MACHINE LEARNING FOR OPTICAL AMPLIFIER CONTROL IN OPTICAL NETWORKS

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ABSTRACT

We report on a machine learning module using neural networks able to predict the optical power excursions introduced by an Erbium Doped Fiber Amplifier (EDFA) with a high accuracy.

KEYWORDS: *machine learning; optical networks; EDFAs; optical power excursion*

1. INTRODUCTION

IP traffic is experiencing a continuous growth driven by different applications e.g. Internet of Things (IoT), video, gaming, etc. In parallel, current optical communications systems are approaching the capacity limit for standard single-core single-mode fiber transmission systems. Different solutions are being investigated to face this challenge, some of them focused on the idea of efficiency, using the already available resources in a more intelligent way. To do so, traditional planning strategies for optical networks, based on fixed and static traffic demands should adapt to flexible and dynamic traffic, by using a flexible frequency grid or by tuning different parameters as bit rate or modulation format. As all these parameters will have an impact in the Quality of Transmission (QoT), not only network layer but also the physical layer has to be taken into account before a connection establishment with a given set of features. Focusing on a more specific case, the adding (dropping) of channels in dynamic optical networks remains still a challenge due to the power dynamics associated with the wavelength reconfiguration. Here, our work in this topic is presented. A closer look to this problematic in the next section, reveals to what extent it is important to solve this issue. Then, our proposed solution together with the obtained results are presented, to finally summarize its importance in dynamic optical networks.

2. OPTICAL POWER EXCURSION

In the context of optical communications systems, the use of Wavelength Division Multiplexing (WDM) together with Erbium Doped Fiber Amplifiers (EDFAs) was a major breakthrough. Despite this progress, some issues remained unresolved, being the case of optical power excursions, main topic of this paper. EDFAs, which exhibit a wavelength dependent gain, produce undesired optical power excursions, deviations of the channel instantaneous power from the channel average power. Although irrelevant for single channel transmission, the effect of this phenomenon in WDM systems is remarkable, as certain channels experience high gain leading to an operation limited by non-linearities while other channels suffer from low gain resulting in a noise limited performance.

Over time, different solutions were proposed, being the based on mid-stage Gain Equalization Filters (GEFs) one of the most popular, working well for an specific operating point of the amplifier, for which the GEF is designed. However, it provides a lower performance in dynamic optical networks, where the action of adding (dropping) channels changes the input power to the EDFA and therefore, the operating point. As a consequence, optical power excursions become visible again. Consequently, to deal with this dynamics, a more flexible and agile solution is required. Power per channel control utilizing Wavelength Selective Switches (WSSs) has been proposed [1], but, unfortunately, the time response of WSS devices is a limiting factor in the settling time. For this reason, machine learning, able to address intractable problems providing an almost instantaneous response once trained, is being considered to solve this issue [2], in the same way as it has already done in many others areas as computer vision or natural processing. The interest in this topic is demonstrated by the increase in the number of publications in the last years. In 2017, a power excursion prediction based on Linear Regression and Radial Based Function (RBF) has been investigated [3]. In the same year, a neural network based solution has been presented to predict maximum power excursion in a link [4]. Just one year after, in the same line, a deep neural network was presented [5] to as well predict the maximum power excursion. In the next section, we report on a machine learning approach based on artificial neural networks to predict optical power excursion with high accuracy [6].

3. Proposed machine learning based approach

Used for solving different types of problems involving classification, optimization or forecasting, neural networks have demonstrated to be a versatile machine learning tool, being the reason why it has been selected here to predict optical power excursion. To this aim, an architecture based on 2-layer neural network, containing 160 neurons in the hidden layer, has been deployed using using Keras running on TensorFlow Python library [7]. Contrarily to deep neural networks, in the case of shallow neural networks, as it is this case, the definition of the input feature vector is an important step. In this case, the input layer has been defined with a size equal to the considered number of WDM channels, specifying, for every channel, whether it is active or not. The output vector, of the same size as the input feature vector, represents the power excursion in every channel. Regarding the activations, two different activations have been used: Rectified Linear Unit for the hidden layer and linear activation for the output layer. To complete the definition of the used neural network, optimization methodology for weights update is done by Stochastic Gradient Descent. The selection of the mentioned parameters, as number of hidden layers and neurons, was decided during the training period of the developed machine learning module on the used dataset. Therefore, as in every machine learning application, the data collection previous to the training and validation of the algorithm was an essential part of this work.

