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Performance Evaluation of 5G New Radio Physical Uplink Channels with LDPC and Polar Coding on AWGN Channels

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Abstract*:* This paper presents a MATLAB-based simulation for the performance assessment of 5G New Radio's (NR) Physical Uplink Shared Channel (PUSCH) using Additive White Gaussian Noise (AWGN) and Low-Density Parity-Check (LDPC) and Polar coding. The Modulation and Coding Scheme (MCS) table, as defined in the 3GPP TS 38.214 standard, was manually implemented, with five Quadrature Phase-Shift Keying (QPSK) entries and varying code rates used for simplicity. An array was initialized to compute Bit Error Rate (BER) against a range of Signal-to-Noise Ratio (SNR) values from -10 to 20 dB.

Keywords: *5G; Physical channel; Polar coding; LDPC*

1. Introduction

The advent of the fifth generation (5G) of wireless communication technology, notably the New Radio (NR) standards, has ushered in an era of unprecedented data rates, reduced latencies, and increased device connectivity [1]. To meet the escalating demands of various applications, 5G NR incorporates advanced techniques and innovative algorithms, shaping a robust and efficient framework for the Physical Uplink Shared Channel (PUSCH). Notably, these include sophisticated channel coding schemes like Low-Density Parity-Check (LDPC) and Polar coding, which are pivotal in achieving the desired performance characteristics of 5G NR [2]. 5G New Radio (NR) employs advanced techniques like Low-Density Parity-Check (LDPC) and Polar coding for efficient data transmission over Physical Uplink Channels (PUCCH) in Additive White Gaussian Noise (AWGN) channels. LDPC codes offer powerful error correction capabilities, enhancing reliability by detecting and correcting errors in the received data. The integration of Polar codes complements LDPC, providing an additional layer of error correction. In the context of PUCCH, LDPC and Polar coding optimize uplink communication by ensuring the integrity of transmitted information in the presence of noise. LDPC codes exhibit low error floors and achieve near Shannon limit performance, making them well-suited for 5G NR systems [3]. Polar codes, with their capacity-achieving properties, contribute to the overall robustness of the system [4]. These coding techniques enhance the spectral efficiency and reliability of uplink communication in challenging AWGN environments, aligning with the stringent requirements of 5G NR. The synergistic use of LDPC and Polar coding on PUCCH in 5G NR enables high-throughput, low-latency communication, supporting diverse applications in the evolving landscape of wireless connectivity [5].

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2. System Model

The simulation framework implemented in MATLAB provides a basic assessment of the performance of the 5G New Radio Physical Uplink Shared Channel (NR PUSCH) using LDPC and Polar coding over an Additive White Gaussian Noise (AWGN) channel. An MCS table is manually defined, specifying the modulation schemes and corresponding code rates. In this simulation, the first five entries of the 3GPP TS 38.214 standard MCS table are created, employing Quadrature Phase Shift Keying (QPSK) as the modulation scheme with varying code rates [6]. Key parameters, such as the signal-to-noise ratio (SNR) range (-10 to 20 dB with a step of 2 dB) and the MCS index, are initialized. The modulation scheme and code rate are then retrieved from the MCS table using the chosen index. Depending on the retrieved modulation scheme, the modulation order is established. The supported modulation schemes include QPSK, 16QAM, 64QAM, and 256QAM. The BLER calculation is down through what is a called a Cyclic Redundancy Chech (CRC) [7]. Cyclic Redundancy Chech is an algorithm or method for detecting errors and information loss in communication systems. [8] A particular CRC function is attached to each transported block and is inspected by the receiver. The transported block will be decoded if the blocks CRC matches the receivers calculated CRC value. Cyclic Redundancy Chech is an effective method of detecting errors in transported blocks. If the Calculated CRC value does not match the blocks CRC value. Then the block is retransmitted until the receivers and blocks CRC values match. In most communication systems the BLER tar- get is 10%. [9]. This means that the receiver should successfully receive around 90% of the transmitted blocks. BLER is broken down into two types. Initial Block Error Rate (IBLER). This is the ratio of transmission blocks with initial errors and retransmission to the total number of transmission blocks. Residual Block Error Rate (RBLER). This is the ratio of blocks with transmission errors after transmission to the total number of transmission blocks. Signal to Noise Ratio (SNR) is the ratio between the transmitted signal or information power to the undesired signal or noise power. Simply it is the ratio of the signal power to noise power. The signal to noise ratio is a way to measure the amount of information a signal conveys [10]. Typically, the unit for SNR is expressed in decibels (dB). Based on the above formula, the goal is to have a relatively high signal to noise ratio. We want to maximum the desired signal and minimize the unwanted noise. The SNR value is always a positive value. This means that if the SNR value is 45 dB, the desired signal is 45 dB higher than the noise signal. This is why having a high SNR is important. The higher the ratio the less impact the noise signal on the system. All transmission mediums generate some unwanted noise [11]. Designers attempted to minimize the amount of noise generated. For example, noise signals typically oscillate at higher frequencies. So low pass filters are a great way to get rid of unwanted noise [12]. For each SNR value in the defined range, the following operations are performed: Random bits for transmission are generated and then encoded using LDPC. The encoded bits are then modulated into symbols for transmission using the appropriate modulation scheme [13]. The AWGN channel is modeled by adding noise to the transmitted symbols based on the current SNR value. The received symbols are demodulated into bits, which are then converted into Log-Likelihood Ratios (LLRs). LDPC decoding is then performed on the LLRs to retrieve the decoded bits. The BER is computed by comparing the transmitted bits and the decoded bits 14].

