5G Technology for Smarter and Secure Connectivity

# Project Report: End-to-End 5G NR Link-Level Simulation with Adaptive Modulation

## 1. Introduction

### Problem Statement

This project focuses on building an end-to-end link-level simulation model of the 5G New Radio (NR) physical layer in MATLAB. The model incorporates Adaptive Modulation and Coding (AMC) strategies and Low-Density Parity-Check (LDPC) error correction, and evaluates performance over various channel environments.

### Objectives

- Simulate OFDM-based 5G NR transmission using different modulation schemes (QPSK, 16-QAM, 64-QAM, 256-QAM).  
- Implement LDPC channel coding and decoding as defined in 3GPP TS 38.212.  
- Adapt modulation schemes based on Signal-to-Noise Ratio (SNR) levels.  
- Evaluate system performance via Bit Error Rate (BER) vs. SNR under Rayleigh, Rician, and mmWave channel models.

## 2. Methodology

### MATLAB Implementation Approach

The simulation is developed using modular MATLAB scripts and functions:  
  
- main.m: The main script that initializes parameters, runs simulations, and saves plots and results.  
- ofdm\_modulator.m / ofdm\_demodulator.m: Handle IFFT/FFT processing and modulation/demodulation.  
- ldpc\_encoder.m / ldpc\_decoder.m: Perform LDPC encoding/decoding using MATLAB 5G Toolbox functions.  
- channel\_model.m: Simulates Rayleigh, Rician, and mmWave fading channels.  
- ber\_simulation.m: Orchestrates the full simulation loop, handling SNR sweeps and BER calculation.  
  
Functions and parameters are modular and well-documented, supporting flexible testing of AMC strategies.

## 3. Simulation Setup

### Key Parameters

|  |  |
| --- | --- |
| Parameter | Value |
| Modulation Schemes | QPSK, 16-QAM, 64-QAM, 256-QAM |
| Channel Coding | LDPC (Base Graph 1) |
| Number of Bits | 8448 |
| SNR Range | 0 dB to 20 dB (step = 2 dB) |
| Channel Models | Rayleigh, Rician (K=5), mmWave |
| FFT Size | 1024 |
| Cyclic Prefix Length | 72 |
| Max LDPC Decoding Iterations | 25 |

### Assumptions

- Perfect channel estimation is assumed.  
- All simulations are performed under flat-fading conditions (per-subcarrier fading not modeled).  
- mmWave channels are approximated using Rayleigh fading.

## 4. Results & Discussion

### BER vs. SNR Plots

The BER performance of different modulation schemes was plotted under three channel conditions. Below is a summary:  
- QPSK consistently performs best in low SNR scenarios due to its robustness.  
- Higher-order modulations (64-QAM, 256-QAM) offer higher data rates but suffer more from noise, showing higher BERs unless the SNR is sufficiently high.  
- Rician channels (with LOS component) yield slightly better performance than Rayleigh and mmWave.  
  
(All plots are saved in results/figures/BER\_<channel>.png)

### Observations

- AMC is beneficial for optimizing throughput across a wide SNR range.  
- LDPC decoding significantly reduces BER, especially with adequate SNR.  
- Proper selection of modulation and coding schemes is critical for reliable 5G NR performance in diverse channel environments.

## 5. Conclusion

### Summary

The simulation successfully demonstrates an end-to-end 5G NR link-level model with adaptive modulation and LDPC coding. It validates the impact of modulation choices and fading types on BER performance and highlights the effectiveness of adaptive strategies.

### Future Improvements

- Integrate MIMO and beamforming features for enhanced spatial diversity.  
- Incorporate channel estimation and synchronization impairments for real-world modeling.  
- Extend to frequency-selective fading with time-varying channels.

## Appendix

### Included Files

- main.m: Main execution script  
- ofdm\_modulator.m, ofdm\_demodulator.m  
- ldpc\_encoder.m, ldpc\_decoder.m  
- channel\_model.m, ber\_simulation.m  
- BER plots: results/figures/\*.png  
- Simulation logs: results/logs/\*.csv