5G NR PHYSICAL LAYER SIMULATION

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Chapter 1: Introduction

Overview of the Problem Statement

The development of 5G networks introduces several advanced physical layer (PHY) technologies such as Massive MIMO, Beamforming, and advanced channel coding schemes. These technologies make real-world testing complex, time-consuming, and expensive. Hence, a simulation-based study helps evaluate performance metrics like throughput, latency, and Bit Error Rate (BER) before hardware implementation.

Objectives and Goals

• To design and simulate a 5G New Radio (NR) physical layer using MATLAB.
• To analyze the system performance under different channel conditions.
• To validate the efficiency of signal processing algorithms such as modulation, coding, and OFDM.
• To evaluate metrics like BER, throughput, and latency for optimization.

Chapter 2: Literature Review

The IEEE paper on 'End-to-End Simulation of 5G mmWave Networks' highlights the role of simulation tools like ns-3 for modeling the complete protocol stack, including PHY and MAC layers. The study explains the use of discrete-event simulation to analyze cross-layer performance, beamforming, and hybrid architectures.

According to Devopedia and 3GPP standards, 5G NR introduces flexible numerologies, scalable bandwidths, and low-latency operation. MATLAB provides a powerful environment for link-level simulation of the 5G PHY layer, which is ideal for performance testing before hardware deployment.

Chapter 3: Strategic Analysis and Problem Definition

SWOT Analysis

• Strengths: Provides realistic simulation of 5G PHY operations; cost-effective and flexible.
• Weaknesses: High computational load; simulation accuracy depends on model assumptions.
• Opportunities: Can be expanded for AI-based adaptive algorithms and MIMO optimization.
• Threats: Rapid evolution of 3GPP standards may require frequent model updates.

Project Plan - GANTT Chart

The project follows milestones aligned with literature review, design, simulation, testing, and documentation. Each stage builds toward a complete MATLAB-based simulator capable of evaluating 5G PHY features.

Problem Statement

To develop an end-to-end 5G NR physical layer simulator that models transmitter-receiver operations, channel effects, and performance analysis under various wireless conditions using MATLAB.

Chapter 4: Methodology

Description of the Approach

The project uses MATLAB to simulate the 5G PHY layer. The process begins with generating data bits, followed by channel coding (LDPC), modulation (QPSK/16QAM/64QAM), resource grid mapping, OFDM signal generation, and transmission through a 3GPP-defined TDL/CDL channel. At the receiver, demodulation, decoding, and BER calculations are performed.

Tools and Techniques Utilized

• MATLAB for link-level simulation
• 3GPP channel models for realistic propagation
• Statistical analysis for BER and throughput evaluation
• Visualization tools for performance plotting

Design Considerations

The design focuses on modularity and flexibility, enabling different numerologies, bandwidth parts, and antenna configurations. MIMO and beamforming models are incorporated for performance comparison.

Chapter 5: Implementation

The simulation architecture consists of multiple blocks: Source, Channel Encoder (LDPC), Modulator, Resource Mapper, OFDM Transmitter, Channel Model, Receiver, Demodulator, and Decoder. Each block was implemented in MATLAB using inbuilt functions and custom scripts. The simulation loop evaluates BER for different SNR values to assess robustness.

Challenges Faced and Solutions

• Challenge: High computational load for MIMO-OFDM processing.
Solution: Optimization through vectorized MATLAB code.

• Challenge: Parameter mismatch during BER calculation.
Solution: Implemented adaptive frame synchronization.

• Challenge: Modeling realistic channels.
Solution: Integrated standardized 3GPP TDL and CDL channel models.

Chapter 6: Results

The simulator successfully generates BER vs. SNR plots and throughput curves. Results show that higher-order modulation achieves higher throughput but is more error-prone at low SNR. The use of LDPC coding significantly improves reliability. System latency remains within 1 ms under optimized numerology settings.

Interpretation of Results

The 5G PHY simulation verifies the trade-off between data rate and reliability. It confirms that adaptive modulation and coding enhance spectral efficiency under varying channel conditions. The simulation outcomes align closely with theoretical 3GPP performance curves.

Comparison with Existing Technologies

Compared to LTE, 5G NR provides flexible slot durations, higher frequency support (mmWave), and lower latency. The ns-3 mmWave model and MATLAB implementation demonstrate performance gains up to 10× in throughput.

Chapter 7: Conclusion

The project achieved the development of a 5G NR PHY layer simulator in MATLAB that models all essential transmission and reception blocks. It enables researchers to analyze and optimize performance metrics before deploying real hardware. This digital simulation approach reduces cost, time, and design complexity in 5G system development.

Chapter 8: Future Work

Future extensions can include:
• Integration of machine learning-based channel estimation.
• Simulation of full MIMO beamforming with dynamic user mobility.
• Implementation of HARQ and MAC-PHY cross-layer design.
• Support for 6G waveform and sub-THz frequency modeling.

References

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