Computer Networks Lab Report

Assignment – 1

Problem Statement:
Design and implement an error detection module which has two schemes, namely Checksum and Cyclic Redundancy Check (CRC).

Student Details

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Subject:

Computer Networks

Design

Purpose of the Program

The program aims to **design and implement an error detection module** in a simulated network environment. It demonstrates how transmitted data can be protected against errors during communication using two different techniques:

1. **Checksum (16-bit)** –
    - Ensures data integrity by computing the one's complement sum of all 16-bit words in the data.
    - At the receiver side, if the recomputed checksum plus data results in zero, the data is assumed error-free.
2. **Cyclic Redundancy Check (CRC)** –
    - Uses predefined generator polynomials (CRC-8, CRC-10, CRC-16, CRC-32) to append check bits to data.
    - At the receiver, polynomial division is applied to detect errors such as single-bit, multiple-bit, odd errors, and burst errors.

Additionally, the program includes an **error injection module** that deliberately introduces random errors in transmitted data (e.g., single-bit, double-bit, odd-bit, burst) to test the robustness of these schemes.

The overall purpose is to:

- Simulate **sender-receiver communication** with error-prone transmission.
- Compare how effectively **Checksum** and **CRC** detect different types of errors.
- Highlight cases where one scheme may succeed while the other may fail, showing their strengths and limitations in real-world networking.

Structural Diagram of the Program

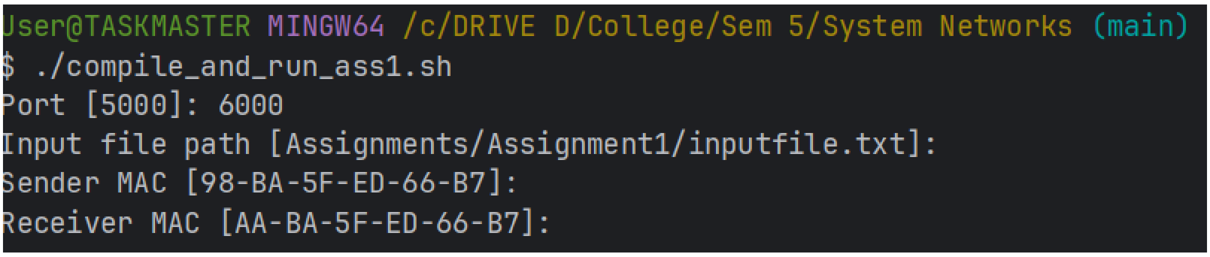
The program is organized into **9 files**:

- **7 Java files** – Core implementation (Sender, Receiver, Error Injectors, etc.)
- **1 Python file** – Analytics (plots and performance metrics)
- **1 Shell script** – Compilation and execution automation

File Structure

1. **ChecksumErrorInjector.java**
    - Implements error injection specific to checksum scheme.
2. **CrcErrorInjector.java**
    - Implements error injection specific to CRC scheme.
3. **ErrorInjector.java**
    - Base module for introducing different types of errors:
        - Single-bit error
        - Two isolated single-bit errors
        - Odd number of errors
        - Burst errors
4. **FrameBuilder.java**
    - Prepares frames by combining datawords with their corresponding error-detection codes (checksum or CRC).
5. **Receiver.java**
    - Simulates the receiver side of communication.
    - Verifies received frames using checksum or CRC.
    - Accepts or rejects frames based on error detection results.
6. **Sender.java**
    - Reads input data file.
    - Builds frames using **FrameBuilder**.
    - Optionally calls **ErrorInjector** before transmission.
    - Sends frames to the Receiver.
7. **Utils.java**
    - Contains helper functions shared across modules (e.g., binary operations, polynomial division, checksum calculation).
8. **analytics.py**
    - Generates **histogram plots** and **performance_metrics.csv** to analyze error detection effectiveness of both schemes.
9. **compile_and_run_ass1.sh**
    - Automates the compilation and execution workflow.
    - **Steps performed:**

