PolarNet: A Deep Learning Decoder for Polar Codes on Flat Rayleigh fading Channels

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Abstract

This paper presents a deep learning (DL)-based decoding framework for polar codes. The system model incorporates a standard polar encoder and models a flat Rayleigh fading channel. A complete polar codebook is constructed using the reliability-based design. To address the challenge of decoding in such conditions, we propose a neural decoder architecture composed of a convolutional layer followed by multiple bidirectional long short-term memory (Bi-LSTM) layers. This structure captures both spatial and temporal dependencies within the received log-likelihood ratios (LLRs). The decoder is trained end-to-end using a mean squared error loss and evaluated under a wide range of SNR conditions. Simulation results demonstrate the proposed neural decoder's ability to generalize across channel conditions and effectively minimize packet error rates (PER) when compared to other decoding techniques. The proposed method shows promise for future adaptive, learned communication systems in wireless environments.

Ⅰ. Introduction

In recent years, the primary challenge in digital communication has been the design of capacity-approaching codes capable of delivering reliable performance over fading channels. Polar codes, introduced by Erdal Arikan, represent a breakthrough as the first class of error-correcting codes proven to achieve the capacity of symmetric binary-input discrete memoryless channels [1]. Their outstanding performance and flexibility across diverse communication scenarios have made polar codes a cornerstone in modern error correction coding. In [2], the authors presented a capacity-achieving polar coding scheme tailored to AWGN channels. Similarly, [3] focused on designing polar codes for memoryless AWGN channels. However, polar codes depend heavily on accurate CSI to optimize their encoding and decoding processes. When applied to fading channels, these otherwise robust and efficient codes face significant challenges due to the varying nature of the channel.

DL may be a good solution for decoding polar code [4]. A DL-based decoder for polar codes employs neural networks to enhance decoding accuracy and efficiency. Previous studies include a DNN-based approach in [5] and a CNN-based method applied to polar codes over flat fading channels in [6]. In this work, we propose a robust DL architecture that leverages LLRs, incorporating a 1D CNN layer followed by multiple Bi-LSTM layers to improve performance under fading conditions.

Ⅱ. Proposed System Model

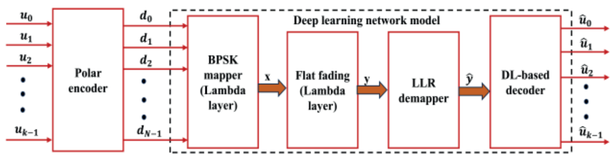

Fig-1. Block diagram for the proposed system model.

The system models a digital communication setup using polar coding. All 2^k possible bit sequences of length k are encoded into polar codewords of length N using Arikan's scheme, selecting the k most reliable bit-channels via the Bhattacharyya method [7]. Modulated via BPSK, the symbols traverse a Rayleigh fading channel with AWGN. At the receiver, LLRs are computed assuming perfect CSI, forming the input to the decoder.

Ⅲ. Proposed DL Model and Performance Evaluation

The decoder uses a DNN to map LLRs to the original information bits. It starts with a reshaped input followed by a Conv1D layer and passes through three BiLSTM layers (with 256, 128, and 128 units) to capture temporal dependencies. A final dense layer with sigmoid activation outputs soft decisions for the k information bits. The model is trained with MSE

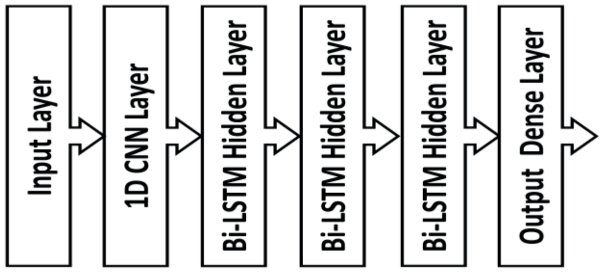

Fig2. Proposed DL-based decoder for polar code.

loss using the Adam optimizer and evaluated over 0 dB training SNR, 128 batch size, 0.001 learning rate, and 2^16 epochs using PER metrics. The PER performance is evaluated for a system setup with k=8 information bits and a polar codeword length of N=16. The DL-based decoder is trained using (2^4×2^16) training samples and tested on 10,0000 separate samples. This approach offers a robust, learning-based alternative to traditional decoding in fading environments.

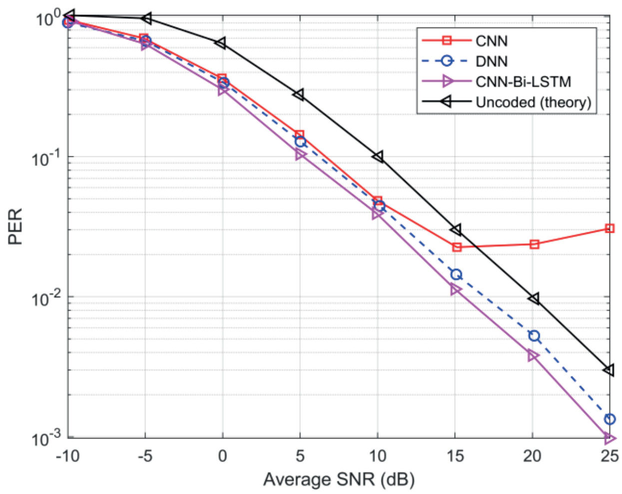

Fig3.PER comparison of the proposed detector.

From the PER performance, we can see that our proposed CNN-Bi-LSTM decoder achieve coding gain and outperforms the CNN, and DNN models.

IV. Conclusions

This work presents a decoder architecture combining CNN and Bi-LSTM for short packet transmission over flat Rayleigh fading channels. We evaluated the system's PER performance. Simulation results show that the proposed model provides significant coding gains, even when using a simple codebook originally designed for AWGN channels without fading. Furthermore, the proposed DL-based decoder consistently outperforms both CNN and DNN-based counterparts under identical conditions.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(2020R1A6A1A03038540). This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) under the metaverse support program to nurture the best talents (IITP-2025-RS-2023-00254529) grant funded by the Korea government(MSIT). Also, this work was supported by the IITP(Institute of Information & Communications Technology Planning & Evaluation)-ITRC(Information Technology Research Center) grant funded by the Korea government(Ministry of Science and ICT)(IITP-2024-RS-2024-00437191)

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