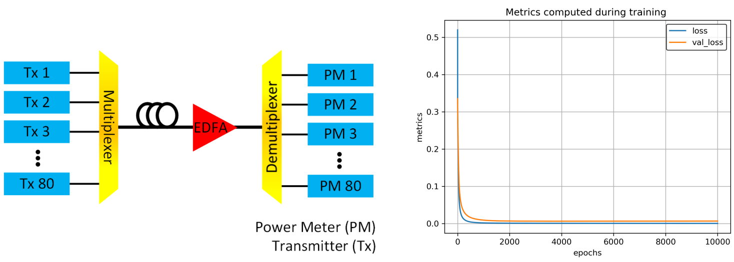

Figure 1 : Simplified diagram of the simulated system (left) and evolution of the loss for the training and the validation sets (right).

Data was collected from simulations using VPI Photonics [8], an advanced software for simulation of optical communication systems. Figure 1 (left) illustrates a simplified diagram of the simulated system. At the transmitter side, a total of 80 channels (100 Gb/s, 16-QAM) with 0 dBm power per channel, in a 50 GHz frequency grid, are generated and multiplexed. After the signal propagation in a 100 km single mode fiber, losses are compensated using one Automatic Gain Control (AGC) EDFA. Finally, at the receiver side, in order to calculate the power excursion per channel, WDM channels are demultiplexed and the optical power in every channel is measured. The generated dataset comprises 300 simulations, where the occupancy was varied within a range from 40 % to 87.5 %, by adjusting the number of active channels. From these 300 simulations, 80 % were used for training, 15 % for validation and remaining 5 % for testing purposes. During the training and validation phase, the evolution of the mean square error loss function was monitored. As expected, shown in Figure 1 (right), the training and validation loss were decreasing with the increase of the number of epochs.

For one of the samples of the test dataset, Figure 2 (left) shows the estimated power excursion calculated by simulation and the predicted values using the presented approach, while Figure 2 (center) illustrates the corresponding algorithm accuracy as a function of the minimum acceptable difference between the real values and the predicted values. Considering a threshold of 1 dB, quite low compared to the 3 dB critical value [9], the algorithm achieves 100% of accuracy. For a 0.2 dB threshold, our neural network model is still achieving more than 90% of accuracy which is a good result from gain equalization point of view.

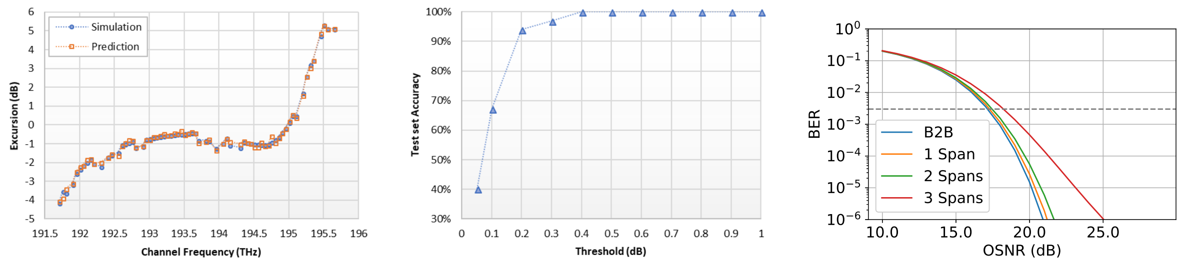

Figure 2 : Estimated power excursion calculated by simulation and the predicted values using the presented approach, for one of the samples of the test dataset (left), algorithm accuracy on one of the samples of the test dataset (center) and BER for different OSNR and number of spans (right).

Although only one span was considered in this work, simulations were done in order to know about the feasibility of a cascade. Figure 2 (right) shows preliminary results, for a single channel transmission, of the Bit Error Rate (BER) with respect to Optical Signal to Noise Ratio (OSNR) for different number of spans. Considering a BER of 3×10^{-3}, 3 spans could be used in cascade requiring an OSNR of approximately 18 dB.

Conclusion

Power excursion prediction in EDFAs using neural networks has been demonstrated in this article. Requiring a relatively small amount of data, it obtains a good accuracy, resulting in a remarkable advantage with respect to other techniques. Future work will focus on the cascade of EDFAs.

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