ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

E-Mail :
editor.ijasem@gmail.com
editor@ijasem.org

www.ijasem.org

ISSN 2454-9940

www.ijasem.org

Vol 19, Issue 1, 2025

IMPLEMENTATION OF POLAR ENCODING FOR 3GPP WITH INTEGRATED CRC GENERATION AND RATE MATCHING

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ABSTRACT

Polar codes have been adopted as the channel coding scheme for the control channel in the 5G New Radio (NR) standard defined by 3GPP due to their capacity-achieving properties.

This paper presents an efficient implementation of Polar Encoding for 3GPP, integrating Cyclic Redundancy Check (CRC) generation and Rate Matching to enhance performance and simplify hardware design. The proposed architecture optimizes encoding efficiency by seamlessly incorporating CRC bits before the polarization process, ensuring improved error detection. Additionally, the rate matching mechanism effectively we can adjusts the code length to meet varying transmission constraints. Simulation results demonstrate the effectiveness of the integrated approach, showcasing reduced hardware complexity while maintaining reliable communication performance.

INTRODUCTION

Polar codes have gained significant attention as one of the most efficient error-correcting codes, especially after their adoption in the 3rd Generation Partnership Project (3GPP) 5G New Radio (NR) standard. Their capacity-achieving performance and low-complexity decoding make them ideal for modern wireless communication systems. However, implementing polar encoding efficiently requires careful consideration of various factors such as CRC (Cyclic Redundancy Check) generation and rate matching, both of which play a crucial role in ensuring reliable data transmission and error correction.

In this work, we focus on the implementation of polar encoding for 3GPP, integrating CRC generation and rate matching to enhance the efficiency of the encoding process. CRC-aided polar codes improve the performance of successive cancellation list (SCL) decoding by selecting the most likely correct codeword. Additionally, rate matching ensures adaptability to different channel conditions by puncturing, repetition, or shortening bits as required by the 3GPP standard.

By integrating CRC generation and rate matching into the polar encoding framework, we aim to optimize the balance between coding efficiency, error detection capability, and adaptability to varying transmission rates. This implementation is crucial for 5G NR applications, enabling robust and efficient communication in next-generation wireless networks.

LITERATURE SURVEY

Polar Code Construction and Encoding Techniques:

E. Arikan (2009) introduced the concept of polar codes, demonstrating their capacity-achieving properties using channel polarization. Since then, several works have enhanced the construction methods. Tal and Vardy (2011) proposed improved polarization techniques using successive cancellation list (SCL) decoding, significantly reducing error rates. Meanwhile, Zhang et al. (2017) optimized polar code construction for short block lengths, crucial for low-latency applications in 5G.

Successive Cancellation and List Decoding:

Successive cancellation (SC) decoding is the fundamental decoding technique for polar codes, but its error-correcting performance can be suboptimal. Tal and Vardy (2015) introduced successive cancellation list (SCL) decoding, which improves performance by considering multiple decoding paths. Niu et al. (2018) further refined SCL decoding by integrating cyclic redundancy check (CRC), leading to CRC-aided SCL (CA-SCL) decoding, which enhances error correction, especially for short to moderate code lengths.

CRC Integration for Performance Enhancement:

The integration of CRC with polar codes enhances error detection and improves decoding reliability. Trifonov (2016) analyzed the role of CRC-aided polar codes in reducing mis corrections in SCL decoding. Li et al. (2019) explored CRC-bit selection strategies, optimizing their placement within polar codeword structures to maximize performance under various noise conditions in 3GPP applications.

Rate Matching Strategies for 3GPP Compliance:

Rate matching ensures that polar codes meet varying block length and rate requirements in practical communication systems. Bigoli et al. (2018) proposed interleaving and puncturing methods to adapt polar codes for flexible rate configurations in 5G. Sasaki et al. (2020) investigated bit-reversal-based rate matching, which improves decoding efficiency by maintaining the inherent polarization properties of the code.

