Project – Part 2

Wireless Communications

Simulation and Analysis of Digital Communications over Time-Varying Fading Channels

1 Introduction and Objectives

The second part of the course project focuses on the simulation and performance analysis of digital communication systems operating over time-varying wireless channels using MATLAB. The primary challenge in mobile communications is the degradation caused by multipath fading and Doppler spread due to user mobility. This part of the project is designed to provide a practical understanding of these effects and the techniques used to mitigate them.

This is divided into two main tasks. First, you will implement and analyze a fixed-rate communication system to understand how its performance is influenced by the combination of multipath (small-scale fading) and user mobility. Second, you will design and implement an adaptive-rate system that leverages Channel State Information (CSI) to optimize performance.

2 Core Simulation Parameters

All simulations must use the parameters specified in the table below to ensure consistency.

Table 1: Core Simulation Parameters

Parameter	**Symbol**	**Value**	**Units**
Carrier Frequency	f_c	2	GHz
Symbol Rate	R_s	100	kilo-symbols/sec
Modulation (Task A)	-	QPSK	-
Modulation Set (Task B)	-	BPSK, QPSK, 16-QAM, 64-QAM	-
User Velocities	v	3, 50, 120	km/h
Fading Distribution	-	Rayleigh	-
Doppler Spectrum	-	Jakes	-
Channel Model	-	Narrowband (Flat Fading)	-
Target Instantaneous BER (Task B)	$P_{b,target}$	10^{-3}	-

3 Task A: Fixed-Rate Transmission with CSIR

Objective: To implement a fixed-rate digital communication system and quantify the impact of user mobility on its Bit Error Rate (BER) performance. In this scenario, the receiver has perfect CSI for demodulation, but the transmitter does not.

3.1 System Model

Your task is to model a standard digital communication chain transmitting over a time-varying, narrowband Rayleigh fading channel. The effect of user mobility is modeled by incorporating a Jakes Doppler spectrum, where the maximum Doppler shift is given by $f_{d,max} = v/\lambda$, with λ being the carrier wavelength.

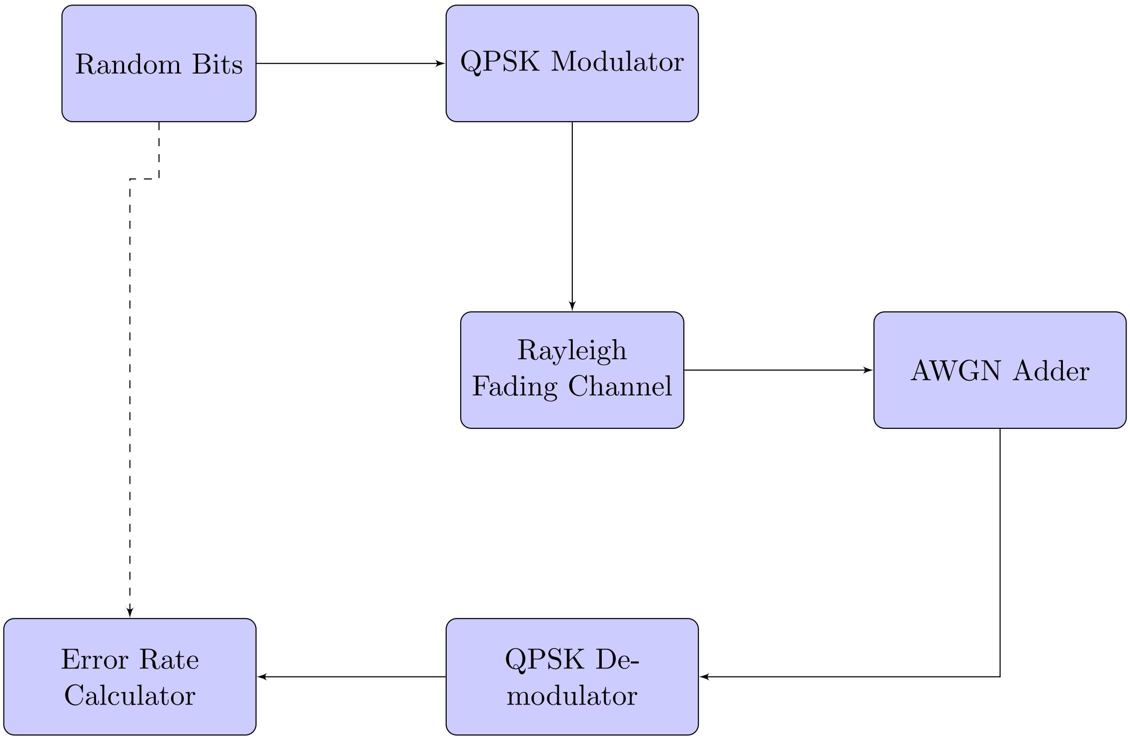

Figure 1: System Block Diagram for Task A (CSIR)

3.2 Tasks and Deliverables for Task A

A1. **System Implementation**

- Implement the complete simulation chain in MATLAB: Random Bit Generator → QPSK Modulator → Time-Varying Rayleigh Fading Channel → AWGN Channel → QPSK Demodulator → BER Calculator.
- Configure the `comm.RayleighChannel` object to model a narrowband channel with a Jakes Doppler spectrum for each specified velocity.

