Combining Belief Propagation and Successive Cancellation List Decoding of Polar Codes on a GPU Platform

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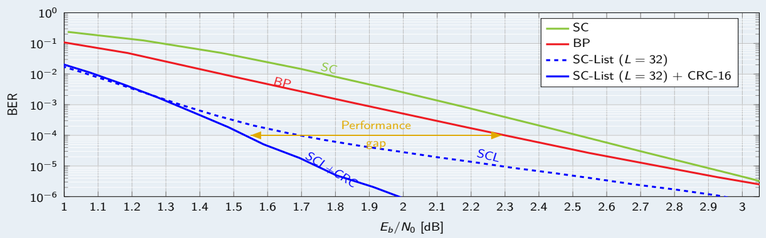
Motivation

Polar codes are proven to be capacity achieving under successive cancellation (SC) decoding [1] for infinite block lengths. However, for short lengths:

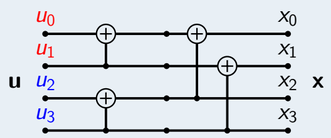
- Error correction capabilities of polar codes depend on decoding algorithm
- SCL-CRC shows best correction performance
- But: SCL decoding algorithm exhibits low throughput



Polar Codes

A Polar encoder maps the k information bits onto the k most reliable bit positions of the vector $\mathbf{u}$ while the remaining $N - k$ positions are treated as frozen positions.

- Frozen bits u_f are set to an arbitrary value
- Encoder graph can be used to encode information bits $\mathbf{u}$
- Codeword $\mathbf{x}$ can be transmitted

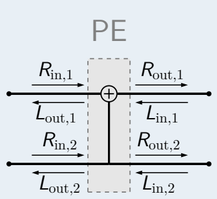


Iterative Decoding of Polar Codes

BP decoding of polar codes is a message passing algorithm based on the encoding scheme with decoding complexity $\mathcal{O}(N \cdot \log(N))$. The transmitted codeword $\hat{\boldsymbol{x}}$ and the message $\hat{\boldsymbol{u}}$ can be both estimated simultaneously.

- Iterative decoder, update stage-per-stage
- $\frac{N}{2}$ processing elements (PE) per stage, n stages
- Log-likelihood ratios calculated:

$$R_{\text{out},1} = \text{g}(R_{\text{in},1}, L_{\text{in},2} + R_{\text{in},2})$$
$$R_{\text{out},2} = \text{g}(R_{\text{in},1}, L_{\text{in},1}) + R_{\text{in},2}$$
$$L_{\text{out},1} = \text{g}(L_{\text{in},1}, L_{\text{in},2} + R_{\text{in},2})$$
$$L_{\text{out},2} = \text{g}(R_{\text{in},1}, L_{\text{in},1}) + L_{\text{in},2}$$



Successive Cancellation List Decoding and CRC Aided Decoding

SC decoding:

- Inherently serial algorithm (Complexity: $\mathcal{O}(N \cdot \log(N))$ [1])
- Sequential bit decision aided by previous decisions

SCL decoding:

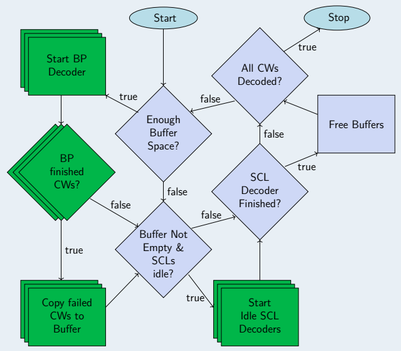
- Adds a list of size L (Complexity: $\mathcal{O}(L \cdot N \cdot \log(N))$ [2])
- Estimates L different possible codewords

The decoding performance can be enhanced by an additional CRC check [2]:

- For SCL: Final estimate is chosen by a reliability metric M_l
- For SCL-CRC: Final estimate is chosen by reliability metric M_l from a CRC-correct subset of the estimated codewords

