Gradient Boosting for Nonlinear Equalization in Optical Transmission Systems

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The performance of modern optical communication systems is a bottleneck of modern technology, and to enhance this performance, we must mitigate the linear and nonlinear distortions that occur during signal propagation through optical fibers. There have been numerous studies devoted to this problem, with ideas for digital signal processing (DSP) algorithms for fiber nonlinear equalization. In recent years, the advantages of machine learning (ML) techniques have inspired researchers to expand these advantages for nonlinear equalization. Several works have demonstrated the ability of smart equalizers based on neural networks (NN) to "understand" system parameters and predict nonlinear distortions [1]. The goal of this study was to explore the use of Gradient Boosting (GB) technique for nonlinear equalization in optical transmission systems. GB is an ensemble learning method that operates by constructing a multitude of decision trees. In this case, GB is used as a regression model, which returns the average prediction of the individual trees for nonlinear shift. In practical implementation, the use of GB can be implemented through the use of pretrained switchers on a field-programmable gate array (FPGA) [2].

Our training set consisted of 1 million data samples and 5 neighbour points, and the resulting model was evaluated using a test set with 130 thousands of points with neighbours, which was not involved in the training process. The parameters used for the fibre optical line in this study included a dual-polarization 16-quadrature amplitude modulation (16-QAM) symbol sequence at 34.4 [GBd] symbol rate, a digital root-raised cosine (RRC) filter with a roll-off factor of 0.1, and transmission over 20×80 [km] spans of standard single-mode fibre (SSFM) with an erbium-doped fibre amplifier with 4.5 [dB] noise figure. A simulation was conducted using a model of SSFM at a wavelength of $\lambda = 1550$ [nm], with an attenuation coefficient $\alpha = 0.2$ [dB/km], a dispersion coefficient of $D = 16.8$ ps/[nm $\cdot$ km], and a nonlinear coefficient of $\gamma = 1.2$ $[\mathrm{W} \cdot \mathrm{km}]^{-1}$. We applied the GB technique for an average input signal power of 6 [dBm], which resulted in an improvement of Q-factor by 0.65 [dB] as demonstrated in Fig. 1. This improvement is reflected in a decrease in the bit error rate (BER) from 0.051 to 0.039, which is below the forward error correction (FEC) level. Additionally, the GB demonstrated its ability for transfer learning by applying the same model to different power levels, resulting in improved equalization, as evidenced by the results displayed on the left pane of Fig. 1.

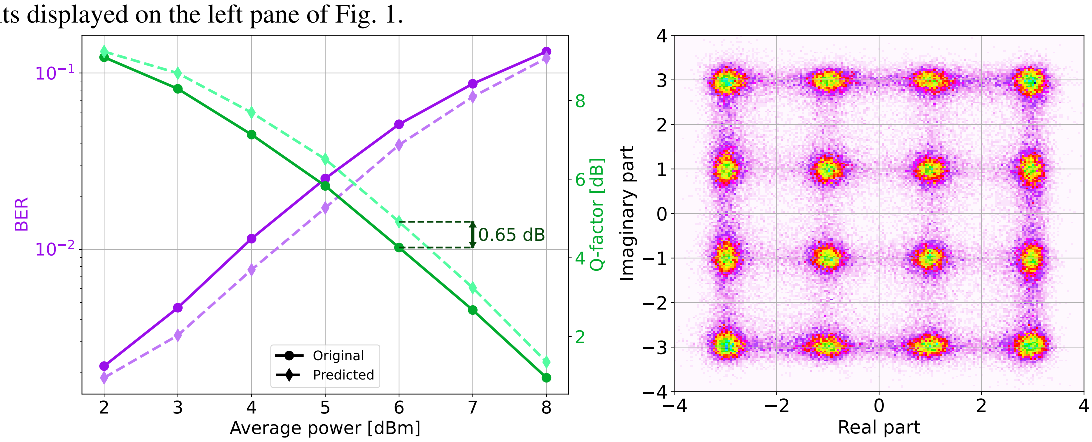

Fig. 1 The left panel illustrates the improvement in BER and Q-factor achieved through the use of the GB model, which was trained on an average input signal power of 6 [dBm], for various power levels. The right panel displays the equalized constellation diagram.

This study has demonstrated the potential of using GB technique for nonlinear equalization in optical transmission systems. Our results showed that the application of GB trained on a large dataset resulted in a significant improvement of the Q-factor and decreasing of BER. These findings highlight the ability of GB to accurately predict nonlinear distortions and enhance the performance of modern optical communication systems. Furthermore, the fact that this technique can be implemented using FPGA technology makes it a highly promising solution for nonlinear equalization in practical scenarios, as it can be easily integrated into existing systems. The potential of forest machine learning techniques in this field warrants further research and investigation.

References

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