Forest Equalization for Coherent Optical Transmission Systems

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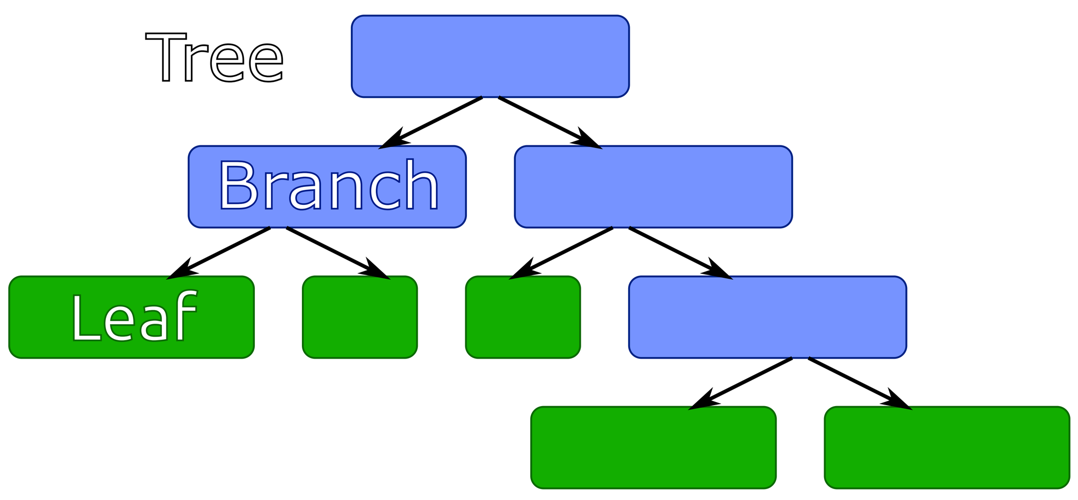
Motivations

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. In recent years, the advantages of machine learning techniques have inspired researchers to expand these advantages for nonlinear equalization. Several works have demonstrated the ability of **smart equalizers** based on neural networks to "understand" system parameters and **predict nonlinear distortions**. The goal of this study was to explore the use of **Gradient Boosting** (GB) technique for **nonlinear equalization in optical transmission systems**. In practical implementation, the use of GB can be implemented through the use of pretrained switchers on a field-programmable gate array (**FPGA**)

Decision Tree and Regression



Decision tree is a machine learning algorithm used for regression and classification problems. It splits a dataset into smaller subsets based on the most significant feature, creating a tree-like structure of decisions and outcomes. Each internal node represents a test on a feature, each branch represents the outcome, and each leaf node represents a prediction. However, it can overfit.

Gradient Boosting is an ensemble technique that merges weak models to form a strong overall prediction. It trains new models to **correct previous mistakes**, using decision trees to **reduce residuals**. The final prediction is a combination of all tree predictions, weighted by **learning rate**.

Data Generation

Our training set consisted of **7 million** data samples and 5 neighbour points for each average input signal power, 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:

- WDM signal format,
- dual-polarization 16-QAM modulation symbol sequence at 34.4 $[\mathrm{GBd}]$ symbol rate,
- digital RRC filter with a roll-off factor of 0.1,
- transmission over 20×80 $[\mathrm{km}]$ spans of standard single-mode fibre (SSFM) with an erbium-doped fibre amplifier with 4.5 $[\mathrm{dB}]$ noise figure,
- model of SSFM at a wavelength of $\lambda = 1550$ $[\mathrm{nm}]$, with an attenuation coefficient $\alpha = 0.2$ $[\mathrm{dB/km}]$,
- dispersion coefficient of $D = 16.8$ $\mathrm{ps}/[\mathrm{nm}\cdot\mathrm{km}]$, and a nonlinear coefficient of $\gamma = 1.2$ $[\mathrm{W}\cdot\mathrm{km}]^{-1}$.

