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Machine Learning for Accelerating Multi-band Optical Communication Systems Optimization

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Abstract. Multi-band systems have demonstrated to be a viable solution to sustain capacity growth required by optical communication systems, thanks to the availability of wide bandwidth amplification technologies, like the Raman amplifier (RA). However, extreme levels of optimization are needed to extract all the potential, requiring super-fast and accurate evaluation of the impact of nonlinear effects. This is a tricky task when the transmission bandwidth is very large, as all fiber parameters becomes frequency dependent and the number of data channels and RA pumps is large. Also, the inter-channel stimulated Raman scattering (ISRS) become impactful. Optimization approaches based on Gaussian Noise (GN) models turn to be very complex, with a consequent slow down of the whole design process. Resorting to the fast GN-based closed-form-models (CFMs), it requires a full spectral and spatial knowledge of the signal power profile along the fiber span. This is particularly computational heavy when backward RA is considered. We propose an approach based on machine learning (ML) and neural networks (NN) to accelerate the process. The method, tested for a super-(C+L) system (12 THz bandwidth) and backward Raman amplification, guarantees a high level of accuracy and a significant speed increase.

1 Introduction

Multi-band technology is a promising solution to cope with continuous traffic growth, as it can be implemented on existing single-mode fibers without the installation of new cables [1, 2]: the transmission bandwidth is extended beyond the C-band, considering the L- and S-bands, and potentially the O-, E-, and U-bands. To optimize multi-band systems (signal and RA pump power levels), a fast and accurate physical modeling is required. This is typically achieved using GN-based CFMs [3, 4], which require full knowledge of spectral and spatial power profile evolution along the link. After having defined a cost function based on the individual $GSNR_i = \left(\frac{1}{GSNR_{NLI,i}} + \frac{1}{GSNR_{ASE,i}}\right)^{-1}$ of all WDM channels, the optimization relies on the evaluation of both $GSNR_{NLI,i}$ and $GSNR_{ASE,i}$ [1]. However, given the high channel count of wide-band systems and the repeated evaluation, up to hundreds or even thousands of cases, to search for the best solution, the task becomes highly time consuming. Main bottleneck is solving coupled Raman equations for signals and backward propagating RA pumps: each single evaluation can require up to minutes of computation. We propose the use of a ML approach based on NNs to predict pump power levels at the span input, so that a regular forward integration method can derive the full power profile for channels and pumps, as needed by the CFM to evaluate $GSNR_{NLI,i}$.

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2 Machine learning framework and results

We analyze a super-(C+L) system with 60 channels per band and 6 counter-propagating RA pumps, centered at $f_{j=1,...,6}$ =[210.56, 208.87, 206.72, 204.51, 199.00] THz and with power $P^{in}_{p_j}$. The signal, launched at the start of a single span of 100 km SMF, is described by the power of the central channel P^{avg} and the power tilt P^{tilt} of both C- and L-bands. Fig. 1 shows the block diagram of the proposed ML-based method (*fast model*) compared to the reference *full model* that solves the Raman equations using the slow two-points boundary conditions bi-directional integration method. The result is the power profile $\mathbf{P^{full}_{S_{out}}}$, that is provided at the input of the CFM. In the fast model, same inputs are fed into a pre-trained NN–3 hidden layers each with 20, 100 and 150 hidden nodes, hyperbolic tangent activation function and mean square error loss function–that determines the pump power levels $\mathbf{P^{pred}_{p_{out,j}}}$ at the span input. Then a regular ODE fast forward solver evaluates the full power profile $\mathbf{P^{fast}_{S_{out}}}$ to be sent as input to CFM. In both cases, the output of the CFM is given as $GSNR_{NLI}$. The method is

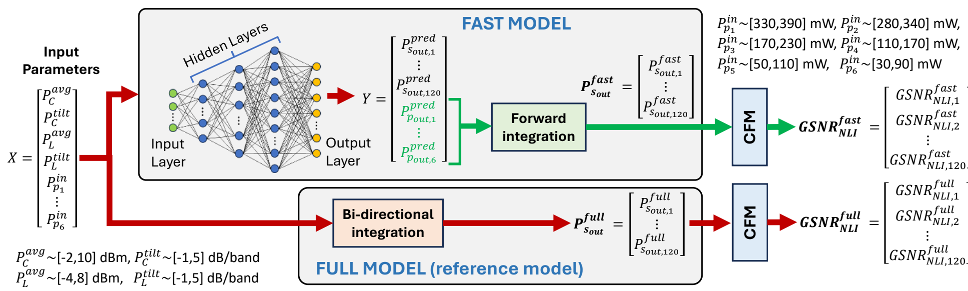

Figure 1. Block diagram of the proposed approach and schematic of the NN model.

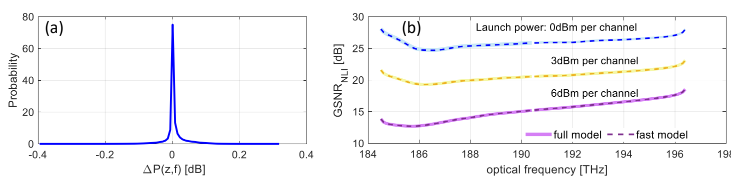

Figure 2. (a) Probability density function of the signal power profile error for all channels at all distances. (b) $GSNR_{NLI,i}$ for all channels in three selected cases for both *full* and *fast* models.

tested and validated over hundred thousands data generated by randomly extracting the signal power average, power tilt and pump powers from uniform distributions, ranges are reported in Fig. 1. The accuracy is evaluated by computing the error between the profiles given by the two methods. The probability density function of the error is illustrated in Fig. 2(a): for 97.5% of the cases the absolute value is lower than 0.1 dB. In Fig. 2(b), the $GSNR_{NLI,i}$ is shown for three selected cases (no signal power tilt and RA pump powers set to the median value of the respective range): the maximum absolute error is lower than 0.06 dB.

3 Conclusions

The proposed optimization accelerator for multi-band systems proved a negligible impact on NLI estimation accuracy, with a considerable improvement in speed by a factor >1000.

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