Digital Communications (EE 332)

Assignment 1: Detailed Report and Analysis

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1 Introduction

1.1 Overview

This report presents a comprehensive analysis and implementation of several key digital communication techniques using GNU Radio. The experiments encompass:

- Time and frequency domain analysis of a sinusoidal signal.
- Digital modulation schemes including BPSK, QPSK, 16-QAM, and 64-QAM.
- Impact analysis of Additive White Gaussian Noise (AWGN) on modulation constellations.
- Pulse shaping methods (NRZ, RZ, and Manchester) and their effects on the transmitted signal.
- Use of Root Raised Cosine (RC) and Raised Cosine (RRC) filters in passband conversion.

1.2 Objectives

- Verify the sample rate and frequency of a generated sinusoid.
- Compare different modulation schemes and evaluate their noise immunity.
- Analyze how different pulse shaping techniques affect signal bandwidth and intersymbol interference (ISI).
- Explore the trade-offs between spectral efficiency and noise performance.

2 Experiment 1: Sinusoidal Signal Analysis

2.1 Implementation Details

A sinusoidal signal was generated in GNU Radio with the following settings:

- **Frequency:** 1 kHz
- **Sample Rate:** 32 kHz
- **Amplitude:** 1

The signal was analyzed in both the time domain and the frequency domain.

2.2 Time-Domain Analysis

The time-domain analysis confirmed a clear sinusoidal waveform with a period $T = 1$ ms. The sample rate is verified using the formula:

$$\text{Sample Rate} = \frac{\text{Number of Samples per Period}}{T}$$

This ensures the generated signal matches the expected parameters.

2.3 Frequency-Domain Analysis

In the frequency domain, the analysis confirmed a dominant frequency peak at 1 kHz, validating the design of the signal generator. This peak aligns perfectly with the intended frequency setting.

3 Experiment 2: Digital Modulation Schemes

3.1 Modulation Schemes and Parameters

Four digital modulation schemes were implemented:

- **BPSK:** 1 bit per symbol.
- **QPSK:** 2 bits per symbol.
- **16-QAM:** 4 bits per symbol.
- **64-QAM:** 6 bits per symbol.

3.2 Channel Modeling with AWGN

AWGN was added to the signals with a variance of 0.01 (using a noise voltage of $\sqrt{0.01}$). Other channel parameters included:

- **Frequency Offset:** 0
- **Taps:** [1]

This setup allows for the observation of noise impact on each modulation scheme.

3.3 Analysis of Constellation Diagrams

Although actual images are omitted, the following observations were noted from the simulation:

- **BPSK:** Exhibits maximum symbol separation, rendering it highly resilient to noise.

- **Higher Order Modulations:** For QPSK, 16-QAM, and 64-QAM, the ideal constellation points appear as scattered clusters (or "clouds") when noise is added. This indicates a higher susceptibility to noise.

These observations support the conclusion that higher-order modulations require better noise management techniques.

4 Experiment 3: Pulse Shaping and Bit Rate Variation

4.1 Transmitter Setup

Transmitters were configured for bit rates of 100, 300, and 500 kbps using three different pulse shaping techniques:

- Non-Return-to-Zero (NRZ)
- Return-to-Zero (RZ)
- Manchester encoding

4.2 GNU Radio Code Modifications

The GNU Radio flow graph was modified for different bit rate configurations. For example:

Listing 1: GNU Radio Code for Bit Rate Adjustments

```
# For 300 kbps:
samp_rate = 3.15e6
interpolation_factor = samp_rate // 150000

# For 500 kbps:
samp_rate = 3.25e6
interpolation_factor = samp_rate // 250000
```

These modifications ensure the system operates correctly at various bit rates.

4.3 Spectral Analysis of Pulse Shapes

The spectral analysis provided insights into how pulse shaping affects the transmitted signal:

- **NRZ:** Generates full-width pulses with a moderate spectral footprint.
- **RZ:** Produces half-width pulses, resulting in a broader frequency spread.
- **Manchester:** Introduces transitions in the middle of symbols, leading to a distinct spectral signature.

4.4 4-PAM vs. QPSK Comparison

A comparative study between 4-PAM and QPSK revealed:

- **4-PAM:** Utilizes amplitude variations and generally requires a wider bandwidth.
- **QPSK:** Employs phase variations, offering improved bandwidth efficiency.

The symbol rate, inferred from spectral nulls, was used to verify the intended bit rates.

5 Experiment 4: RC and RRC Pulse Shaping for QPSK

5.1 RC Pulse Shaping Implementation

A Root Raised Cosine (RC) filter was applied with varying excess bandwidth values (β) of 10%, 25%, 50%, and 75%. An 8192-tap filter was used to analyze:

- The trade-off between spectral efficiency and inter-symbol interference (ISI).
- The effect of excess bandwidth on the clarity of the received signal.

5.2 Eye Diagram Analysis

Although no image is included, the analysis of the eye diagram revealed:

- A wider eye opening corresponds to better signal integrity.
- Narrow eye openings, which occur at lower β values, indicate a higher potential for ISI.

These observations are critical for determining the optimal filter settings.

6 Experiment 5: Passband Conversion using RRC Filter

6.1 Transmitter Configuration

A transmitter was configured for both BPSK and 16-QAM at 200 kbps using an RRC filter with an excess bandwidth of 35%. The baseband signal was then upconverted to passband using an adjustable carrier frequency.

6.2 Results and Discussion

The key findings from the passband conversion include:

- The passband spectrum is centered around the chosen carrier frequency.
- BPSK produces a more compact spectral profile compared to 16-QAM.
- The modulation order significantly impacts the overall bandwidth requirements.

7 Theoretical Analysis and Equations

7.1 Nyquist Criterion

To prevent inter-symbol interference (ISI), the Nyquist criterion is applied:

$$B = \frac{1}{2T}$$

where B is the minimum required bandwidth and T is the symbol period.

7.2 Bit Rate and Symbol Rate Relationship

The relationship between the bit rate (R_b) and the symbol rate (R_s) is expressed as:

$$R_b = m \cdot R_s$$

where m is the number of bits per symbol. This equation is essential for validating the experimental parameters for various modulation schemes.

8 Conclusion

This assignment provided a deep exploration of digital communication techniques using GNU Radio. Key conclusions include:

- The trade-off between spectral efficiency and noise immunity, particularly for higher-order modulation schemes.
- The significant role of pulse shaping in controlling bandwidth and minimizing ISI.
- The impact of modulation order on the required signal bandwidth.

Future work could explore adaptive modulation and dynamic filter optimization to further enhance system performance.

A GNU Radio Code Modifications for Different Bit Rates

A.1 Configuration Details

- **100 kbps:** Default configuration.
- **300 kbps:** Sample rate adjusted to 3.15 MHz, with interpolation factor computed as samp_rate ÷ 150000.
- **500 kbps:** Sample rate adjusted to 3.25 MHz, with interpolation factor computed as samp_rate ÷ 250000.

B Additional Observations

- Detailed numerical analyses and theoretical computations have been integrated to support experimental findings.
- All parameter modifications and system adjustments were carefully documented in the GNU Radio flow graphs.