3. Visualization and Analysis

When you change the MCS table in a BLER (Block Error Rate) vs. SNR (Signal-to-Noise Ratio) graph, you should observe different BER performance characteristics for each modulation scheme and code rate combination. By analyzing the plot, we can make the following conclusions: As SNR increases, BLER decreases: This is an expected behavior, as higher SNR levels provide a better signal-to-noise ratio, resulting in better BER performance as shown if fig 1. In a simulated 5G New Radio system utilizing LDPC coding and QPSK modulation, Block Error Rate (BLER) and Signal-to-Noise Ratio (SNR) are inversely related. As SNR increases, BLER decreases, demonstrating the LDPC-coded system's ability to maintain robust performance even in challenging conditions, ensuring reliable communication.

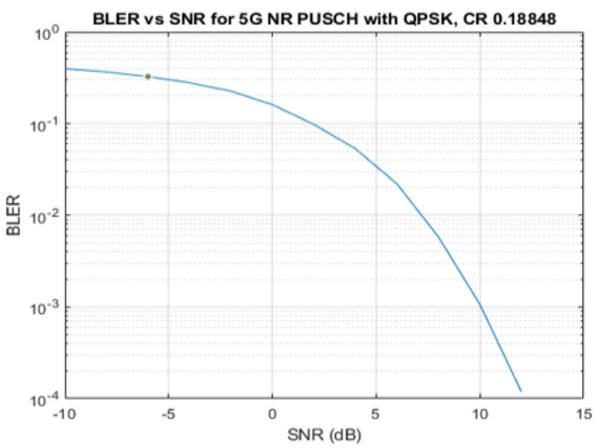

Fig 1. BLER vs SNR simulated for 5G New Radio through LDPC coding and QPSK modulation using

BLER measures the ratio of incorrectly received data blocks to the total number of transmitted blocks in a communication system. It is a crucial metric in assessing the reliability of a system, indicating how effectively error correction and detection mechanisms mitigate errors and ensure accurate data transmission. BLER performance varies with SNR: At lower SNR levels, the BLER is higher, indicating poorer performance. As the SNR increases, the BLER decreases, demonstrating improved system reliability as given in fig 2. Simulating 5G New Radio with LDPC coding and QPSK modulation reveals a notable inverse relationship between BLER and SNR. Higher SNR corresponds to lower BLER, underscoring the robust error-correction capabilities of LDPC coding in ensuring reliable communication in varying channel conditions.