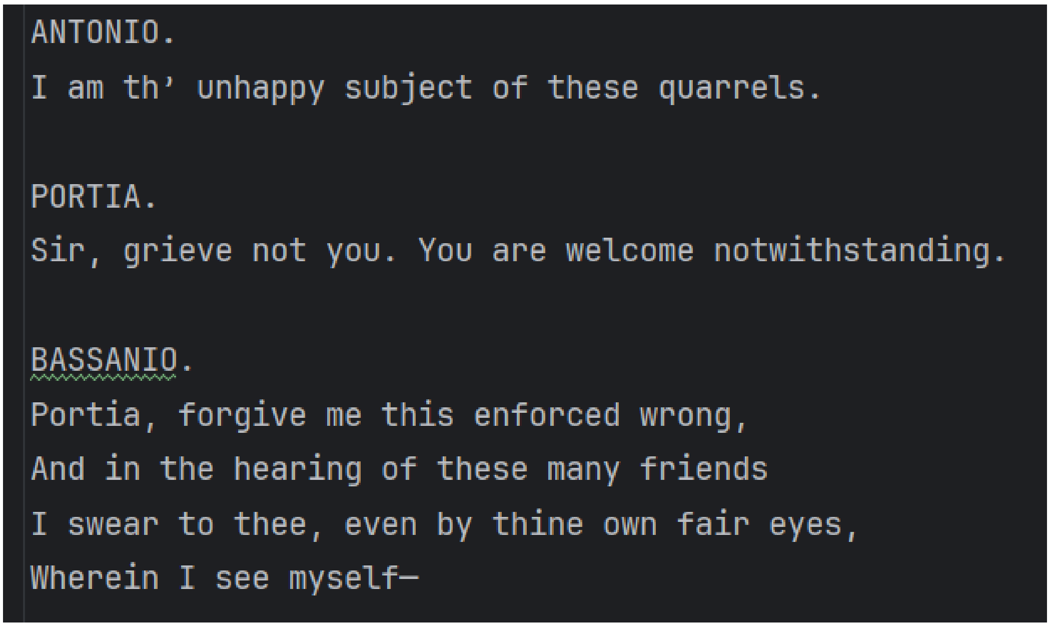
1. Takes input parameters: `port`, `sender MAC`, `receiver MAC`, and `input file`.
2. Compiles all Java files.
3. Starts **Receiver** at the given address.
4. Starts **Sender** at the given address.
5. Runs **analytics.py** to produce visual and tabular results.



```
User@TASKMASTER MINGW64 /c/DRIVE D/College/Sem 5/System Networks (main)
$ ./compile_and_run_ass1.sh
Port [5000]: 6000
Input file path [Assignments/Assignment1/inputfile.txt]:
Sender MAC [98-BA-5F-ED-66-B7]:
Receiver MAC [AA-BA-5F-ED-66-B7]:
```

Input / Output Specification

- **Input Format:**
  - A text file containing any txt data

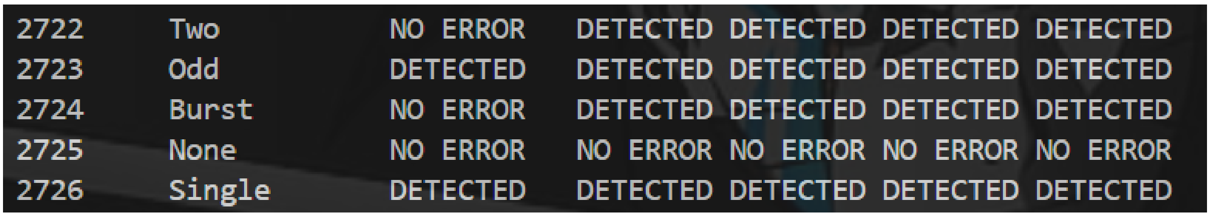


```
ANTONIO.
I am th’ unhappy subject of these quarrels.

PORTIA.
Sir, grieve not you. You are welcome notwithstanding.

BASSANIO.
Portia, forgive me this enforced wrong,
And in the hearing of these many friends
I swear to thee, even by thine own fair eyes,
Wherein I see myself—
```

- **Output Format:**
  - For each transmitted frame:
    - Display whether **Checksum** and **CRCs** detected an error.
  - Final analytics:
    - Histogram plots
    - `performance_metrics.csv` file