A2. **Channel Visualization**

- For each velocity ($v = 3, 50, 120$ km/h), generate a plot showing the magnitude of the complex channel gain in dB versus time over a 500 ms interval.

A3. **Performance Evaluation**

- For each velocity, generate a single plot of the Average BER versus Average SNR (from 0 dB to 25 dB).
- This plot must contain three curves (one for each velocity) and a fourth curve showing the theoretical BER for QPSK in an AWGN-only channel for reference. Use a logarithmic scale for the BER axis (`semilogy`).

A4. **Analysis and Discussion**
Answer the following questions in your report:

(a) Calculate the theoretical coherence time ($T_c \approx 0.423/f_{d,max}$) for each velocity. Compare these values to a visual estimate from your plots in Task A2. Discuss the relationship between the coherence time and the system's symbol duration.

(b) Based on your BER curves from Task A3, explain why system performance degrades as velocity increases. Relate your explanation to the concepts of Doppler spread and coherence time.

(c) Verify whether your results for the highest velocity show evidence of an "error floor." Explain the physical phenomenon behind an error floor in fast-fading channels.

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4 Task B: Variable-Rate Transmission with CSITR

Objective: To design and implement an adaptive modulation system that uses CSI at the transmitter (CSIT) to maximize spectral efficiency while maintaining a target quality of service. This part assumes perfect, instantaneous CSI is available at both the transmitter and receiver.

4.1 System Design

In this task, you will enhance the system from Task A by implementing support for adaptive modulation and coding (AMC). To do this, you will assume an ideal channel estimator at the receiver, which provides perfect, instantaneous Channel State Information (CSI). This CSI is then sent back to the transmitter via an error-free, zero-delay feedback path. The transmitter's adaptive modulator will use this CSI to select a modulation scheme from a predefined set to maximize the data rate, subject to a constraint on the instantaneous BER.