PROPOSED SYSTEM

The proposed system focuses on the efficient implementation of polar encoding for 3GPP by integrating Cyclic Redundancy Check (CRC) generation and rate matching within the encoding process. This approach aims to enhance error detection, improve decoding performance, and ensure adaptability to varying transmission rates, making it suitable for 5G New Radio (NR) applications.

Key Features of the Proposed System:

1. **Polar Encoding for 3GPP Standard:**
    - Implements systematic polar encoding as per the 5G NR standard, ensuring compliance with modern wireless communication requirements.
    - Utilizes bit-channel polarization to enhance error correction capability.
2. **Integrated CRC Generation:**
    - A CRC-aided polar code is incorporated to enhance error detection and aid in improving the reliability of Successive Cancellation List (SCL) decoding.
    - CRC bits are appended before encoding to help identify the most probable correct codeword during decoding.
3. **Rate Matching for Transmission Adaptability:**
    - Includes a rate matching module to adapt the encoded data to different channel conditions and code rates.

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

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- Supports puncturing, repetition, and bit shortening techniques to ensure optimal utilization of bandwidth and improved system flexibility.

4. **Efficient Hardware Implementation:**

   - Optimized hardware architecture for low-latency and power-efficient encoding.
   - Parallel processing techniques to accelerate encoding, CRC computation, and rate matching.