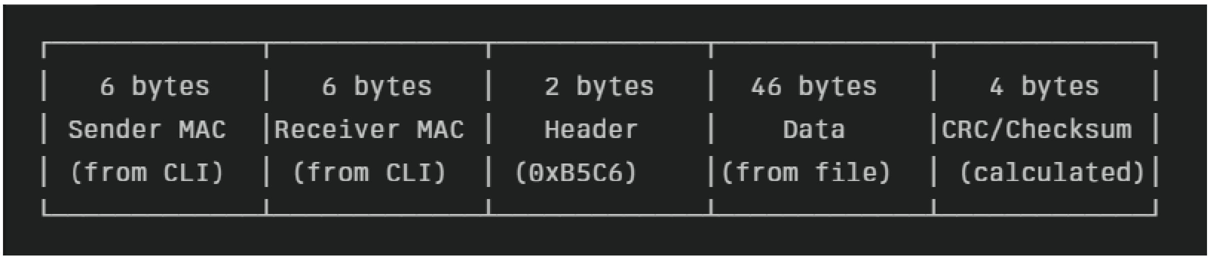
```
2722      Two          NO ERROR    DETECTED DETECTED DETECTED DETECTED
2723      Odd          DETECTED    DETECTED DETECTED DETECTED DETECTED
2724      Burst        NO ERROR    DETECTED DETECTED DETECTED DETECTED
2725      None         NO ERROR    NO ERROR NO ERROR NO ERROR NO ERROR
2726      Single       DETECTED    DETECTED DETECTED DETECTED DETECTED
```

Implementation

Sender Side

1. Frame Creation

1. The **input file** is read entirely and divided into **frames of 64 Bytes (512 bits)**.



```
┌─────────────┬─────────────┬─────────────┬─────────────┬─────────────┐
│   6 bytes   │   6 bytes   │   2 bytes   │  46 bytes   │   4 bytes   │
│ Sender MAC  │Receiver MAC │   Header    │    Data     │CRC/Checksum │
│ (from CLI)  │ (from CLI)  │ (0xB5C6)    │(from file)  │ (calculated)│
└─────────────┴─────────────┴─────────────┴─────────────┴─────────────┘
```

2. The **payload (46 Bytes)** is extracted from the text file.
3. A function `createFrames()` is used to construct frames:
   - **a. Frame Construction**
     - The 46 Bytes is converted to binary 0 and 1
     - Each frame is built with:
       - Sender MAC address
       - Receiver MAC address
       - 2-byte header
       - Payload (46 Bytes)
     - If the payload is **less than 46 Bytes**, it is padded with **zeros**.
   - **b. Frame List Creation**
     - All frames are stored in a **list**.
   - **c. Error Detection Code Appending**
     - For each frame, **Checksum, CRC-8, CRC-10, CRC-16, and CRC-32** values are calculated.
     - These values are appended to the frame, making it a complete **64 Byte frame**.
     - Finally, all frames are stored in a **List<List<String>>** structure.
   - **d. Error Injection Preparation**
     - The list of frames is passed to the **Error Injector module**, which introduces errors as described below.

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2. Error Injection

There are **four types of errors** simulated. The error type is chosen based on the **frame index**:

- **i % 5 = error type**
  - `0` → No Error
  - `1` → Single-bit Error
  - `2` → Two isolated-bit Errors

    - `3` → Odd-bit Errors
    - `4` → Burst Error

Error Injection Process:

- **a. Single-bit Error**
    - A random bit in the frame is flipped.
- **b. Two isolated-bit Errors**
    - The frame is divided into **16-bit segments**.
    - Two different segments `i` and `j` are selected such that:
        - `segment[i] = 1` and `segment[j] = 0`
    - These bits are flipped → `segment[i] = 0`, `segment[j] = 1`.
    - The modified segments are placed back into the frame.
- **c. Odd-bit Errors**
    - A **random odd number of bits** are flipped.
- **d. Burst Error**
    - An **error vector E** is created such that it is a **multiple of g(x)** (generator polynomial).
    - This ensures that CRC will not detect it.
    - Construction of **E**:
        - `g_full = x^degree + (poly bits)` (degree = n).
        - Several shifted copies of `g_full` are XORed together.
        - Shifts overlap by 1 position to create a **contiguous (or near-contiguous) error burst**.
        - This guarantees that the burst span is at least equal to the target burst length.
- **e. Final Frame List**
    - All error-injected frames are stored in **List<List<String>> errorInjectedFrameList**.
    - The list is returned to the **Sender**.