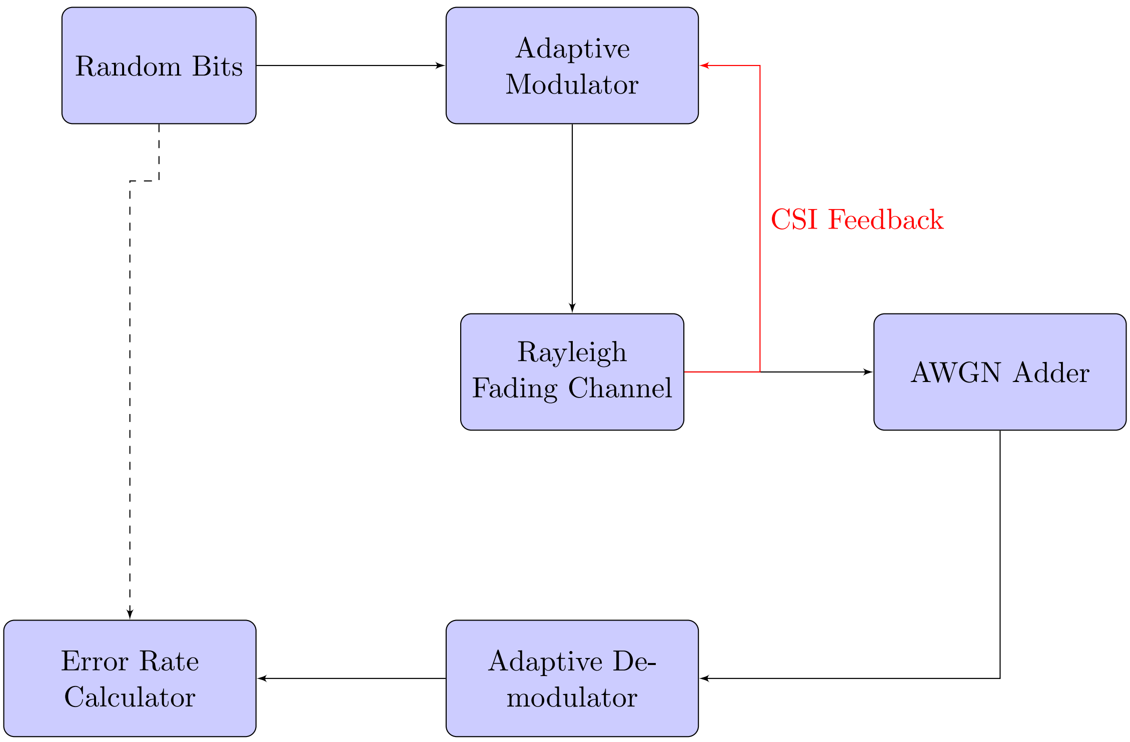

Figure 2: System Block Diagram for Task B (CSITR)

4.2 Tasks and Deliverables for Task B

B1. **Design the Adaptive Modulation Policy**

- Design an AMC policy that selects from the set {BPSK, QPSK, 16-QAM, 64-QAM} to maintain a target instantaneous BER of $P_{b,target} \leq 10^{-3}$.
- To determine the required SNR threshold for each modulation scheme, use the following BER approximation for M-QAM in an AWGN channel:

$$\bar{P}_b \approx 0.2 \exp\left(-\frac{1.5\gamma_s}{M-1}\right)$$

where γ_s is the symbol SNR. Note that BPSK and QPSK can be treated as special cases of QAM.

- Present your final policy in a table that clearly defines the SNR range for each modulation scheme and the corresponding spectral efficiency (in bps/Hz). Include a fifth region for "No Transmission" (outage) when the SNR is insufficient for even the most robust scheme.

B2. **System Implementation**

- Modify your MATLAB script from Task A to implement the adaptive system. At each time step, the simulation must:
  (a) Obtain the instantaneous channel gain.
  (b) Calculate the instantaneous SNR.
  (c) Select the modulation mode according to your policy from Task B1.
  (d) Modulate and transmit the data.
  (e) Keep track of the necessary statistics to calculate average spectral efficiency.

B3. **Visualize the Adaptation**

- Set the average SNR to 20 dB and the velocity to 50 km/h. Generate a single figure with two time-aligned subplots over a 500 ms interval:
  - **Top:** Instantaneous SNR (dB) vs. time.
  - **Bottom:** Selected spectral efficiency (bps/Hz) vs. time.

B4. **Characterize Mode Selection**

- For an average SNR of 20 dB and a velocity of 50 km/h, generate a bar chart showing the percentage of time the system spends in each transmission mode (No Transmission, BPSK, QPSK, 16-QAM, 64-QAM).

B5. **Performance Evaluation**

- Generate a plot of the Average Spectral Efficiency (bps/Hz) versus Average SNR (from 0 dB to 30 dB) for the adaptive system at a velocity of 50 km/h.
- On the same plot, show the spectral efficiency of the fixed-rate QPSK system from Task A (2 bps/Hz). Indicate the region where the fixed-rate system's average BER exceeds an unacceptable threshold (e.g., $> 10^{-2}$).

B6. **Analysis and Discussion**
Answer the following questions in your report:

(a) Using your plot from Task B3, explain how the system's choice of modulation directly tracks the instantaneous channel quality.

(b) Discuss the mode selection histogram from Task B4. How would you expect this distribution to change if the average SNR were increased to 30 dB? If it were decreased to 10 dB? Justify your reasoning.

(c) Analyze the spectral efficiency curve from Task B5. Compare the performance of the adaptive and fixed-rate systems. Explain the significant gain of the adaptive system at high SNRs and its low efficiency at low SNRs.

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5 Submission Guidelines

You must submit a single `.zip` file containing:

1. **A comprehensive report** in PDF format.
2. **Your MATLAB code** (`.m` files) that can reproduce all figures and results in your report.

5.1 Report Structure

Your report must be structured as follows:

- State assumptions clearly if you have made any.
- **Task A: Fixed-Rate System:** Include your methodology, results (all required plots), and a detailed analysis answering the questions in Section 3.2.
- **Task B: Adaptive System:** Describe your AMC policy design (including threshold calculations), implementation, results (all required plots), and a detailed analysis answering the questions in Section 4.2.
- Each plot must be referenced and thoroughly discussed in the report.
- Try to explain the concepts involved in your own words and summarize the key findings and principles learned.
- Mention the contributions of both teammates.

Note: All submissions will be checked for plagiarism. Any instance of academic dishonesty, including copying from other students or online sources without proper citation, will result in zero score for the entire project. It is expected that all work submitted is original.

Deadline: 18th October, 11:59 PM
