LDPC Coded Modulation with Probabilistic Shaping for Optical Fiber Systems

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Introduction

Abstract

An LDPC coded modulation scheme with probabilistic shaping, optimized interleavers 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.

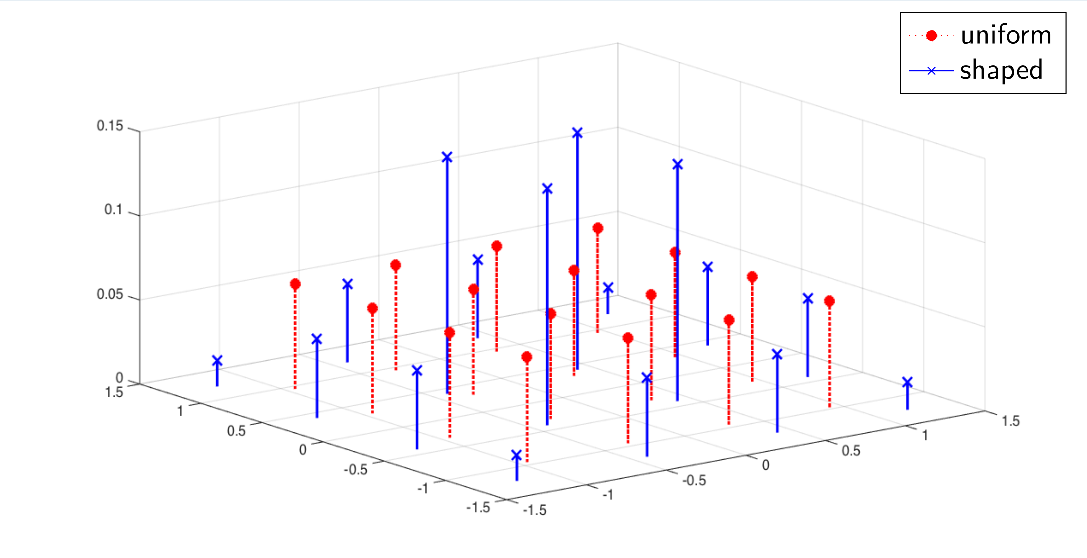

Figure 1: Illustration of uniform (red) and shaped (blue) 16-QAM at unit energy. Here, shaped 16-QAM has a 30% larger minimum Euclidean distance and hence a higher noise tolerance than uniform input.

System Design

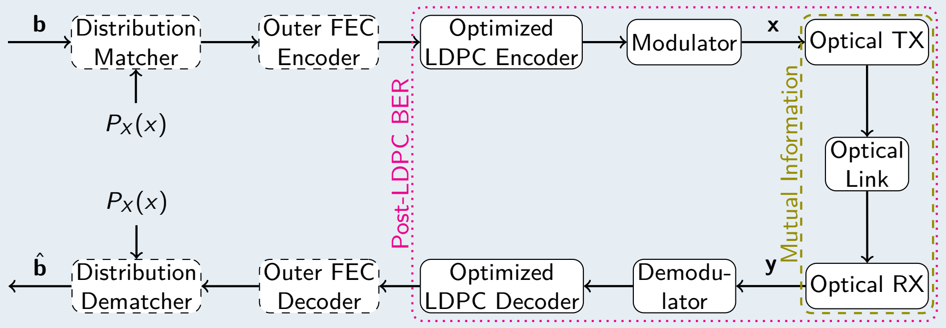

Figure 2: System Diagram. **b** and $\hat{\mathbf{b}}$ are uniformly distributed information bits.

- 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].

References

[1] P. Poggiolini *et al.*, "The GN-model of fiber non-linear propagation and its applications," *JLT* **32**(4), 2014.

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[3] P. Schulte and G. Böcherer, "Constant composition distribution matching," arXiv:1503.05133, 2015.

[4] G. Böcherer, P. Schulte, and F. Steiner, "Bandwidth efficient and rate-compatible low-density parity-check coded modulation," arXiv:1502.02733, 2015.

[5] B. P. Smith *et al.*, "Staircase codes: FEC for 100 Gb/s OTN," *JLT* **30**(1), 2012.