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3. Frame Transmission

- `Sender.java` establishes a **TCP socket connection** with the receiver.
- Each frame, along with its **error type**, is transmitted to the receiver for validation.

Receiver Side

1. Frame Checking

1. The **Receiver** accepts incoming frames sent by the **Sender**.
2. Each received frame is structured as:
3. `[frameNumber, errorType, checksum_data, crc8_data, crc10_data, crc16_data, crc32_data]`
    - **frameNumber** → Identifier of the frame
    - **errorType** → Type of error injected by the sender (none, single-bit, two-bit, odd-bit, or burst)
    - **checksum_data, crc8_data, crc10_data, crc16_data, crc32_data** → The frame encoded using respective error detection schemes
4. Each scheme's data is passed to the function `checkFrame()`:
    - The function validates whether the received frame contains an error.
    - Results are stored in a **List<List<Integer>> detectedFrames** in the following format:
        - `0` → No error detected
        - `1` → Error detected

---

2. Analysis

1. From **detectedFrames**, the program generates a `detected_frames.csv` file.
2. A **detection summary** is printed on the terminal, showing which schemes detected which errors.
3. The **Receiver** then closes the socket connection.
4. Finally, the **Bash script** (`compile_and_run_ass1.sh`) triggers the **analytics.py** script to:
    - Generate a **histogram** of error detection by type and scheme.
    - Produce a `performance_metrics.csv` file summarizing the effectiveness of each error detection scheme.

Test Cases

To verify the correctness of the program, the following test cases are designed. They cover all required error types (none, single-bit, two-bit, odd-bit, burst) and validate both **Checksum** and **CRC schemes**.

Test Case 1: No Error

- **Input Data:**
  Frame: `1011001110001111…` (any random binary sequence from file)
  Error Type: None
- **Expected Output:**
  - Checksum → No error detected
  - CRC (all variants) → No error detected
- **Purpose:**
  To confirm that valid frames are **not falsely rejected** by either scheme.

Test Case 2: Single-Bit Error

- **Input Data:**
  Frame with 1 flipped bit, e.g., original: `1011001110001111`, modified: `1011001110001101`.
- **Expected Output:**
  - Checksum → Error detected
  - CRC-8 / CRC-10 / CRC-16 / CRC-32 → Error detected
- **Purpose:**
  To verify that all schemes reliably detect single-bit errors.

Test Case 3: Two Isolated Bit Errors

- **Input Data:**
  Frame with 2 flipped bits at different positions, e.g., original: `1011001110001111`, modified: `1011001010001110`.
- **Expected Output:**
  - Checksum → Error detected in ~80% cases; may fail in ~20% cases
  - CRC (all variants) → Error detected
- **Purpose:**
  To validate that **CRC is stronger** than Checksum for two-bit errors.

Test Case 4: Odd Number of Bit Errors

- **Input Data:**
  Frame with an odd number of flipped bits (e.g., 3 or 5).
  Example: `1011001110001111` → `1011001010001101`.
- **Expected Output:**
  - Checksum → Usually detects error (randomized injection may affect outcome)
  - CRC (all variants) → Error detected
- **Purpose:**
  To test robustness against **odd-bit errors** and confirm CRC's consistency.

Test Case 5: Burst Error (Short Burst < CRC Degree)

- **Input Data:**
  Frame with a burst error (e.g., flipping a contiguous block of 6 bits).
- **Expected Output:**
  - Checksum → Fails to detect
  - CRC-8 → May fail (if burst length ≥ 8)
  - CRC-10 → Detects if burst < 10 bits
  - CRC-16 → Detects if burst < 16 bits
  - CRC-32 → Detects if burst < 32 bits
- **Purpose:**
  To validate CRC's **degree-based detection ability** for burst errors.

Test Case 6: Burst Error (Long Burst ≥ CRC Degree)

- **Input Data:**
  Frame with a burst error longer than the CRC polynomial degree.
- **Expected Output:**
  - Checksum → Always fails
  - CRC-n → May fail if burst ≥ n
- **Purpose:**
  To test the **limitations of CRC detection capability** when burst errors exceed polynomial degree.

