**Introduction**

- Combination of high-order constellations and coding for bandwidth limited communication.
- Need for binary labeling of constellation points to be able to use binary codes.
- Bit-Interleaved coded modulation (BICM) is widely used in standards (DVB-S2, Wi-LAN, WiMax).
- It employs a bit-parallel decoder (BMD) at the receiver.
- Resulting information-theoretic system model consists of a set of parallel channels.

**System Model**

- Single Input, Single Output AWGN channel with ASK input:
  \[ Y = X + Z = \Delta x + Z, \quad Z \sim N(0, 1) \]
- 2^n ASK input constellation, labeled by a reflected Gray code in \( n \in \{ \pm 2, \pm 4, \ldots, \pm 2^n \} \), \( \Delta \in \mathbb{R}^2 \): constellation scaling, parameterizes the SNR.
- The demapper calculates E-values:
  \[
  \begin{align*}
  &B_{1,1} = \rho_{B,1}(Y) = \mathbb{I}(B_1 = B_1), \\
  &B_{2,1} = \rho_{B,2}(Y) = \mathbb{I}(B_1 = B_1), \\
  &B_{3,1} = \rho_{B,3}(Y) = \mathbb{I}(B_1 = B_1), \\
  \end{align*}
  \]
- Achievable rate [3]:
  \[
  R_{\text{ach}} = \sum_{i=1}^{2^n} \mathbb{I}(B_i = B_i) \approx \frac{1}{2^n} \sum_{i=1}^{2^n} \mathbb{I}(B_i = B_i) - \mathbb{I}(B_i = B_i)
  \]

**Design Challenge**

- The m binary input channels \( p_{B,i} \) are of different reliability: The employed channel code has to take this into account.
  - Need for structured ensembles to inherit the different bit-channels: multi-type edge (MET) or Protograph-based codes.
  - Usual toolchain assumes binary-input symmetric-output (BISO) channels. Does not hold for \( p_{B,i} \).

## References


## Probabilistic Amplitude Shaping – PAS [2]

**Optimal Shaping**

- Capacity \( 1/2 \log(1 + \text{SNR}) \) is achieved by Gaussian input.
- Optimal constellation constrained capacity can be found as the solution of
  \[
  \max_{\Delta \in \mathbb{R}^2} \Delta \mathcal{D}(Y|\Delta X), \quad \Delta \mathcal{D}(Y|\Delta X) = \frac{1}{2} \log \frac{\mathcal{D}(Y|\Delta X)}{\mathcal{D}(Y|\Delta X)}
  \]
- Optimal distribution \( P_\Delta \equiv P_{\Delta} \) is symmetric and therefore exhibits an Amplitude-Sign Factorization
  \[
  P_{\Delta}(x) = P_\Delta |x| P_\Delta(\text{sign}(x))
  \]
- Sign is uniformly distributed, i.e., \( P_\Delta(-1) = P_\Delta(1) = \frac{1}{2} \).

**Combining Linear Codes with Probabilistic Shaping – PAS**

- Use existing LDPC code and optimize the interleaver, i.e., assign the different coded bits belonging to the m channels to the different variable node degrees (e.g., Li, Ryan, 2015: Hager et al. 2012).
- “Wholistic approach”: tackle problem of interleaver and code design at the same time. (Zhang, Kschischang, 2013: Uses multidimensional extension of EXIT analysis and channel adapters.)

**Our contribution**

- Wholistic approach based on protographs.
- Threshold analysis via P-EXIT and surrogate channels.
- New matching criteria based on rate backoff.

## Protograph-Based LDPC Code Design [4]

**Existing approaches**

- Use existing LDPC code and optimize the interleaver, i.e., assign the different coded bits belonging to the m channels to the different variable node degrees (e.g., Li, Ryan, 2015: Hager et al. 2012).
- “Wholistic approach”: tackle problem of interleaver and code design at the same time. (Zhang, Kschischang, 2013: Uses multidimensional extension of EXIT analysis and channel adapters.)

**Our contribution**

- Wholistic approach based on protographs.
- Threshold analysis via P-EXIT and surrogate channels.
- New matching criteria based on rate backoff.

## Simulation Results

- 64-ASK Shaped, Blocklength 64K00, 100 iterations

![Simulation Results](image-url)