Information and Communication Theory (ICT) Lab

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Improved Bit-mappings for IEEE 802.11 LDPC Codes with Applications to Amplitude Shaping

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Low-density Parity-check (LDPC) Codes

- Linear block codes with an $(n-k)$-by-n parity check (PC) matrix $\boldsymbol{H}$
- Each n-bit codeword $\boldsymbol{c}$ satisfies $\boldsymbol{c}\boldsymbol{H}^T = \boldsymbol{0}$
  - There are $n-k$ PC equations
- **Tanner graph:** Check nodes for PC equations, variable nodes for coded bits
- **Variable node degree:** Number of PC equations that a coded bit is a part of

$$\boldsymbol{H} = \begin{bmatrix} 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix}$$

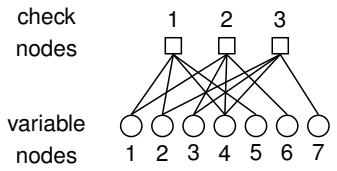

Figure 1: A Tanner graph and the corresponding parity-check matrix [1].

Bit-interleaved Coded Modulation

- For 2^m-ary amplitude-shift keying (ASK)
  - Channel inputs $X \in \mathcal{X} = \{\pm 1, \pm 3, \ldots \pm (2^m - 1)\}$
  - A binary labeling $(B_1, B_2, \ldots, B_m) \to X$

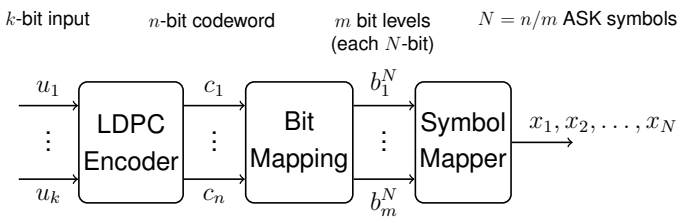

Figure 2: Bit-interleaved coded modulation transmitter.

Unequal Error Protection

- Uncoded bit error rate (BER) is not identical for each bit level b_i
- **Uniform signaling:** $p(b_i)$ is the same for $i = 1, 2, \ldots, m$
  - More significant bit levels (i.e., smaller i) are more protected & have smaller BER
- **Shaped signaling:** $p(b_i)$ is **not** the same for $i = 1, 2, \ldots, m$
  - Protection depends also on the a priori distribution $p(b_i)$

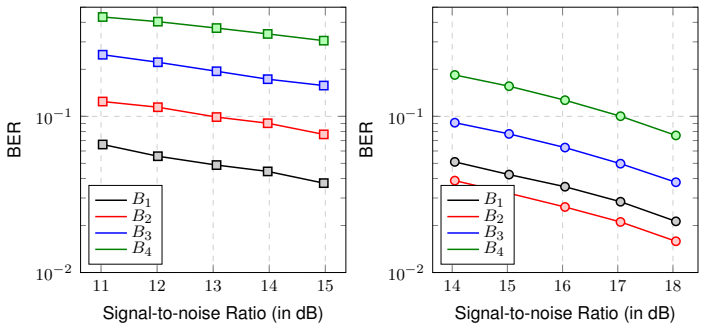

Figure 3: Pre-decoding, hard-detection BER for uniform (left) and shaped [2-3] (right) 16-ASK with 4 and 3.5 bits of entropy, respectively.

Bit Mapping from the Codeword to the Bit Levels

Regular Mapping

- Coded bits are consecutively grouped into m-bit vectors and mapped to symbols
  - $(c_1, c_2, \cdots, c_m) \to x_1$
  - $(c_{m+1}, c_{m+2}, \cdots, c_{2m}) \to x_2$
  - $\vdots$
  - $(c_{n-m+1}, c_{n-m+2}, \cdots, c_n) \to x_N$

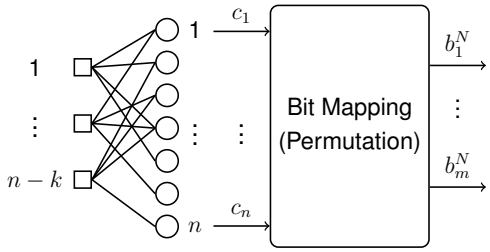

Figure 4: Bit mapping from coded bits to bit levels.

Modified Mapping

- Coded bits with **higher variable node degrees** are mapped to bit levels that are **more protected from the channel**
- Coded bits with **smaller BER** are included in **a higher # of PC equations**

End-to-end Decoding Results

- Transmission of 16-ASK over the AWGN channel
- Rate-5/6 and 3/4 LDPC codes of the IEEE 802.11 standard for uniform and shaped signaling, respectively.

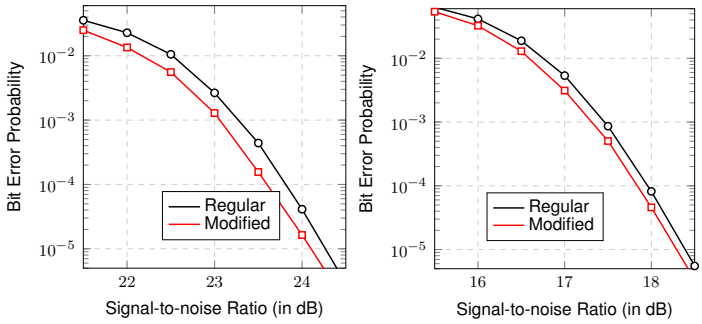

Figure 5: Post-decoding BER for rate-5/6-coded uniform signaling (left, 3.33 bit/1D) and rate-3/4-coded shaped [4] signaling (right, 2.5 bit/1D).

- **Result: 0.2 and 0.1 dB gain for uniform and shaped signaling, respectively.**

[1] T. Richardson et al., "Modern Coding Theory", Cambridge, UK: Cambridge University Press, 2008.
[2] Y. C. Gültekin et al., "Approximate enumerative sphere shaping", International Symposium on Information Theory (ISIT), 2018.
[3] Y. C. Gültekin et al., "Enumerative sphere shaping for wireless communications with short packets", Transactions on Wireless Communications, Feb. 2020.
[3] G. Böcherer et al., "Bandwidth efficient and rate-matched low-density parity-check coded modulation", Transactions on Communications, Dec. 2015.