MANIPAL INSTITUTE OF TECHNOLOGY
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Project Synopsis On

Polar Code Encoding and Decoding Strategies: Simulation of SC & SCL over Noiseless and Noisy Channels

MASTER OF TECHNOLOGY
IN
DIGITAL ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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August 2025

ABSTRACT

Modern digital communication systems demand high reliability, low latency, and efficient utilization of bandwidth, especially in applications related to defense, satellite communication, and wireless systems. Forward Error Correction (FEC) techniques play a vital role in achieving these objectives by enabling reliable data transmission over noisy channels. Among various coding techniques, Polar Codes have emerged as a powerful and theoretically sound solution, being the first class of codes proven to achieve the Shannon capacity of symmetric binary-input discrete memoryless channels.

Polar Codes operate based on the principle of channel polarization, where a set of identical communication channels is transformed into two extreme categories: highly reliable channels and highly unreliable channels. Information bits are transmitted over the reliable channels, while the unreliable channels are assigned predetermined values known as frozen bits. This structured approach improves error correction capability while maintaining low encoding and decoding complexity.

This project focuses on the design, implementation, and verification of a Polar Encoder and Decoder, with emphasis on Successive Cancellation (SC) and Successive Cancellation List (SCL) decoding algorithms. The encoder is implemented using the recursive structure of the polar generator matrix, incorporating bit-reversal ordering and frozen-bit placement. The decoder is realized using LLR-based SC and SCL algorithms to recover the transmitted information bits.

Performance evaluation is carried out through simulation over both noiseless and Additive White Gaussian Noise (AWGN) channels. The decoding performance is analyzed in terms of bit error rate (BER), and a comparative study between SC and SCL decoding is performed. The project provides practical insight into polar code operation and decoder behavior, making it relevant to communication systems developed at BEL where robust and efficient error correction is essential.

INTRODUCTION

Background:

Reliable communication over noisy channels has been a fundamental challenge since the inception of digital communication systems. Channel coding techniques are employed to detect and correct errors introduced during transmission. Traditional error correction schemes such as convolutional codes, Turbo codes, and Low-Density Parity-Check (LDPC) codes have been widely adopted in various communication standards.

Polar Codes, introduced by Erdal Arıkan, represent a significant advancement in coding theory. Unlike conventional codes, polar codes leverage the phenomenon of channel polarization to achieve capacity with low-complexity encoding and decoding. Their recursive and structured nature enables efficient implementation and predictable performance, which is particularly advantageous for real-time and hardware-constrained systems.

Motivation:

Polar codes have been adopted in 5G New Radio (NR) standards, particularly for control channel communication, due to their strong error correction performance and scalability. For defense and strategic communication systems developed at BEL, reliable data transmission under varying channel conditions is critical. Understanding the practical implementation of polar encoders and decoders, as well as their performance trade-offs, is therefore highly relevant. This project is motivated by the need to gain hands-on experience with modern channel coding techniques that are both theoretically optimal and practically deployable.

Relevance:

Academically, this project strengthens understanding of channel coding, decoding algorithms, and performance evaluation techniques. From an industrial perspective, it aligns with the requirements of secure and reliable communication systems used in defense, satellite, and wireless applications. The project bridges the gap between theoretical concepts and practical realization.

Problem Definition:

Although polar codes provide excellent theoretical performance, their practical implementation involves several challenges. These include correct identification of frozen and information bit positions, proper handling of bit-reversal ordering, and accurate implementation of recursive decoding algorithms. Errors in any of these aspects can lead to incorrect decoding and degraded system performance.

The problem addressed in this project is the accurate and reliable implementation of a Polar Encoder and Decoder, ensuring correctness at every stage of encoding and decoding. The project focuses on implementing and validating Successive Cancellation (SC) and Successive Cancellation List (SCL) decoding algorithms and analyzing their performance under different channel conditions. Due to limited project duration, CRC-aided decoding is excluded from the implementation scope.

Objectives:

The specific objectives of this project are:

- To study the theoretical foundations of polar codes and channel polarization.
- To design and implement a Polar Encoder using a recursive generator matrix structure.
- To implement a Successive Cancellation (SC) decoder using LLR-based recursion.
- To design and validate a Successive Cancellation List (SCL) decoder without CRC.
- To evaluate decoding performance under noiseless and AWGN channel conditions.
- To compare SC and SCL decoding in terms of error performance and computational complexity.

Deliverables

At the completion of the project, the following deliverables are expected:

1. **Polar Encoder Implementation:**

   A fully functional Polar Encoder developed using the recursive generator matrix structure. The encoder correctly incorporates bit-reversal ordering and frozen-bit placement for configurable block lengths and code rates. The implementation is verified under noiseless channel conditions to ensure correctness of the encoded output and adherence to polar coding principles.

2. **Successive Cancellation (SC) Decoder Implementation:**

   An LLR-based Successive Cancellation decoder capable of accurately recovering transmitted information bits from received noisy signals. The decoder follows the recursive f and g function operations defined in polar decoding and is validated under both noiseless and AWGN channel conditions. Correct handling of frozen and information bit positions is ensured to achieve reliable decoding performance.

3. **Successive Cancellation List (SCL) Decoder Implementation:**

   A Successive Cancellation List decoder implemented without CRC, supporting multiple decoding paths and list-based decision making. The decoder maintains and updates path metrics during decoding and selects the most likely candidate at the final stage. The implementation demonstrates improved error correction performance compared to SC decoding, especially under low SNR conditions.

4. **Performance Evaluation and Comparative Analysis:**

   A detailed performance evaluation of the implemented polar encoder and decoders through simulation. Bit Error Rate (BER) analysis is carried out over a range of signal-to-noise ratios for both SC and SCL decoding. The results provide a clear comparison of decoding reliability, computational complexity, and performance trade-offs between SC and SCL decoding methods.

Key tools to be used: MATLAB for algorithm development, simulation.

Timeline

October 2025	Study of Polar Codes and channel polarization principles. Understanding frozen bits, bit-reversal ordering and code construction. Implementation and verification of Polar Encoder (noiseless channel).
November 2025	Study of Successive Cancellation (SC) decoding algorithm. Implementation of LLR-based SC decoder. Validation under noiseless and AWGN channel conditions.
December 2025	Study of Successive Cancellation List (SCL) decoding principles. Implementation of SCL decoder (without CRC). Performance comparison between SC and SCL decoding under noisy channel.

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Letter of Permission