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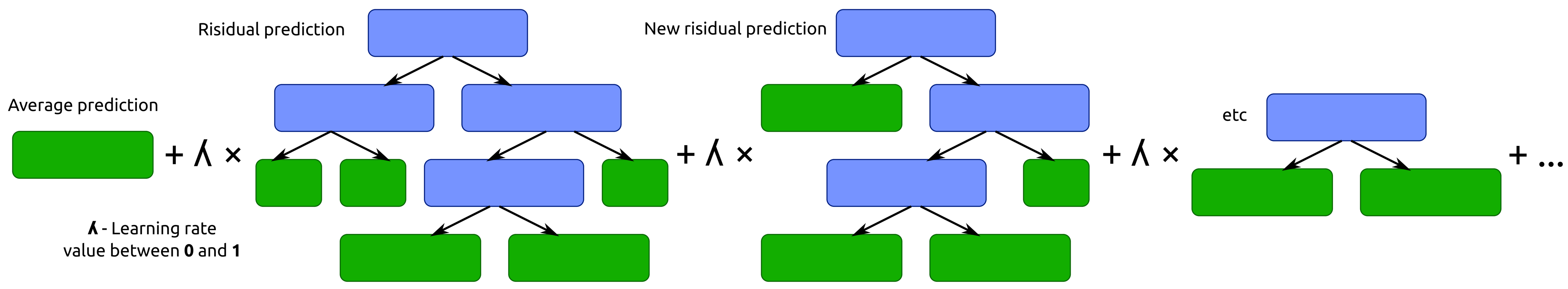