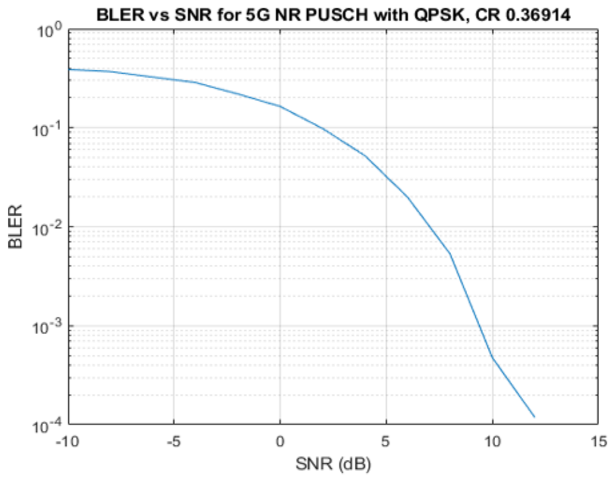

Fig 2. BLER vs SNR simulated for 5G New Radio through LDPC coding and QPSK modulation

The plot can assist in determining the optimal operating point for the system. Engineers can choose an MCS index from the MCS table that pro- vides the desired trade-off between data rate (modulation scheme) and error performance (BLER) based on the specific application's requirements is indicated in fig 3. In a simulated 5G New Radio scenario employing LDPC coding and 64QAM modulation, an inverse relationship between Block Error Rate (BLER) and Signal-to-Noise Ratio (SNR) is evident. Higher SNR leads to reduced BLER, highlighting the efficacy of LDPC coding in mitigating errors and ensuring reliable communication with advanced modulation schemes.

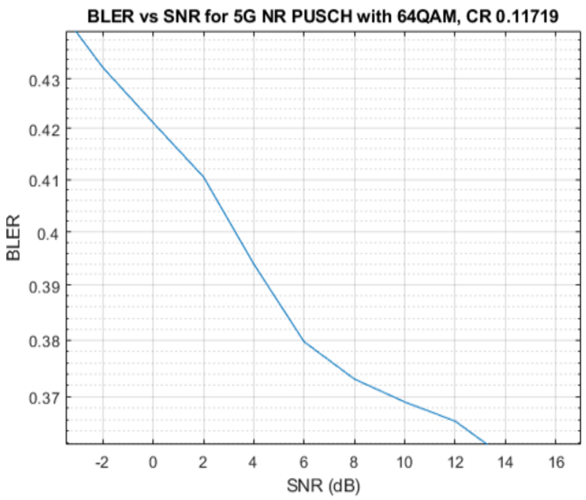

Fig 3. BLER vs SNR simulated for 5G New Radio through LDPC coding and 64QAM modulation

For very high SNR levels, the BLER may level off and reach an error floor. This behavior is typical in LDPC-coded systems, and it indicates that further improvements in SNR will not significantly reduce the BLER. The MCS table may specify different modulation schemes (e.g., QPSK, 16QAM, 64QAM, 256QAM) for different code rates. As the modulation order increases, the SNR required for a certain BER will also increase. Consequently, higher order modulation schemes will have a higher BLER at lower SNR values compared to lower order schemes given in fig 5 and fig 4.

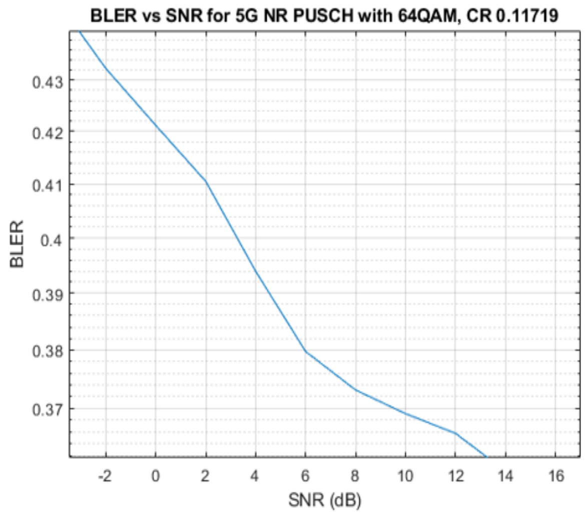

Fig 4. BLER vs SNR simulated for 5G New Radio through LDPC coding and 64QAM modulation

