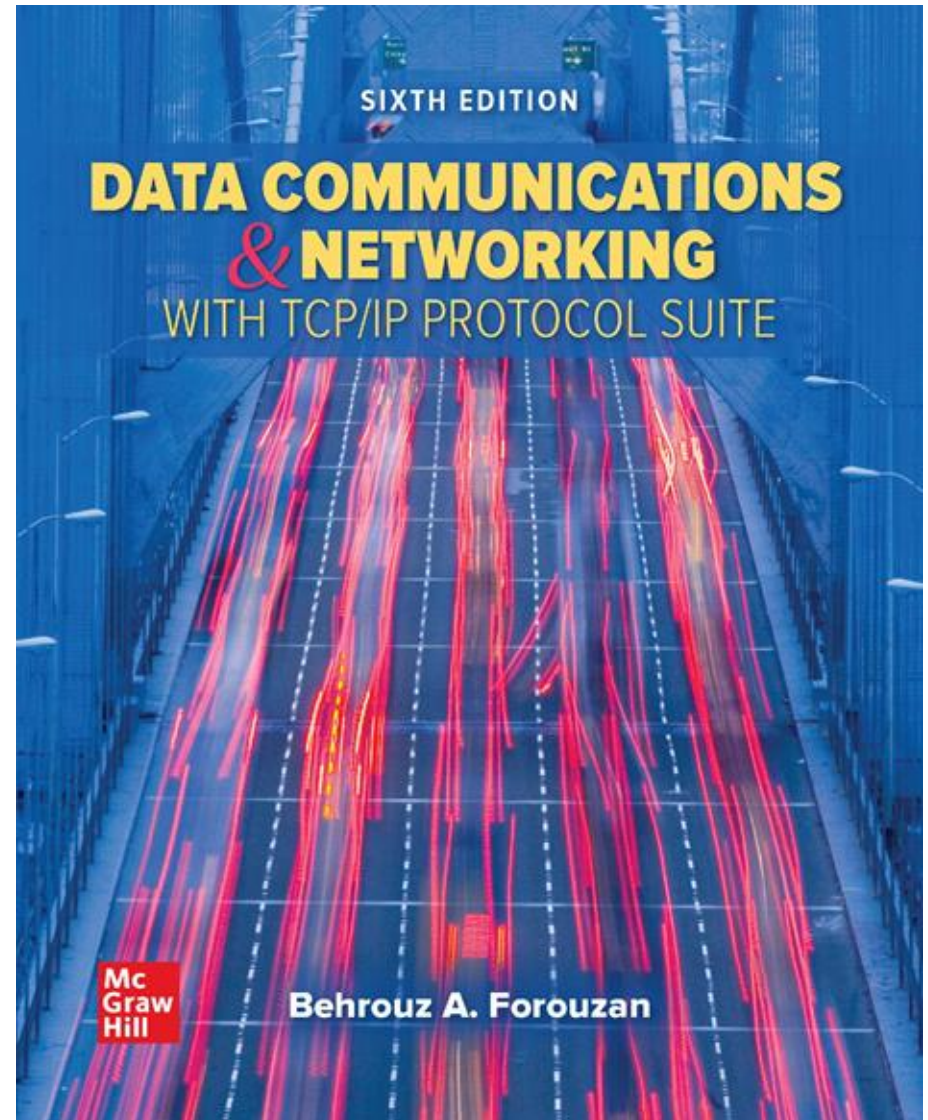


Chapter 03

Data-Link Layer

- Data Communications and Networking, With TCP/IP protocol suite Sixth Edition
- Behrouz A. Forouzan



Chapter 3: Outline

- *3.1 INTRODUCTION*
- *3.2 DATA LINK CONTROL*
- *3.3 MEDIA ACCESS CONTROL*
- *3.4 LINK-LAYER ADDRESSING*

Chapter 3 DLL services

- **Framing/deframing**

- Encapsulate datagram (packet) into frame, adding header, trailer
- Different protocols have different format for the DLL frame
- Deframing at the receiver

- **Addressing**

- In general it is called layer 2 address or data link layer address
- In LAN, called physical address or MAC address
- “physical addresses” used in frame headers to identify source, destination



Framing

- The data-link layer needs to pack bits into frames, so that each frame is **distinguishable from another**.
- Our postal system practices a type of framing. The simple act of inserting a letter into an envelope **separates one piece of information from another; the envelope serves as the 0**.
- Framing in the data-link layer separates a message from one source to a destination by adding a sender address and a destination address.
- The destination address defines where the packet is to go; the sender address helps the recipient acknowledge the receipt.

DLL services

■ Error Control

- Error detection and correction techniques to provide reliable delivery

■ Flow control

- The sender must NOT send frames at a rate faster than the receiver can process them
- Based on set of procedures that tells the sender how much data it can transmit before it must **wait** for an acknowledgment from the receiver

■ Access control

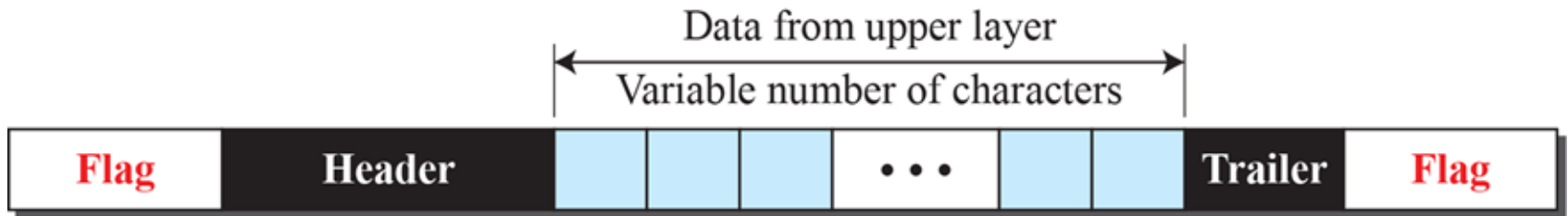
- Controlling access to a shared medium (shared wire, air)
 - This is called Medium Access Control (MAC) sublayer



