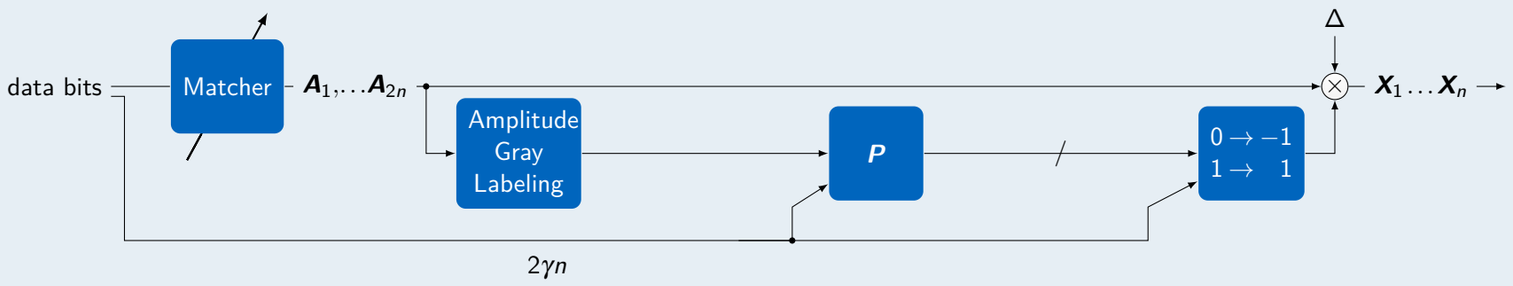
Institute for Communications Engineering
Department of Electrical and Computer Engineering
Technical University of Munich

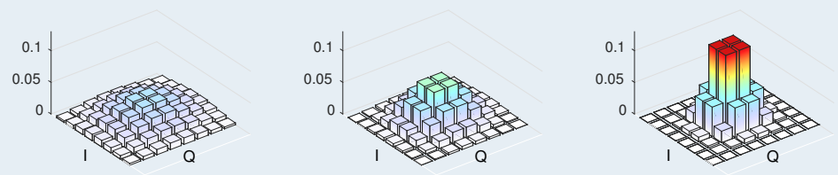
Coding and Modulation for Industrial Applications

Georg Böcherer, Tobias Prinz, Patrick Schulte, Fabian Steiner, Peihong Yuan

Introduction: Power-Efficient Communication for High Spectral Efficiencies



- data bits $\sim$ Bernoulli $\left(\frac{1}{2}\right)$
- Matcher: transform data bits into symbols with desired distribution
- $\boldsymbol{P}$: Parity matrix of a systematic code with code rate $\frac{m-1+\gamma}{m}$
- 2^{2m}-QAM: $\boldsymbol{X}_i = \Delta(\pm\boldsymbol{A}_{2i-1} \pm j\boldsymbol{A}_{2i})$
  $\boldsymbol{A}_i \in \mathscr{A} = \{1,3,\dots,2^m-1\}$
- AWGN: $\boldsymbol{Y}_i = \boldsymbol{X}_i + \boldsymbol{N}_i$, $\boldsymbol{N}_i \sim \mathscr{CN}(0,\sigma^2)$
- control rate and power via P_A and Δ