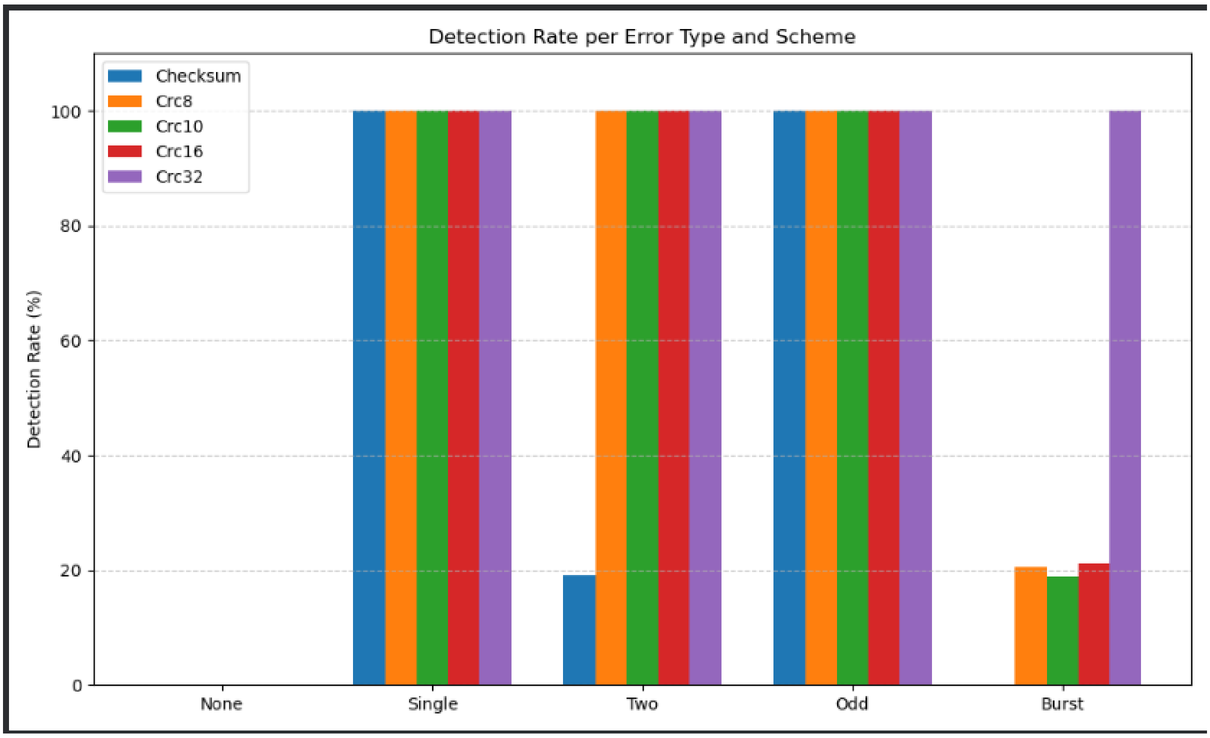
Test Case 7: Mixed Frames Transmission

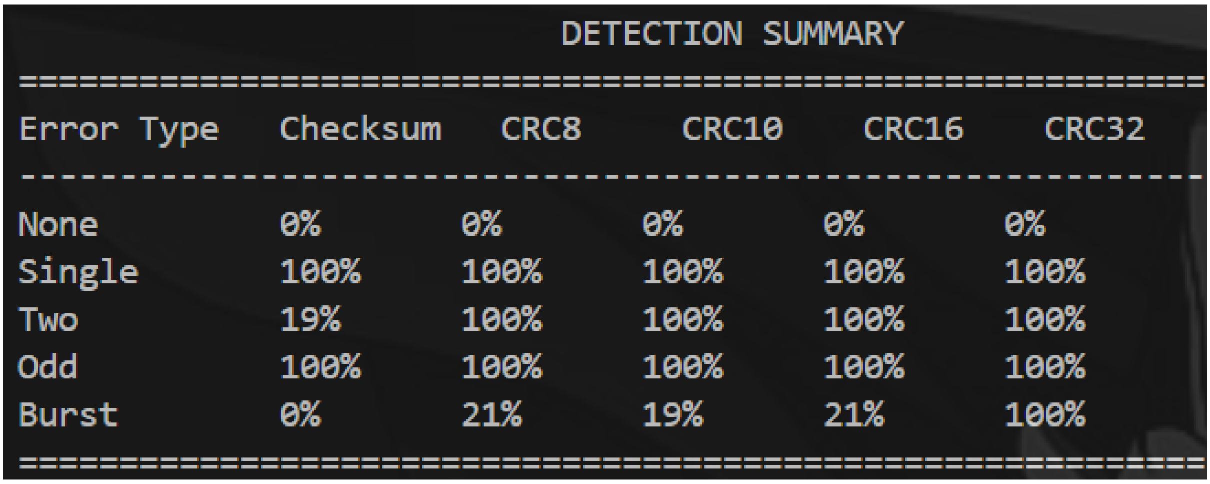
- **Input Data:**
  A file containing multiple frames with different injected error types (no error, single-bit, two-bit, odd, burst).
- **Expected Output:**
  - Correct detection per scheme, summarized in `detected_frames.csv`.