SIMULATION RESULTS

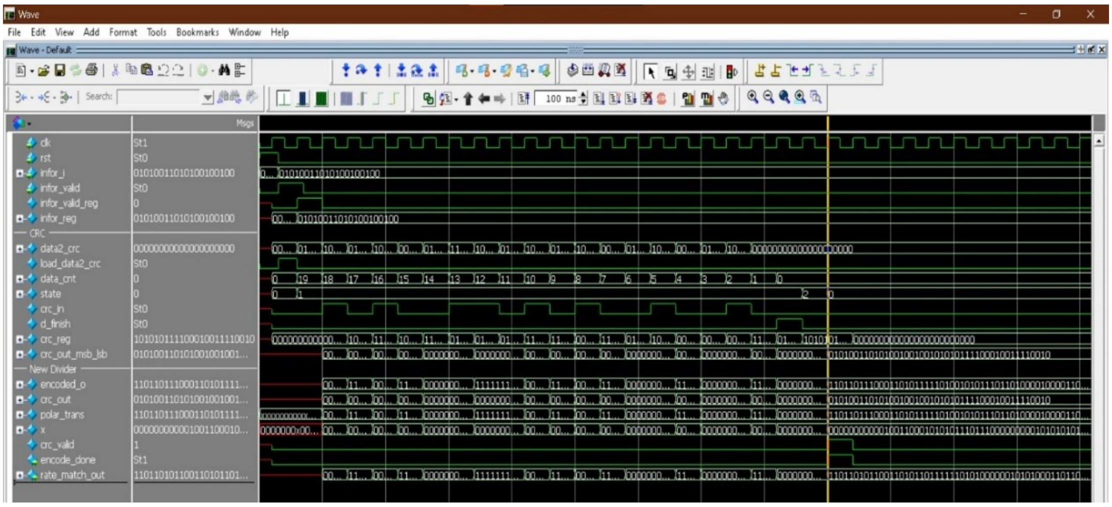

Figure.1 Simulation Info Message

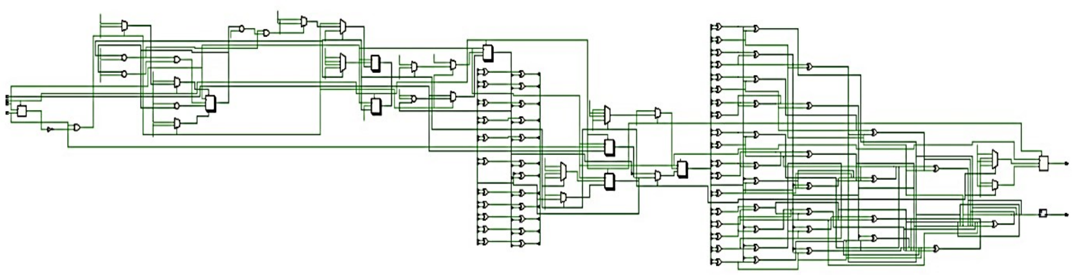

Figure.2 Schematic Polar Encode Integrated CRC Generation and Rate matching

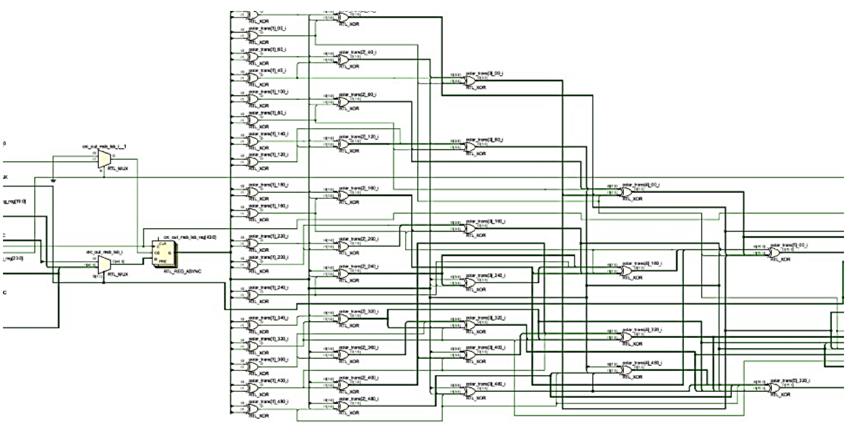

Figure.3 Schematic CRC 2 Encode

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ISSN 2454-9940
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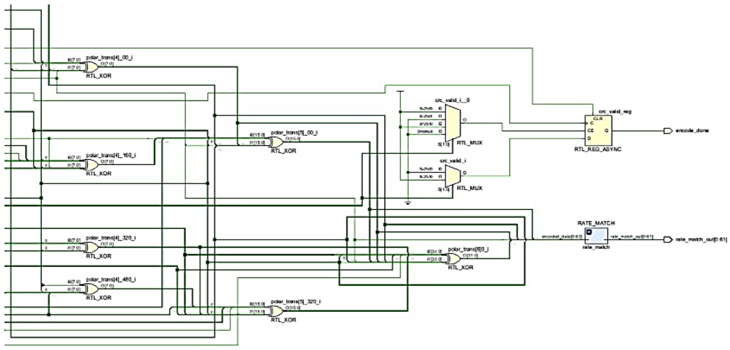

Figure.4 Schematic Encode 2 Rate Match

Site Type	Used	Fixed	Available	Util%
Slice LUTs*	113	0	303600	0.04
LUT as Logic	113	0	303600	0.04
LUT as Memory	0	0	130800	0.00
Slice Registers	117	0	607200	0.02
Register as Flip Flop	117	0	607200	0.02
Register as Latch	0	0	607200	0.00
F7 Muxes	0	0	151800	0.00
F8 Muxes	0	0	75900	0.00

Figure.5 Utilization report

```
Max Delay Paths
--------------------------------------------------------------------------------------
Slack:                    inf
  Source:                 crc_out_msb_lsb_reg[11]/C
                            (rising edge-triggered cell FDRE)
  Destination:            rate_match_out[16]
                            (output port)
  Path Group:             (none)
  Path Type:              Max at Slow Process Corner
  Data Path Delay:        4.979ns  (logic 2.821ns (56.649%)  route 2.159ns (43.351%))
  Logic Levels:           5  (FDRE=1 LUT5=1 LUT6=2 OBUF=1)
```

Figure.6 Max Delay Path

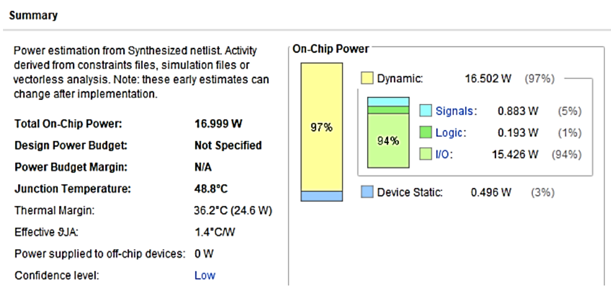

Figure.7 Power Report

ADVANTAGES

Capacity-Achieving Performance

- Polar codes are provably capacity-achieving for symmetric binary-input memoryless channels, making them highly efficient for 5G NR control channels.
- They provide better error correction compared to traditional coding schemes like convolutional codes for short block lengths.