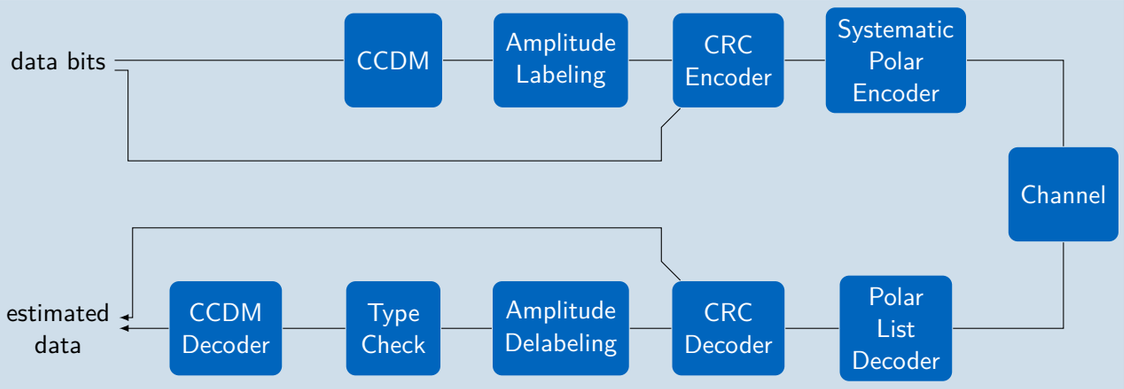
Short Length

Where do short block length codes play a role?

Mobile Communications (e.g., 5G)

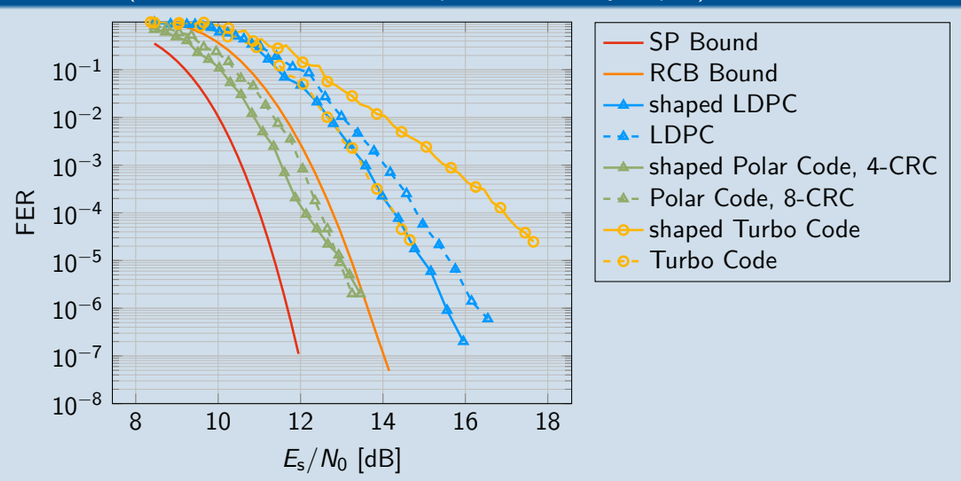
- Enhanced mobile broadband (eMBB).
- Massive machine-type communications (mMTC)
- Ultra-reliable and low-latency communications (uRLLC).

Polar Coded Probabilistic Amplitude Shaping



- Constant Composition Distribution Matcher (CCDM):
  - outputs amplitude sequences $\boldsymbol{a} = a_1 a_2 \cdots a_n$ where
    $$n_\alpha(\boldsymbol{a}) = |\{i \mid a_i = \alpha\}| \quad \alpha \in \mathscr{A} = \{1,3,\dots,2^m-1\}$$
  - The type $[n_1(\boldsymbol{a}), n_3(\boldsymbol{a}), \dots, n_{2^m-1}(\boldsymbol{a})]$ is constant for every CCDM output sequence.
- CRC Encoder: Outer cyclic redundancy codes improve the distance spectrum of polar codes
- Systematic Polar Encoder
  - multilevel polar encoding
  - systematic encoding based on dynamically frozen bits
- Polar List Decoder: outputs a list of possible codewords
- CRC Decoder: Remove codewords from the list which do not pass the CRC-Check
- Type Check: Remove amplitude sequences from the list that do not match the type of the CCDM

Numerical Results (64-QAM, 32 channel uses, spectral efficiency 3 bpcu)



5G Standardization

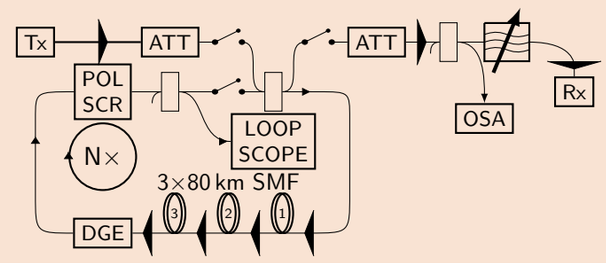
Proposal for probabilistic constellation shaping recently brought into **5G standardization** as Tdoc.

