Error Detection and Correction - Complete Notes

What is an Error?

An **error** occurs when the data sent by the sender is not the same as the data received by the receiver.

Example:

- **Sender sends:** 101 (binary) = 5 (decimal)
- **Receiver gets:** 100 (binary) = 4 (decimal)
- **Result:** Complete change in data meaning

Real-world Scenario:

Consider a sender in India and receiver in USA. How will the receiver know if data got corrupted during transmission? This is where error detection becomes crucial.

Error Detection vs Error Correction

Error Detection

- **Purpose:** At least know that there is some error in the data
- **Benefit:** Prevents receiver from accepting corrupted data unknowingly
- **Method:** Uses redundancy to identify presence of errors

Error Correction

- **Purpose:** Advanced step beyond detection
- **Goal:** Not only detect errors but also find which specific bit is in error
- **Benefit:** Can correct the erroneous bit automatically

OSI Layer Context

Error detection and correction occurs in:

- **Transport Layer**
- **Data Link Layer**

In Data Link Layer, we check **bit-by-bit** for errors.

Types of Errors

1. Single Bit Error

- **Definition:** Error in exactly one bit in the entire data block

- **Example:**
  - Sender sends: 100
  - Receiver gets: 101
  - Only the last bit changed (0 → 1)

2. Burst Error

- **Definition:** Error in more than one bit
- **Example:**
  - Sender sends: 101010
  - Receiver gets: 111011
  - Multiple bits changed

Error Length Calculation

Important Concept: Length includes all bits from first error to last error, even unchanged bits in between.

Example:

- Original: 101010
- Received: 111011
- Changed bits: 2nd and 6th positions
- **Error Length:** 5 bits (from position 2 to position 6)
- **Actually changed:** 2 bits

Causes of Errors

1. **Long distance transmission**
2. **Energy loss (attenuation)**
3. **Environmental effects:**
   - Thunderbolts
   - Lightning
   - Noise from machinery startup
4. **Natural interference**

Impact on Digital Data:

- 1 becomes 0
- 0 becomes 1
- Changes the entire meaning of data

Practical Bandwidth Calculation Example

Scenario: 1 GBPS Channel

- **Bandwidth:** 1 GBPS = 10^9 bits per second
- **Time for 1 bit:** 1/(10^9) seconds = 1 nanosecond

Single Bit Error Duration:

- If error lasts for **1 nanosecond** → Single bit error likely
- If error lasts **longer** → Burst error more likely

Burst Error Calculation:

Question: If error lasts for 1/1000 seconds, how many bits get corrupted?

Solution:

- Error duration: 1/1000 seconds
- Bandwidth: 10^9 bits/second
- **Corrupted bits = (1/1000) × 10^9 = 10^6 bits**

Application Dependency

Audio/Video Applications:

- Can **tolerate some errors**
- Minor corruption may cause slight quality issues but is bearable

Text Applications (WhatsApp, Facebook):

- **Cannot tolerate errors**
- Even small changes can completely alter meaning
- Real-time text data requires high accuracy

Detection Methods

1. **Simple Parity** (Even/Odd parity)
2. **2-Dimensional Parity Check**
3. **Check Sum** (used in Transport Layer)
4. **CRC (Cyclic Redundancy Check)** - Very important method

Correction Methods

- **Hamming Codes** - Primary method for error correction

Fundamental Principle: Redundancy

Core Concept:

- Cannot detect/correct errors with original data alone
- Must send **extra bits** along with actual data

Example:

- Have 8-bit block available
- Send only 5-7 bits of actual data
- Remaining 1-3 bits are **redundant bits**
- Redundant bits used for error detection/correction

Redundancy Trade-off:

- **Benefit:** Enables error detection and correction
- **Cost:** Reduces actual data transmission capacity
- **Necessity:** Essential for reliable communication

Key Takeaways

1. **Burst errors are more common** than single bit errors in real-world scenarios
2. **Error detection is prerequisite** for error correction
3. **All methods rely on redundancy** - extra bits must be transmitted
4. **Application requirements vary** - some can tolerate errors, others cannot
5. **Longer error durations** typically result in burst errors affecting multiple bits
6. **Environmental factors** are major causes of transmission errors

Important Formulas

1. **Bit time = 1/Bandwidth**
2. **Corrupted bits = Error duration × Bandwidth**
3. **Error length = Distance from first error bit to last error bit (inclusive)**