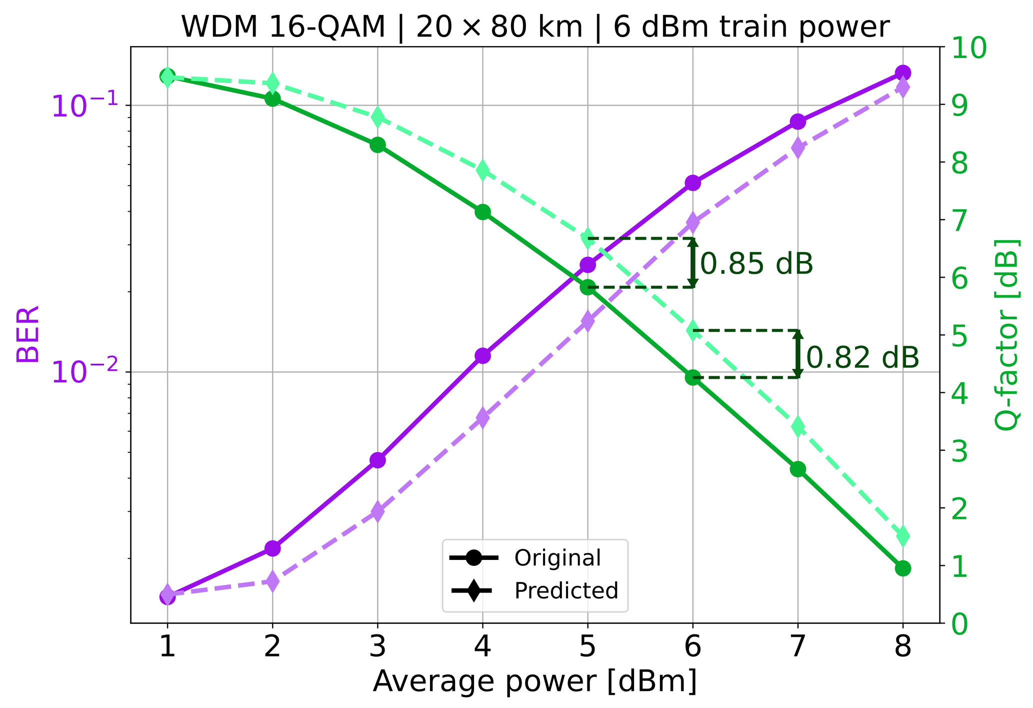
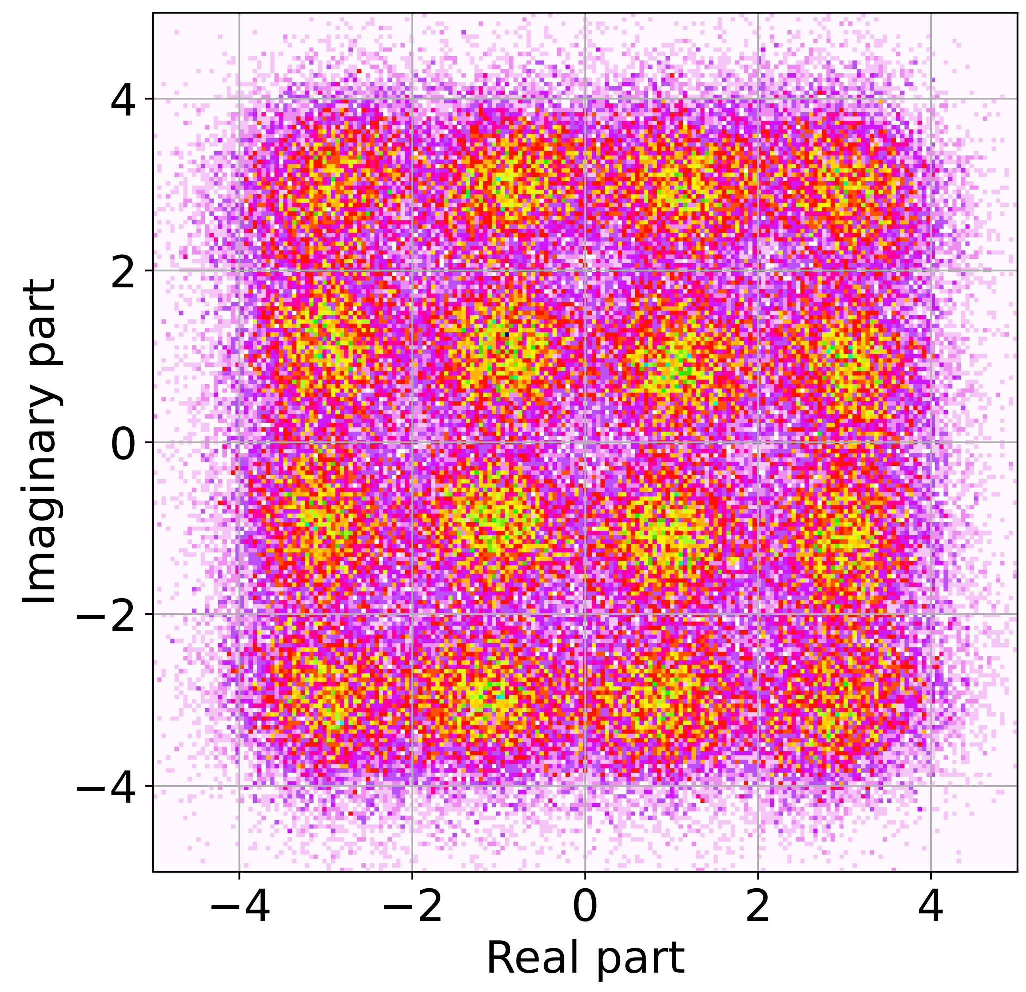
Gradient Boosting



