Machine Learning Equalization Techniques for High Speed PAM4 Fiber Optic Communication Systems

Ilya Lyubomirsky
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We simulate a high-speed 112 Gb/s PAM4 fiber optic link, including the impact of fiber dispersion and amplifier noise. A/D samples the received waveform at 2 samples per symbol, and feeds N samples to the equalizer/decision circuit.

An eye diagram provides a visualization on the impact of transmission impairments. Ideal PAM4 eye diagram should show "open" eyes, as in a) with no noise/dispersion. The addition of amplifier noise in b), closes the eyes, shows more noise on higher PAM4 levels due to square law detection. When both noise and dispersion are included in c), the eye is completely closed and conventional receiver is not able to successfully distinguish the PAM4 symbols.

Machine Learning for Digital Equalization

Machine Learning Algorithms

All the algorithms are implemented using Matlab's Statistics and Machine Learning Toolbox:
- Linear equalization (or linear regression) with minimum MSE parameter fitting: using the fitlm function
- Volterra equalization (or polynomial regression) with minimum MSE parameter fitting: using the fitlm function
- Softmax regression with maximum likelihood estimate of parameters: using the mnrfit function with logit link function
- K nearest neighbors (KNN) classification: using fitcknn function with K optimized using a separate validation data set
- Neural Network, designed with 2 hidden layers, N neurons in each layer: using feedforwardnet function with training based on Levenberg-Marquardt algorithm

Feature Correlation Heat Map

Pairwise Feature Scatter Diagrams

Monte-Carlo Simulation Results

Conclusions

- Machine learning algorithms for regression and classification may provide novel ideas for equalization and detection in digital communication systems
- We employ Monte-Carlo simulation of an 112 Gb/s PAM4 fiber optic communication system to compare several interesting machine learning algorithms in terms of test data set symbol error rate
- The simplest least squares regression scheme shows relatively poor performance; polynomial regression with linear + interaction (x*x) terms offers good performance with modest increase in complexity
- The most complex regression scheme based on Neural Networks gives excellent performance but with a high price in complexity
- Interestingly, the relatively simple KNN (K=5) gives the best performance for small number of samples ~ 9; KNN performs poorly as the feature space expands to > 13 dimensions due to the well known "curse of dimensionality"