HUAWEI

Long Length

Coding for optical communication

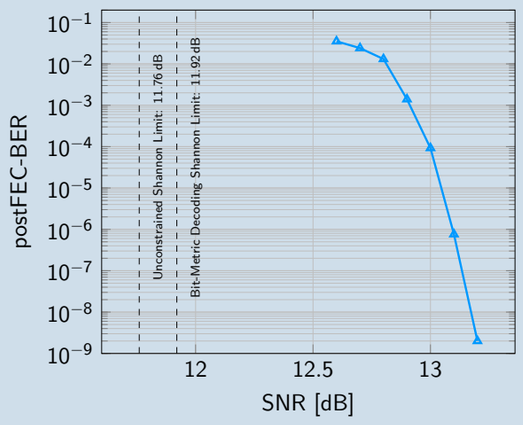
- Extreme high decoding throughput required ($>$ 100 Gbit/s).
- Very low error floors ($< 10^{-15}$ BER).
- Use of spatially-coupled soft or hard decision codes with window decoding.



Spatially-coupled LDPC codes

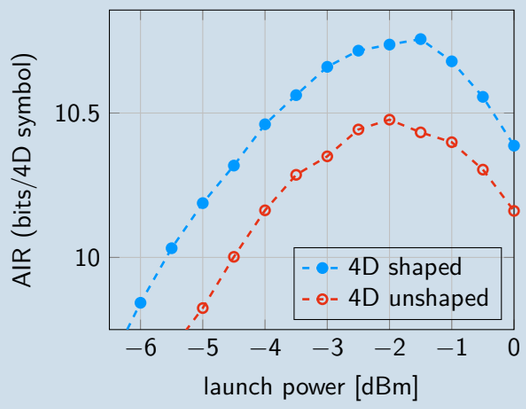
- Convolutional structure with syndrome formers $\boldsymbol{H}_i \in \{0,1\}^{m_c \times n_c}$ with L spatial positions and memory μ.
- Decoding via a window decoder for reduced latency.
- Very good thresholds and error floor behavior with simple code constructions.
- Practical constructions are Protograph based and employ offset-corrected min-sum updates at check nodes.

$$\boldsymbol{H} = \begin{pmatrix} \boldsymbol{H}_0 & & & \\ \boldsymbol{H}_1 & \boldsymbol{H}_0 & & \\ \vdots & \boldsymbol{H}_1 & \ddots & \\ \boldsymbol{H}_\mu & \vdots & \ddots & \\ & \boldsymbol{H}_\mu & \ddots & \boldsymbol{H}_0 \\ & & & \boldsymbol{H}_1 \\ & & & \vdots \\ & & & \boldsymbol{H}_\mu \end{pmatrix}_{(L+\mu)m_c \times Ln_c.}$$



Higher Dimensional Signaling

- Four or higher dimensional signaling to obtain a linear and non-linear shaping (mitigating local power variations is beneficial for phase noise).
- Shaping is performed via simple look-up tables or shell-mapping.
- Complexity tradeoff between facilitated shaping and higher-dimensional demapping.



Field Trials

Field trials of the probabilistic shaping scheme have been performed by Deutsche Telekom, Nokia Bell Labs and Facebook.

NOKIA Bell Labs

Bibliography

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[3] T. Prinz, P. Yuan, G. Böcherer, F. Steiner, O. Iscan, R. Böhnke, and W. Xu, "Polar coded probabilistic amplitude shaping for short packets," in *IEEE Int. Workshop Signal Process. Advances Wireless Commun. (SPAWC)*, 2017.

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