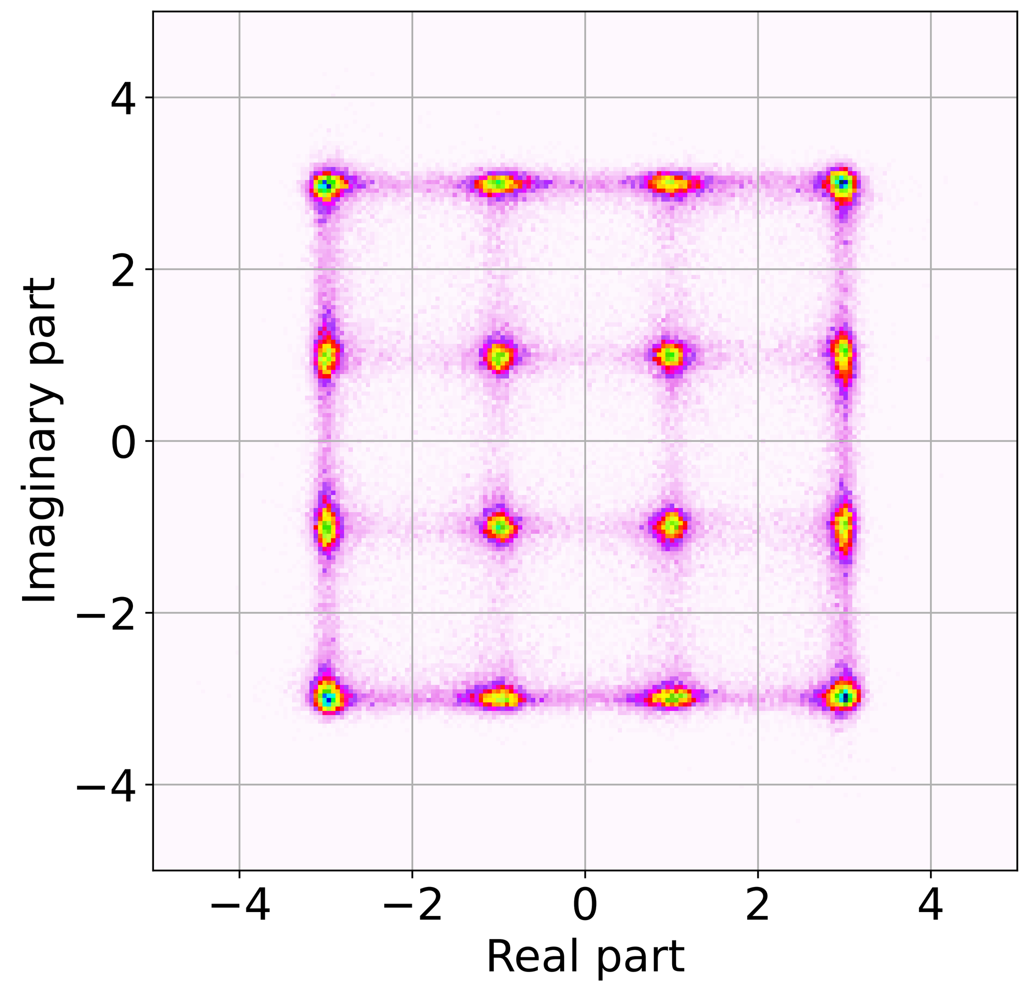
Equalization of Distortion



Before equalization

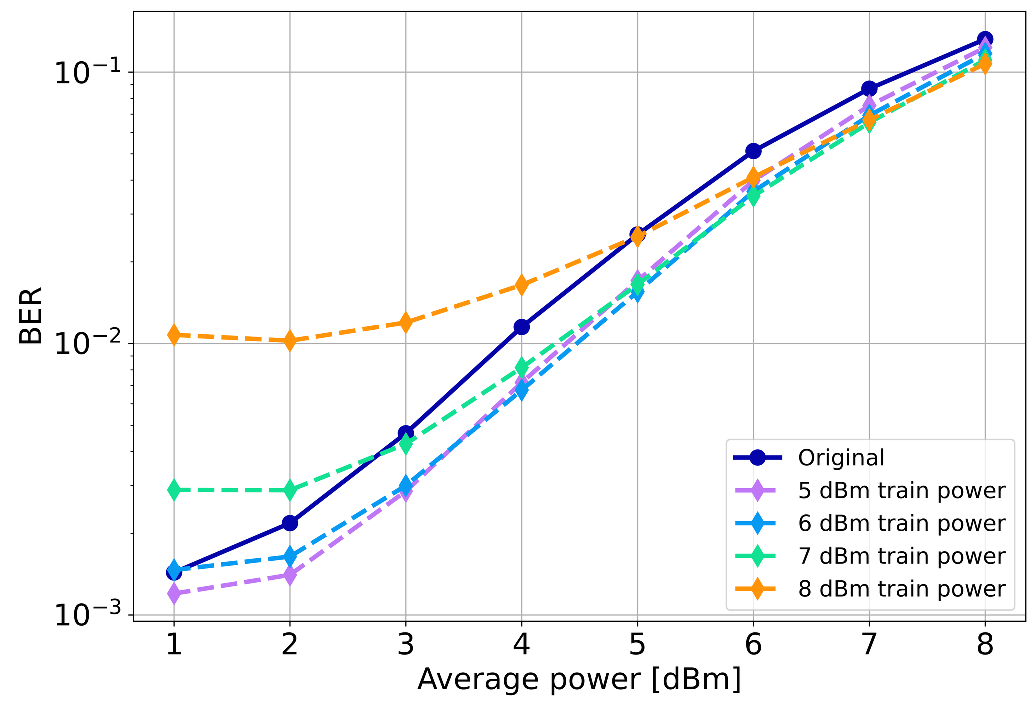


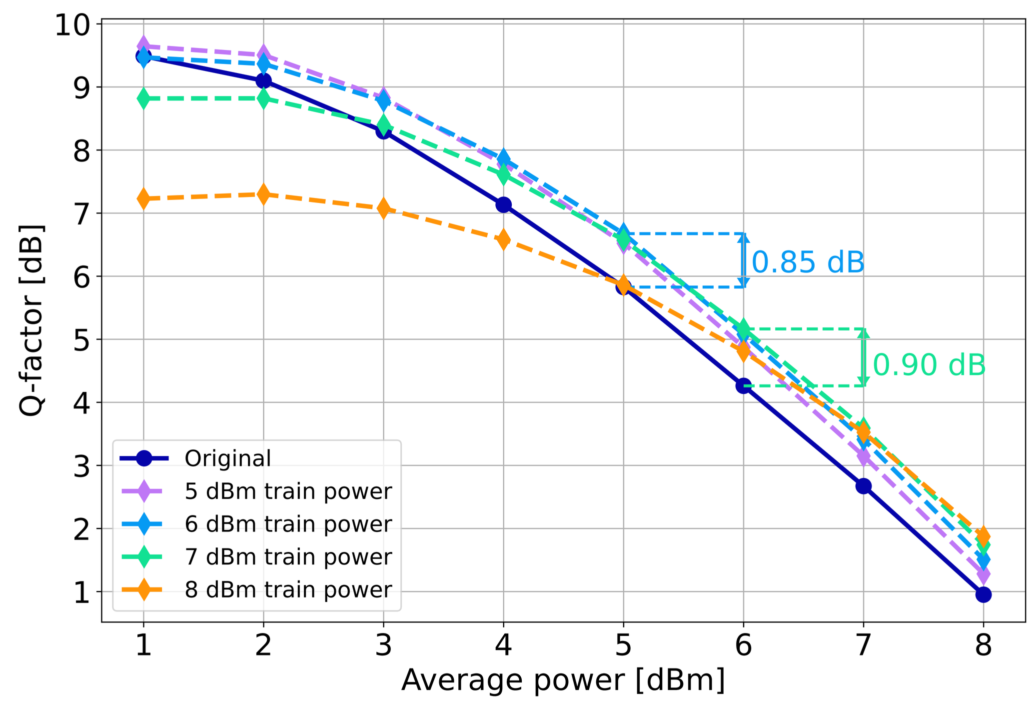
After equalization



The application of Gradient Boosting (GB) technique on average input signal power of 6 $[\mathrm{dBm}]$ yielded remarkable results. The Q-factor was improved by an impressive 0.82 $[\mathrm{dB}]$, leading to a reduction in the bit error rate (BER) from 0.051 to 0.035. This significant improvement in equalization can be attributed to the GB's **ability to transfer learning** across different power levels, proving its versatility and effectiveness in real-world scenarios. This exciting outcome highlights the potential of GB in optimizing signal power and reducing errors in optical transmission systems.

Same Model, Different Power





Conclusion

This study showcases the impressive potential of using Gradient Boosting (GB) for **nonlinear equalization** in optical transmission systems. Our results indicated significant improvement in the Q-factor and a decrease in BER after GB was applied to a large dataset. GB's ability to accurately predict nonlinear distortions makes it a highly promising solution for enhancing the performance of optical communication systems. Its compatibility with **FPGA** technology adds to its practicality, making it easily integrable into existing systems.

It's important to note that GB is part of a larger family of machine learning techniques known as forest methods, which are known for their **robustness and versatility**. The results of this study further emphasize the awesome power of forest methods in the field of nonlinear equalization and warrant further exploration and research.

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