System and Simulation Parameters

System Parameters		Fiber Parameters	
WDM channels	15	Attenuation α	0.2 dB/km
WDM spacing	30 GHz	Nonlinearity γ	1.3 (W·km)$^{-1}$
Symbol rate	28 GBaud	Dispersion D	17 ps/nm/km
Pulse shaping	Root-raised-cosine	Length per span	100 km
RRC roll-off	5% roll-off	Amplification	EDFA (4 dB)

- Center WDM channel is processed
- Electronic dispersion compensation (EDC) at receiver
- Estimation of symbolwise mutual information without memory
- Inner FEC: DVB-S2 LDPC codes with block length of 64800 bits

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

Mutual Information Analysis

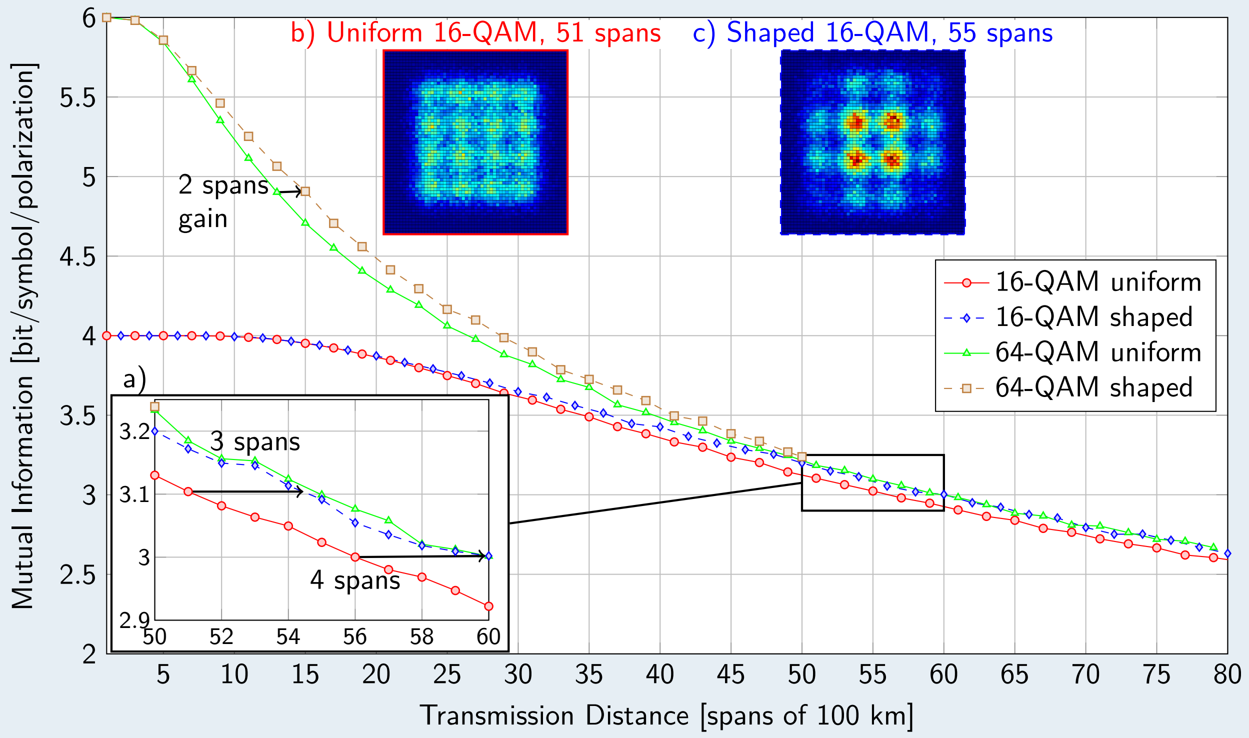

Figure 3: Mutual information versus distance. Each point is obtained at the optimum launch power. Insets: a): Zoom from 50 to 60 spans. b) and c): Distributions of the received symbols for uniform and shaped input.

