependence. Figure 7 shows the power dependent performance of each data point in Fig. 6 along with theoretical fits using Eqs. (8) and (9) where P_N was set to 38μW/THz and η was set to 5.1 THz^2/W^2. Again, an excellent fit is found between numerical simulations and analytical theory, including in particular an accurate prediction of the nonlinear threshold. As expected from Shannon's theorem, a substantial increase in the optimum launch power is required to realize the benefits of cascaded OPC. We observe that for launch power spectral densities beyond the nonlinear threshold, the rate of decrease in performance is substantially more rapid than would be predicted by Eq. (9). This may be due to uncompensated signal depletion effects [4,32] (neglected in Eq. (1)), higher order nonlinear interactions or sub optimal DSP in this region. The precise cause of this degradation is currently under study, as recent information theory calculations suggest that fiber throughput should increase monotonically with signal power [33].

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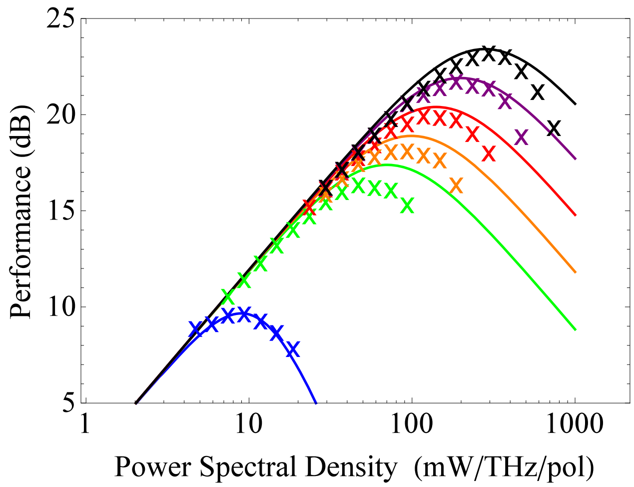

Fig. 7. Comparison of numerically simulated and theoretically predicted performance for a 3 channel WDM transmission comprising ideal Raman amplification and multiple OPCs (number of OPCs: blue-0, green-1, orange-3, red-7, purple-15, black-31).

5. Conclusions

In this paper we have analytically analyzed the impact of multiple optical phase conjugation on an optical transmission system. In addition to the ~50% increase in optimum signal to noise ratio common to all ideal nonlinearity compensation schemes, optical phase conjugation has been shown to interrupt the quadratic growth of parametrically amplified noise. This reduced growth rate enables higher launch powers, and a further increase in optimum signal to noise ratio of $\sqrt[2]{N_{OPC}+1}$, enabling the signal to noise ratio of a long haul system to be more than doubled. We have also shown that the same analytical approach may be used to optimize the distribution of nonlinear compensation between transmitter and receiver DSP and optical phase conjugation, finding that if all inter-channel nonlinearities are compensated optically, the required DSP bandwidth is minimized. For a uniformly spaced OPC system, this optimum performance is obtained when half of a single inter OPC span length is compensated in the transmitter, and half compensated in the receiver (this includes the case of zero OPCs). Assuming such joint nonlinear compensation is applied, we also conclude that an odd number of OPC devices minimizes the required DSP bandwidth.

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