A Polar Code Decoding Algorithm with Joint Neural Belief Propagation Decoder and Channel Equalizer

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Abstract

- Polar Codes
  - Capacity-achieving for codes of infinite length
  - Low-complexity encoding and decoding
  - Selected for 5G eMBB control channel [1]
- Deep Learning aided Approaches for Decoding Linear Codes
  - **One-hot** decoding algorithm
  - Reduce decoding latency of conventional decoders
  - Preserve the symmetric conditions of the codes under specific settings
  - Gradient-based optimization algorithm for conventional decoders

Polar Codes [2]

- $\mathcal{P}(N, K)$: polar code of length N and rate $\frac{K}{N}$
- K best reliable bits to transmit information bits
- Belief Propagation (**BP**) Decoding:
  - Reasonable error-correction performance with enough number of iterations I
  - Latency: $\mathcal{T}_{\text{BP}} = 2I \log_2 N$ (time steps)
  - High throughput

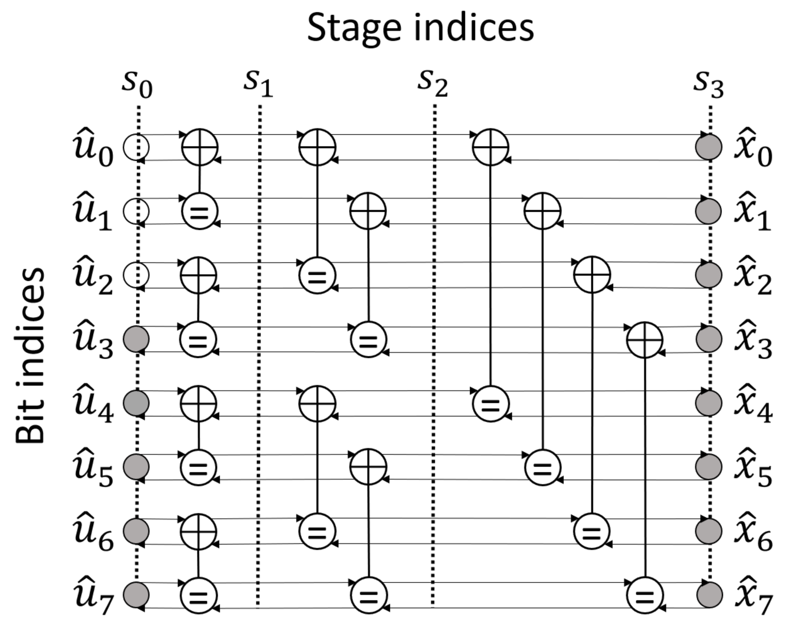
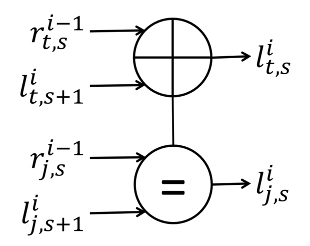
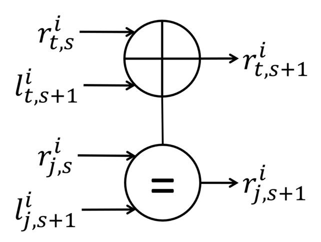


Figure: BP decoding for $\mathcal{P}(8,5)$



(a) A right-to-left Processing Element (PE)



(b) A left-to-right PE

Neural BP Decoding Algorithm [3]

- Assign trainable weights to the inputs of the PEs and train them using backprop
- Mitigate the detrimental effects of the code's short cycles
- Improve the convergence speed of the decoding process

