MACHINE LEARNING-ASSISTED GAIN DESIGN OF FEW-MODE FIBER RAMAN AMPLIFIERS

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This work proposes a fast Machine Learning-based approach to design the gain spectrum of a Raman amplification scheme in few-mode optical fibers, suitable for next-generation spatial division multiplexing elastic optical networks.

Keywords: few-mode fiber, Raman amplification

1. Introduction

Raman amplification (RA) has found application in space division multiplexing (SDM) transmissions [1], where its flexibility allows for gain equalization across wavelengths and modes. To date, the design of the Raman gain profile for SDM links is considered only in [2], where a time-consuming optimization problem needs to be solved for each target profile. Recently, in the context of single-mode RAs, a promising machine learning approach enabling ultrafast gain spectrum design has been demonstrated [3], suitable for real-time applications such as elastic optical networks (EONs). Here, we extend this method to the case of a few-mode co-propagating RA, showing its ability to design flat gain profiles with different levels of mode dependent gain (MDG), which may be needed to compensate the mode-dependent losses of other SDM devices in the link.

2. Results

In multimode fibers, Raman amplification is described by the following set of coupled nonlinear differential equations [2]

$$\frac{dP_i^m}{dz} = -\alpha_i P_i^m + P_i^m \sum_{j,n} g_R(\lambda_i, \lambda_j) f_{m,n} P_j^n \qquad (1)$$

where P_i^m is the power of the i-th wavelength and m-th mode, α_i is the attenuation for the i-th wavelength, $g_R(\lambda_i, \lambda_j)$ is the Raman gain coefficient between wavelengths λ_i and λ_j, and $f_{m,n}$ is the overlap integral between mode m and mode n, which is assumed to be frequency independent. We consider the amplification of entire LP mode groups instead of individual modes under the strong mode coupling assumption [2]. A neural network (NN) is first used to learn the inverse mapping $\boldsymbol{y} = f^{-1}(\boldsymbol{G})$ between the amplifier gains for different wavelengths and modes $\boldsymbol{G} = [G_i^m]$, and the vector of pump powers and wavelengths $\boldsymbol{y} = [\boldsymbol{P} \mid \boldsymbol{\lambda}]$, training it on a set of gain curves generated solving (1) with random initial pump conditions. The NN can be fed with the desired gain profile $\widehat{\boldsymbol{G}}$ to quickly obtain the estimated pump parameters $\widehat{\boldsymbol{y}}$ required to approximate it. The method is tested over a 50 km long step-index fiber with core diameter $d_c = 14$ μm, core refractive index $n_{co} = 1.46$ and a relative refractive index difference $\Delta = 0.28\%$, supporting the LP_{01} and LP_{11} mode groups over the considered band. The loss coefficient is set to 0.2 dB/km, while a standard silica Raman response is assumed. The input signal is a WDM comb of $N = 50$ channels spanning the bandwidth $B = [1520, 1570]$ nm, each with power $P_0 = -10$ dBm. The Raman pumps are injected in each mode group at $M = 2$ different wavelengths. A dataset of $D = 10000$ gain curves is generated by solving (1) drawing initial pump powers and wavelengths from a uniform distribution, $P_i^m \sim \mathcal{U}[20, 200]$ mW, $\lambda_i \sim \mathcal{U}[1420, 1490]$ nm, $i, m = \{0, 1\}$. The NN has $N_l = 5$ hidden layers, each composed of $N_n = 700$ neurons with Parametric Rectified Linear Unit (PReLU) activation functions. We first train the NN on a subset of $D' = 8000$ curves using the Adaptive Moment Estimation (ADAM) optimization algorithm, and then test it on the remaining $D'' = 2000$ curves, achieving an average error of $\delta_\lambda < 1$ nm and $\delta_P \cong 10$ mW over the entire test set. We test the NN performance by comparing the target gain profiles with those obtained by solving (1) with the predicted pumps. In Fig. 1 the results for flat target gain profiles with different gain levels and 0 dB of MDG (left), and 2 dB of MDG (right) are reported. The maximum error on the gain level is lower than 1 dB in both cases, while the error on the predicted MDG is below 0.1 dB (left) and 0.2 dB (right).

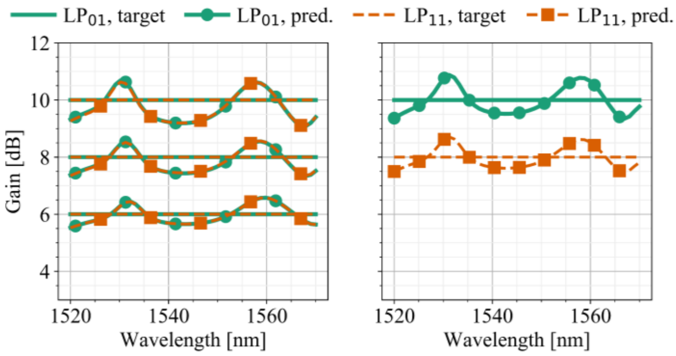

Fig. 1 NN predictions for a flat target gain for each mode (left) and with 2 dB of MDG (right)

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References

1. Ryf, Roland et al. *ECOC*, OSA Tech. Digest, Th.13.K.5 (2011)
2. Zhou, Junhe. *Opt. Express* **22**(18), 21393 (2014)
3. Zibar, Darko et al. *J. Light. Technol.*, to be published (2019)