LDPC Coded Modulation with Probabilistic Shaping for Optical Fiber Systems

Tobias Fehenberger(1), Georg Böcherer(1), Alex Alvarado(2), and Norbert Hanik(1)
(1) Technische Universität München (TUM), Germany (2) University College London (UCL), UK

Abstract

An LDPC coded modulation scheme with probabilistic shaping, optimized interneurons and noniterative demapping is proposed. Full-field simulations show an increase in transmission distance by 8% compared to uniformly distributed input.

- High-order modulation formats are an established technique to increase spectral efficiency.
- Further improvement of the SE by probabilistic shaping, which allows optimization of the signaling without increasing the average launch power.
- Main advantage: No modifications of the digital-to-analog converters and the signal processing.

Probabilistic Shaping

- Probabilistic shaping uses constellations with nonuniform distributions on a regular grid.
- 16-QAM and 64-QAM are shaped by assigning larger probabilities to the points with lower energy.

Introduction

Four Steps to Find a Shaped Input Distribution

1. Use Gaussian noise (GN) model [1] to find the effective signal-to-noise ratio (SNR).
2. Consider AWGN channel operated at this SNR.
3. Jointly optimize the Maxwell-Boltzmann distribution \( P_X(x) \) of the input X and the constellation scaling [2] such that symbolwise mutual information (MI) is maximized.
4. The obtained distribution \( P_X(x) \) is used as shaped input of the optical fiber system.

Probabilistic Shaping

- Probabilistic shaping uses constellations with nonuniform distributions on a regular grid.
- 16-QAM and 64-QAM are shaped by assigning larger probabilities to the points with lower energy.

Figure 2: System Diagram.

- The distribution matcher [3] output is emulated by directly generating the shaped bits.
- LDPC encoder and decoder are optimized for our coded modulation scheme [4].

Four Steps to Find a Shaped Input Distribution

1. Use Gaussian noise (GN) model [1] to find the effective signal-to-noise ratio (SNR).
2. Consider AWGN channel operated at this SNR.
3. Jointly optimize the Maxwell-Boltzmann distribution \( P_X(x) \) of the input X and the constellation scaling [2] such that symbolwise mutual information (MI) is maximized.
4. The obtained distribution \( P_X(x) \) is used as shaped input of the optical fiber system.

Results (BER)

- Implementation of an LDPC coded modulation scheme with probabilistic shaping.
- Low complexity as no iterative demapping is required at the receiver.
- BER analysis confirms: Increase in transmission distance by 8% (16-QAM) and 15% (64-QAM) for shaped input compared to uniformly distributed input.

Figure 4: BER after LDPC decoding at 3 bits per symbol information rate.

Results (Mutual Information)

- Shaped vs. uniform input: Increase in transmission distance by 8% (16-QAM) and 15% (64-QAM).
- Rates of shaped 16-QAM similar to uniform 64-QAM for longer distances.

Figure 5: Shaped 64-QAM outperforms uniform 64-QAM (both with electronic dispersion compensation (EDC)) in rate and distance and gives similar rates as uniform input with SC DBP. Insets a) and b) show the shaped received symbols after 3 and 16 spans, respectively.