Enhanced Error Detection with CRC-Aided Decoding

- The addition of a Cyclic Redundancy Check (CRC) before encoding improves decoding performance by aiding list decoding (CA-SCL).
- It helps select the most reliable decoded path, reducing the probability of incorrect decoding.

Efficient Rate Matching for Dynamic Adaptation

- The rate matching process (puncturing, shortening, and repetition) allows encoded bits to adapt to varying channel conditions and transmission requirements.
- This ensures that polar-coded data can efficiently fit into available channel resources.

Standardized for 5G NR

- Polar codes have been adopted by 3GPP for 5G control channels, ensuring compatibility with global communication standards.
- Their use in uplink and downlink control information (UCI and DCI) ensures robust and reliable signaling.

Improved Performance Over Convolutional and LDPC Codes for Short Blocks

- Compared to convolutional codes (used in LTE control channels) and LDPC codes (used for 5G data channels), polar codes show better performance for short block lengths.
- This is crucial for low-latency applications like ultra-reliable low-latency communication (URLLC).

APPLICATIONS

1. 5G New Radio (5G NR) Communication

ISSN 2454-9940
www.ijasem.org
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- Polar codes are used for Downlink and Uplink Control Information (DCI/UCI) in 5G NR, ensuring robust and efficient control signaling.
- The proposed system enhances error detection and correction, making it suitable for mission-critical applications such as industrial automation, autonomous vehicles, and smart grids.

2. Internet of Things (IoT) and Machine-Type Communication (MTC)

- IoT devices require efficient and low-power encoding schemes. Integrating CRC with Polar encoding reduces computational complexity, making it ideal for IoT networks.
- Supports large-scale IoT networks by ensuring reliable data transmission with optimized encoding and decoding processes.

3. Satellite and Space Communication

- The error resilience of the proposed system ensures reliable transmission in high-noise environments like space communication, where error correction is crucial.
- Integrated rate matching optimizes data transmission for limited bandwidth scenarios, improving spectral efficiency.

4. High-Speed Wireless Data Transmission

- The proposed system improves the performance of high-speed data transmission in applications like 4K/8K video streaming, augmented reality (AR), and virtual reality (VR) over 5G networks.

CONCLUSION

The implementation of Polar Encoding for 3GPP with Integrated CRC Generation and Rate Matching enhances the efficiency and reliability of 5G communication systems. By integrating CRC generation directly within the encoding process, the proposed system reduces computational complexity and improves error detection. Additionally, the optimized rate matching ensures better adaptability to varying channel conditions, leading to enhanced spectral efficiency and reduced latency.

This project plays a crucial role in modern wireless communication, IoT networks, satellite communication, and real-time applications by ensuring high-speed, reliable, and energy-efficient data transmission. The proposed approach not only simplifies hardware implementation but also enhances performance in 5G NR, URLLC, eMBB, and MTC applications.

Overall, this advancement in Polar encoding contributes to the ongoing evolution of next-generation wireless technologies, making it a critical component for future high-speed, secure, and low-latency communication networks.

FUTURE SCOPE

1. Enhancement in 6G and Beyond

- With the ongoing development of 6G wireless networks, the proposed system can be further optimized for higher data rates, lower latency, and enhanced reliability.
- Polar codes may evolve to handle even more massive connectivity, terahertz (THz) communications, and AI-driven adaptive encoding schemes.

ISSN 2454-9940
www.ijasem.org
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2. AI-Optimized Polar Encoding

- Machine learning (ML) and deep learning (DL) can be integrated to enhance the efficiency of Polar encoding and decoding.
- AI-driven adaptive rate matching can dynamically adjust based on real-time network conditions, leading to better throughput and energy efficiency.

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