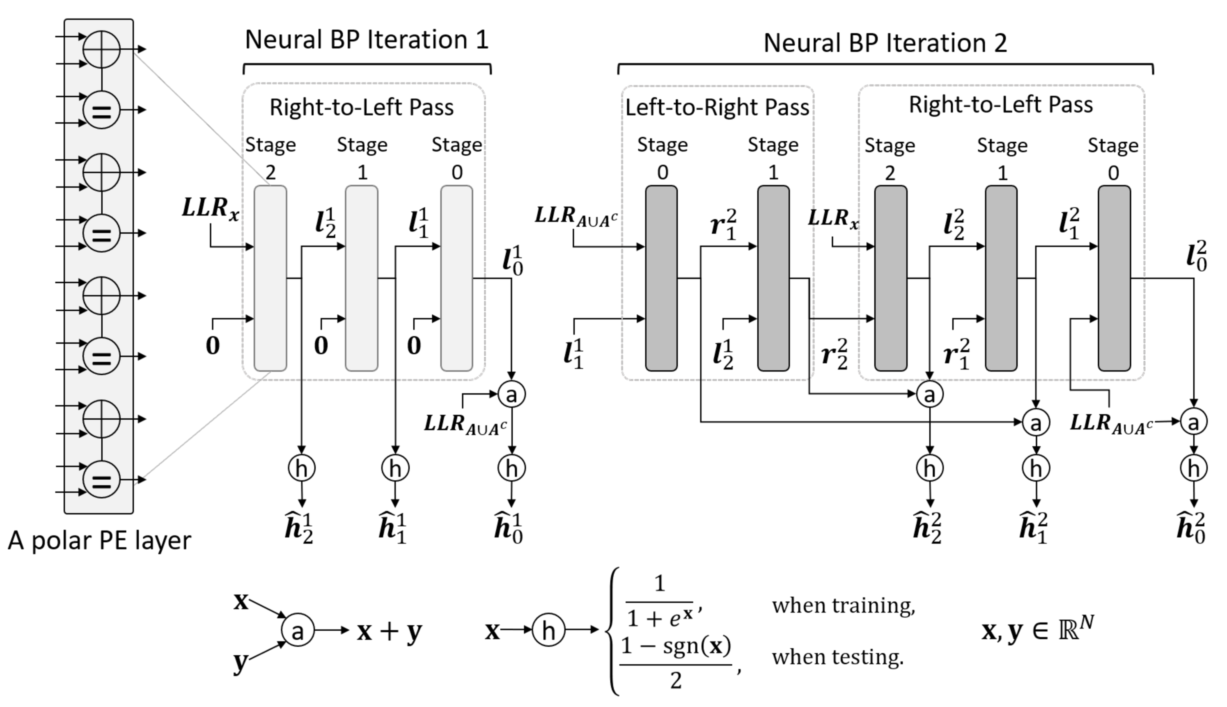


Figure: A Neural BP Decoding Architecture for $\mathcal{P}(8,5)$

Syndrome-Based Decoding Algorithm [4]

- Model the Additive White Gaussian Noise as multiplicative noise
- Reduce the learning problem from regression to classification