- **Purpose:**
  To test **end-to-end system correctness**, ensuring the sender, error injector, receiver, and analytics pipeline all work together.

Results

1. **No Errors**
   - All schemes correctly report **no error**.
2. **Single-Bit Errors**
   - **All schemes (Checksum, CRC-8, CRC-10, CRC-16, CRC-32)** successfully detect single-bit errors.
3. **Two-Bit Errors**
   - **Checksum** fails to detect errors in approximately **20% of cases**.
   - All **CRC schemes** reliably detect two-bit errors.
4. **Odd Number of Errors**
   - All schemes detect the errors, since the injected odd-bit flips are random and easily caught.
5. **Burst Errors**
   - **Checksum** consistently fails to detect burst errors.
   - **CRC-32** detects burst errors in nearly all cases.
   - Other CRC schemes detect burst errors depending on whether the **burst length < degree of the polynomial** used.





```
                           DETECTION SUMMARY
============================================================
Error Type   Checksum   CRC8     CRC10    CRC16    CRC32
------------------------------------------------------------
None         0%         0%       0%       0%       0%
Single       100%       100%     100%     100%     100%
Two          19%        100%     100%     100%     100%
Odd          100%       100%     100%     100%     100%
Burst        0%         21%      19%      21%      100%
============================================================
```

Analysis

1. For **no error, single-bit errors, and two-bit errors**, the results match theoretical expectations.
2. For **odd-bit errors**, since the flipped bits are chosen randomly, the **Checksum** detects errors almost every time.
3. For **burst errors**, the outcomes are also consistent with expectations:
   - **Checksum** fails consistently.
   - **CRC schemes** detect burst errors depending on their polynomial degree.

Improvements Possible

1. The selection of bits for **odd-bit error injection** can be made more controlled.
   - This would create scenarios where the **Checksum** fails occasionally, making the evaluation of its limitations more comprehensive.

Comments

This lab assignment was a valuable exercise in understanding **error detection techniques** in computer networks. It provided hands-on experience with both **Checksum** and **CRC**, showing their practical strengths and limitations under different types of errors.

- **What I learned:**
  - How to implement **Checksum** and different **CRC polynomials**.
  - How various error patterns (single-bit, two-bit, odd-bit, burst) behave differently against these schemes.
  - Why CRC is generally more reliable than Checksum in detecting complex errors such as burst errors.
- **Difficulty Level:**
  - The assignment was **moderately challenging**.
  - The core concepts were clear from theory, but implementing error injection and ensuring realistic scenarios (e.g., burst errors that bypass CRC) required careful thought and debugging.
  - The multi-file structure (Java + Python + Bash) added complexity, but it also made the project feel closer to a **real-world system simulation** rather than a toy problem.

Conclusion

In this lab, I have successfully implemented and compared **Checksum** and **CRC** as error detection techniques. The results showed that while **Checksum** is simple and lightweight, it often fails in detecting complex errors such as two-bit and burst errors. On the other hand, **CRC**, especially higher-degree polynomials like **CRC-32**, demonstrated strong reliability in detecting almost all error patterns. Overall, CRC proves to be a more robust and practical choice for real-world network communication, whereas Checksum is suitable for simpler, low-cost error detection scenarios.