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

BER Analysis: Comparison of the BERs of uniform and shaped 16-QAM

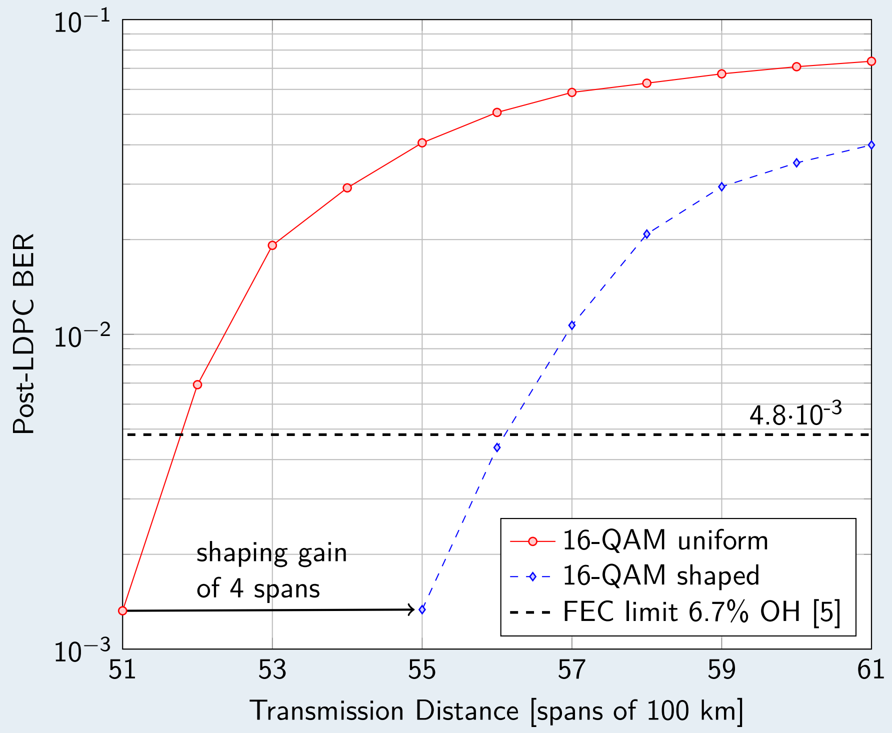

Figure 4: BER after LDPC decoding at **3 bits per symbol information rate**.

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

Shaping is as Powerful as Ideal Single-Channel Digital Back-Propagation (SC DBP)

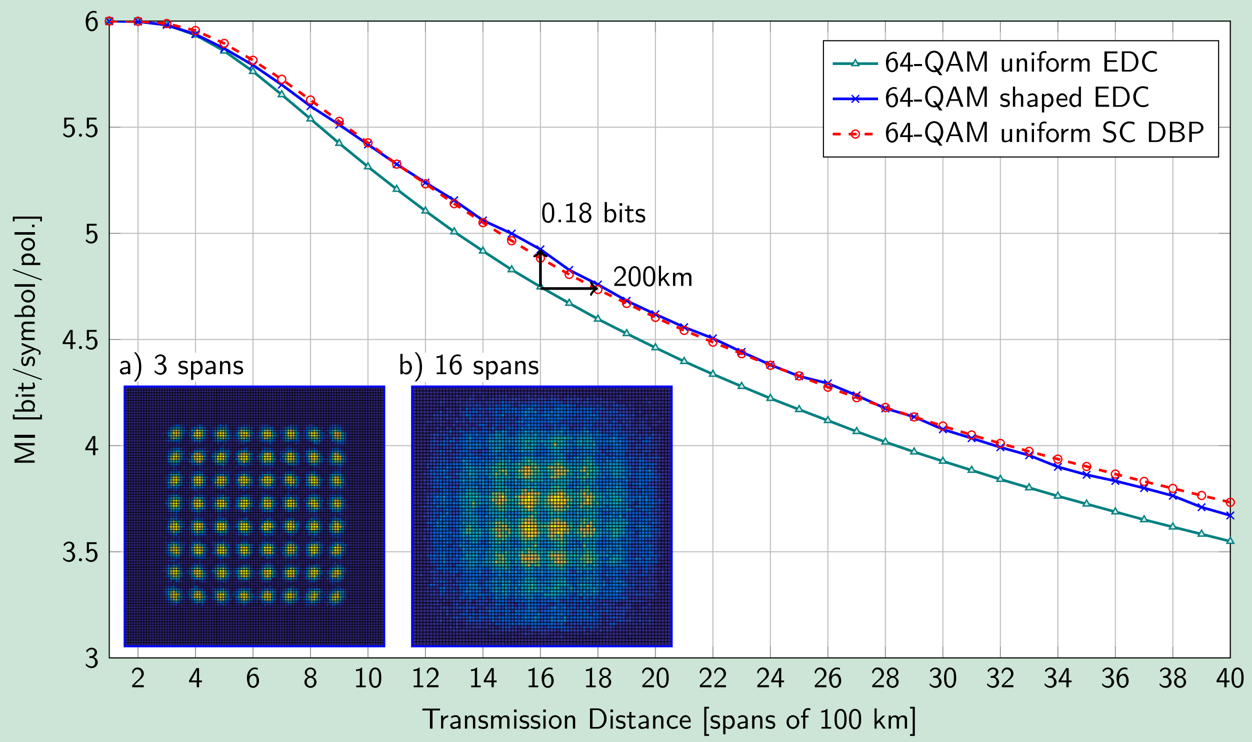

Figure 5: Shaped 64-QAM outperforms uniform 64-QAM (both with electronic dispersion compensation (EDC)) in rate and distance and gives similar rates as uniform input with SC DBP. Insets a) and b) show the shaped received symbols after 3 and 16 spans, respectively.

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