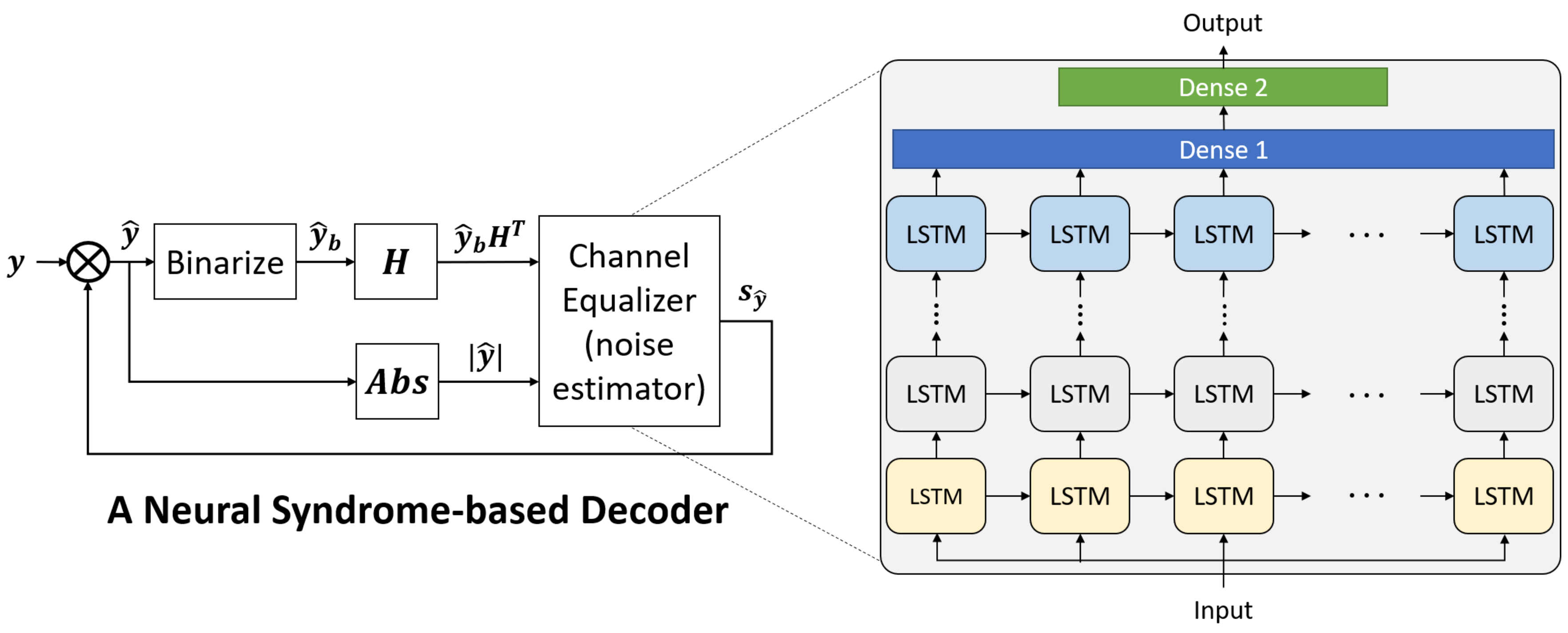


Figure: A Neural Syndrome-based Decoding Architecture for Linear Block Codes

Joint Neural BP Decoder and Channel Equalizer

- Iteratively improve the channel reliability and decoding performance
- Resemble a cooperative learning system
- The Neural BP Decoder is firstly trained
- The Channel Equalizer is then trained to minimize decoding errors

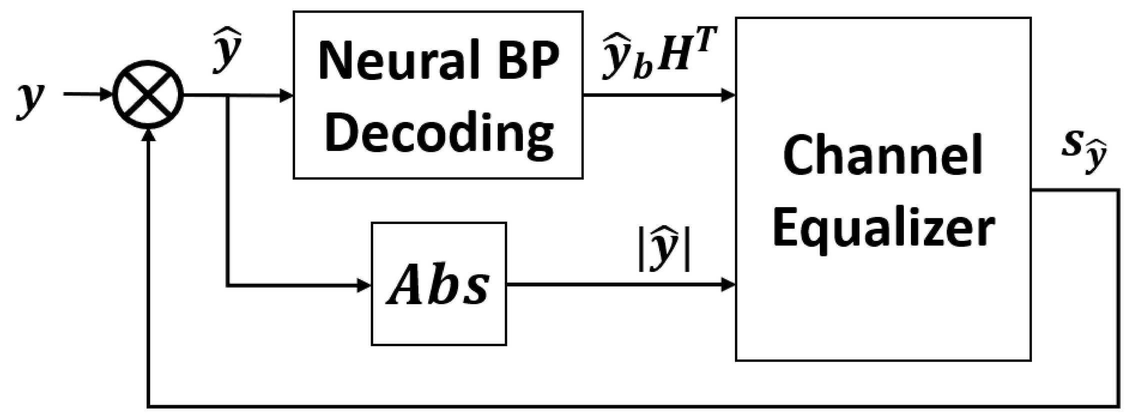


Figure: The Proposed Decoding Algorithm with Joint Neural BP Decoder and Channel Equalizer

Configurations

- Polar codes: $\mathcal{P}(64, 32)$, used in 5G.
- Neural BP Decoder
  - Training at $SNR \in \{3, 3.5, 4, 4.5, 5, 5.5, 6\}$ dB
  - Obtain 10^5 random codewords at each SNR value
  - Epochs: 50, batch size: 350, iterations: 5, optimizer: RMSPROP
- Channel Equalizer
  - Model: 4-layered LSTMs with 5 time steps, 2 fully connected layers
  - Training at $SNR \in \{3, 3.5, 4, 4.5, 5, 5.5, 6\}$ dB
  - Obtain 10^5 random codewords at each SNR value
  - Epochs: 50, batch size: 350, optimizer: RMSPROP
- Deep Learning Framework: Tensorflow
- Testing
  - Simulate at least 10^5 random codewords
  - Minimum number of frames in errors: 50