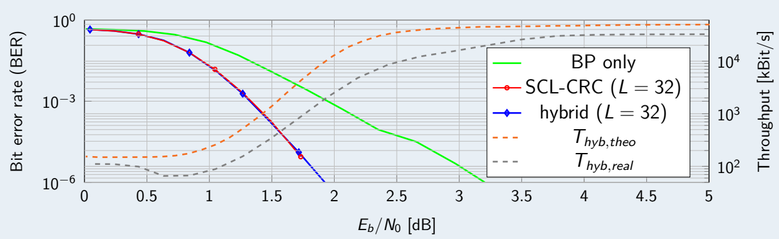
Combining BP and SCL Decoding

- BP algorithm: High throughput (More suitable for GPU implementation [3])
- SCL-CRC algorithm: Superior BER performance compared to BP [4]
- Idea: If BP-decoder fails SCL-CRC decoder is started
  - Throughput of hybrid decoder depends on SNR
  - BER performance equals SCL performance



Decoding Performance

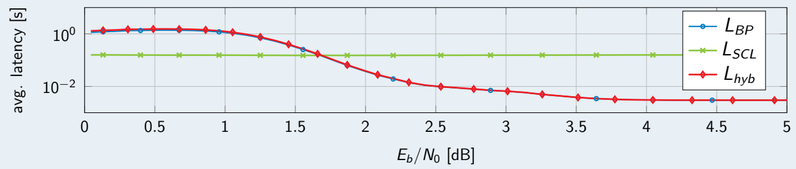
- Hybrid decoder exhibits same error correction capabilities as SCL-CRC
- Throughput of hybrid decoder depending on channel SNR
- Maximum achieved decoding throughput 34 Mbit/s (N=4096, L=32 and R=0.5)



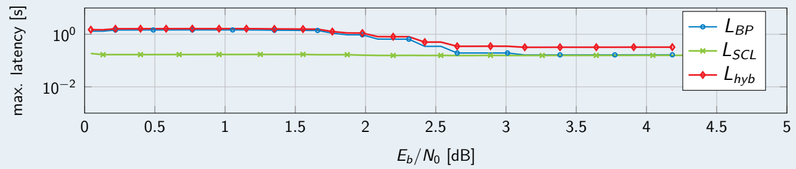
Latency

Whenever BP decoding fails and SCL decoding must be performed the total latency L_{hyb} increases.

- Average latency of SCL-CRC is independent of the SNR
- The hybrids latency is strongly dependent on the BPs latency



The maximum latency of the hybrid is lower bounded by the SCL-CRCs latency. For BP decoding the maximum latency depends on the maximum number of iterations.



Improved latency performance compared to e.g. [5] for target SNR region.

Summary and Outlook

- SCL-CRC decoding algorithm:
  - Not optimal for a parallel implementation
  - Small speedup observable for optimized parallel version
  - Advantage: For parallel simulations no data transfer between GPU and CPU necessary
- Hybrid decoder algorithm:
  - Achievable throughput: Up to $30\frac{\text{MBit}}{\text{s}}$
  - No degradation of error correction behaviour of SCL-CRC decoder
  - Decrease in average latency

References

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[2] I. Tal and A. Vardy, "List decoding of polar codes," vol. 61, no. 5, pp. 2213–2226, May 2015.

[3] B. K. Reddy L. and N. Chandrachoodan, "A GPU implementation of belief propagation decoder for polar codes," in *Proc. Asilomar Conf. on Signals, Systems, and Computers*, Nov. 2012, pp. 1272–1276.

[4] K. Niu, K. Chen, J. Lin, and Q. T. Zhang, "Polar codes: Primary concepts and practical decoding algorithms," vol. 52, no. 7, pp. 192–203, Jul. 2014.

[5] B. Li, H. Shen, and D. Tse, "An adaptive successive cancellation list decoder for polar codes with cyclic redundancy check," *IEEE Comm. Letters*, Dec. 2012.

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