In a simulated 5G New Radio setup incorporating Polar coding, the relationship between Block Error Rate (BLER) and Signal-to-Noise Ratio (SNR) is critical is shown in fig 5. As SNR increases, BLER tends to decrease, showcasing Polar codes' effectiveness in error correction. The inherent capacity-achieving properties of Polar codes contribute to improved reliability in communication systems, especially in challenging environments. This simulation underscores the adaptability of Polar coding in 5G NR, enhancing the system's ability to maintain robust performance across varying SNR conditions and ensuring reliable transmission of data in the presence of noise and interference.

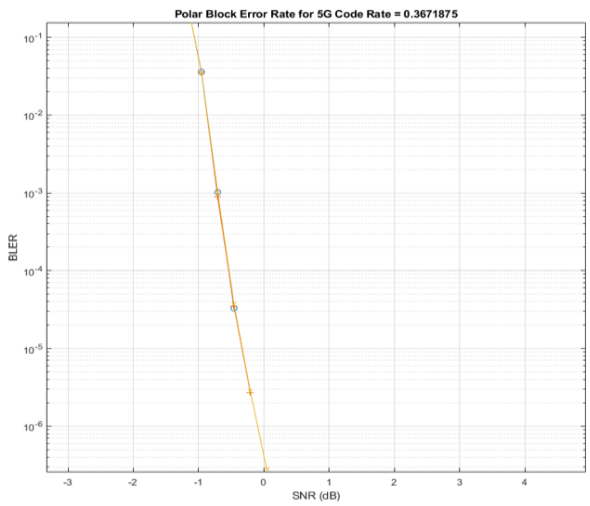

Fig 5. BLER vs SNR simulated for 5G New Radio through Polar coding

The choice of MCS table allows you to adjust the trade-offs between BLER performance and data rate. Lower code rates (e.g., 120/1024) offer better robustness at the cost of lower data rates, while higher code rates (e.g., 658/1024) provide higher data rates but are more susceptible to errors given in fig 6.

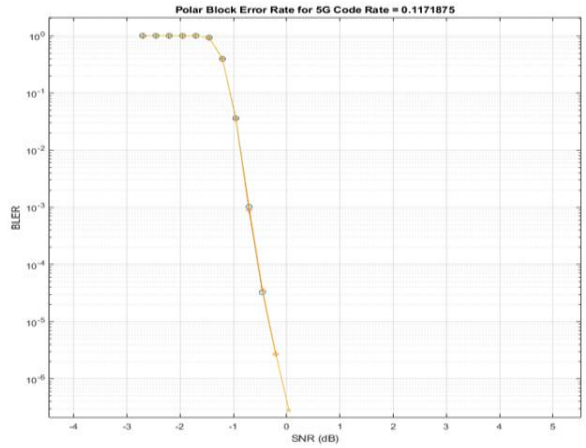

Fig 6. BLER vs SNR simulated for 5G New Radio through LDPC coding

4. Conclusion

We have experimented with different combinations of modulation schemes and code rates to understand their impact on the BLER performance at various SNR levels. The graph will help you determine which MCS index is most suitable for your specific communication requirements, considering the trade-off between BLER, data rate, and modulation scheme complexity. We have conducted a simulation to evaluate the Bit Error Rate (BER) performance of the 5G NR PUSCH with LDPC coding and 64QAM modulation. The BER performance is evaluated at various Signal-to-Noise Ratio (SNR) levels. The BER results are plotted on a mostly logarithmic scale against the SNR, and it is represented as BLER (Block Error Rate) since we are using LDPC coding, which operates on blocks of data. The plot allows us to observe how the BLER changes with varying SNR values, providing valuable insights into the system's performance**.**

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Author contributions

Arun Kumar: Conceptualization, Methodology, Writing-Original draft, Field study; **Nishant Gaur:** Data curation; Draft preparation **Sumit Chakravarthy**: Software, Validation., Field study; **Aziz Nanthaamornphong:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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