Experimental Results

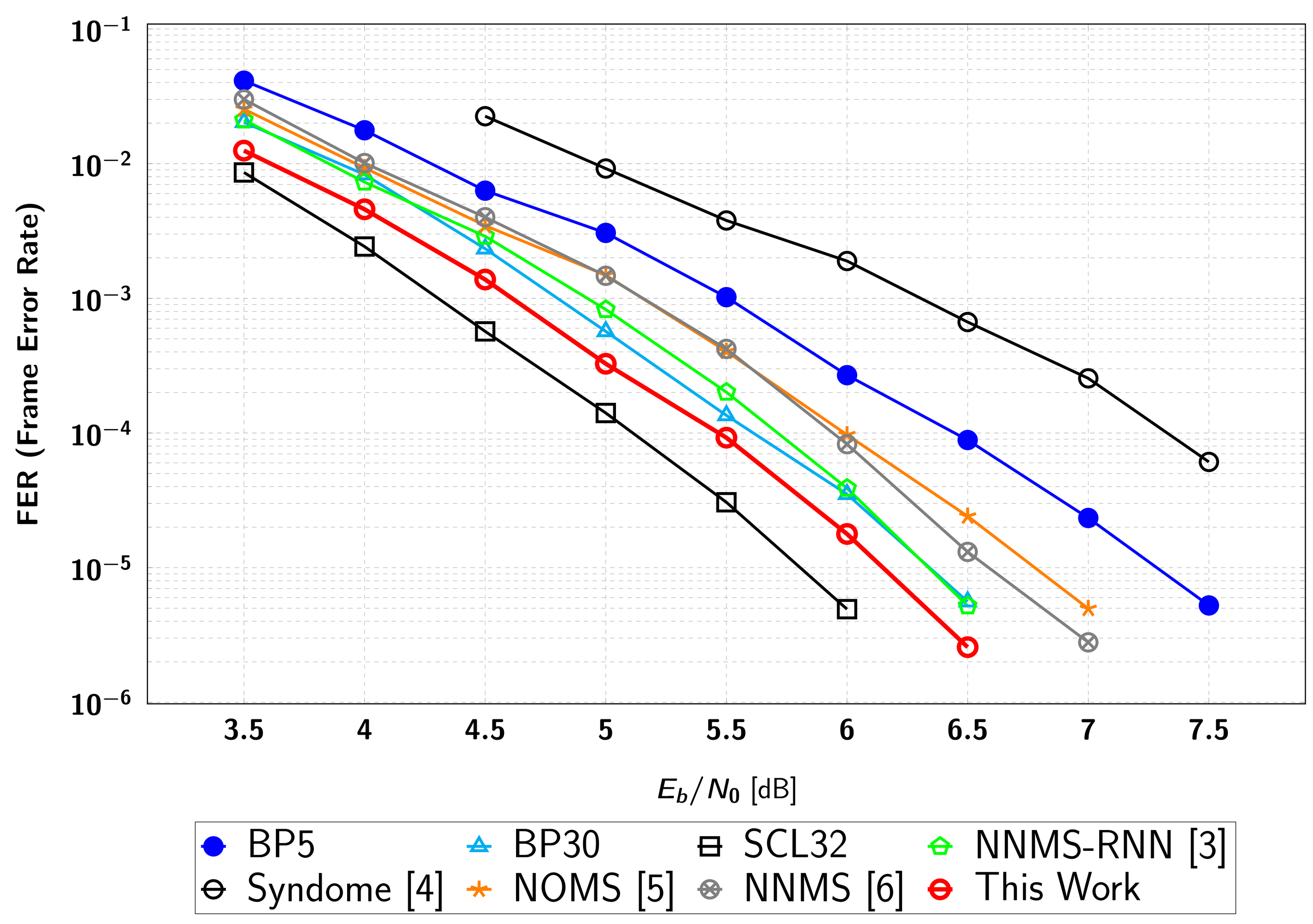


Figure: Frame Error Rate (FER) Performance of Various Decoders for $\mathcal{P}(64, 32)$.

Conclusion

- Gain 0.2 dB at $FER = 10^{-5}$ compared to the state-of-the-art neural BP decoder [3]
- Gain more than 1 dB compared to the conventional BP decoder
- Require a considerably large LSTM-based model for the noise estimator

Reference

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