Framing

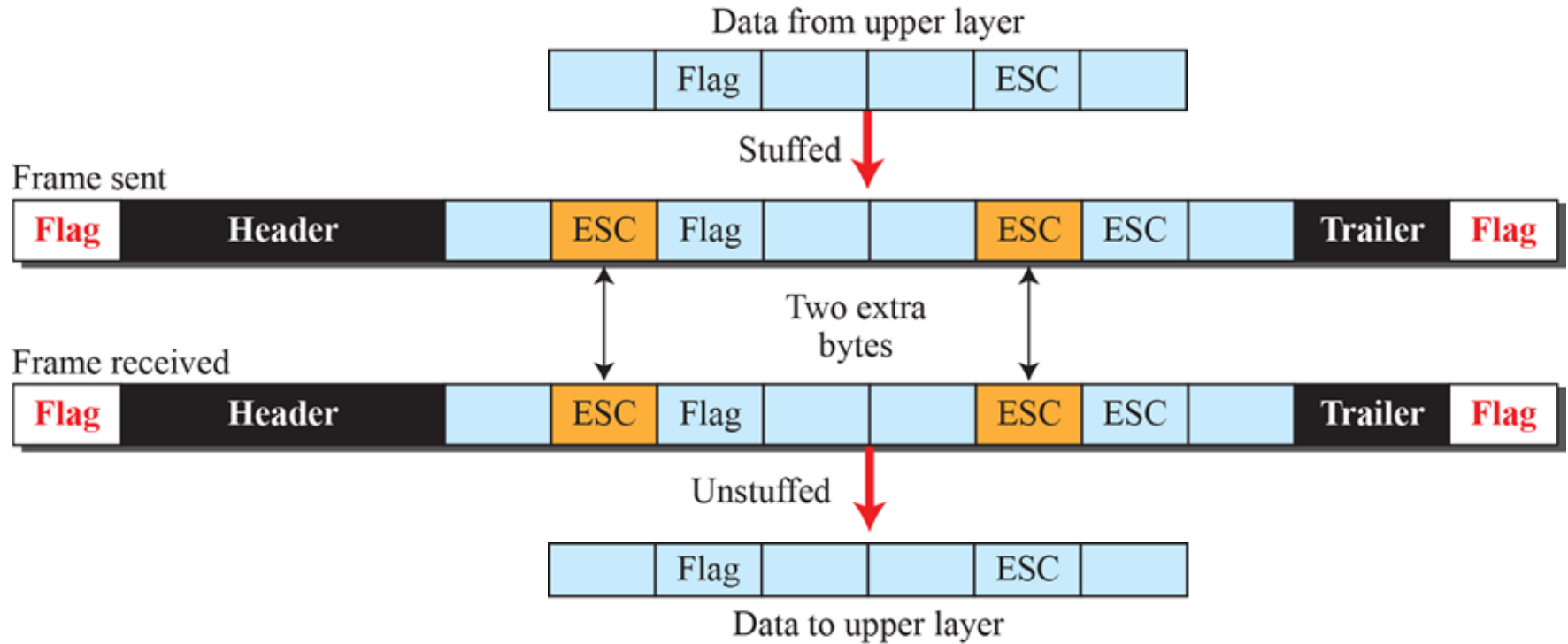
- **Two types of framing protocols:**
 - **Character oriented: length of frame is multiple of bytes (multiple of 8)**
 - **Bit oriented: length of frame is not multiple of bytes (NOT multiple of 8)**

Figure: A frame in a character-oriented protocol



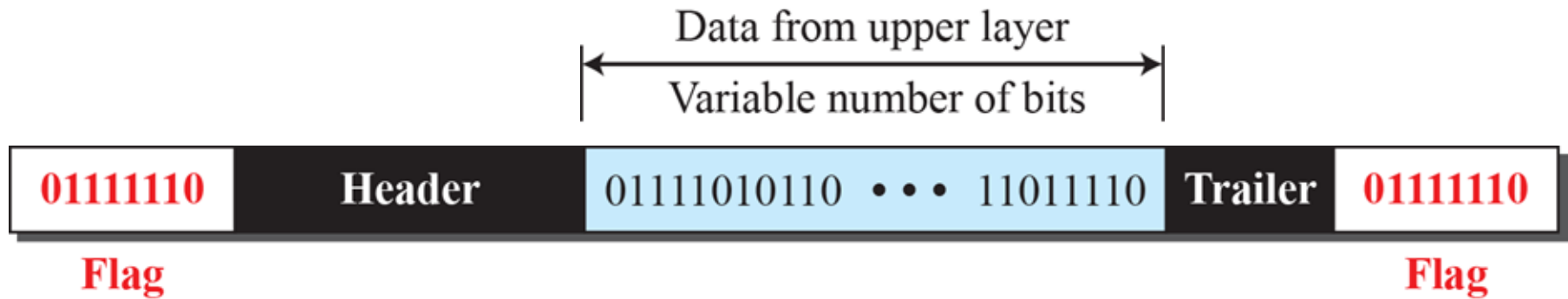
- To separate one frame from another an 8-bit flag is added at the beginning and end of the frame
- Flag is protocol dependent usually (01111110)

Figure : Byte stuffing and unstuffing



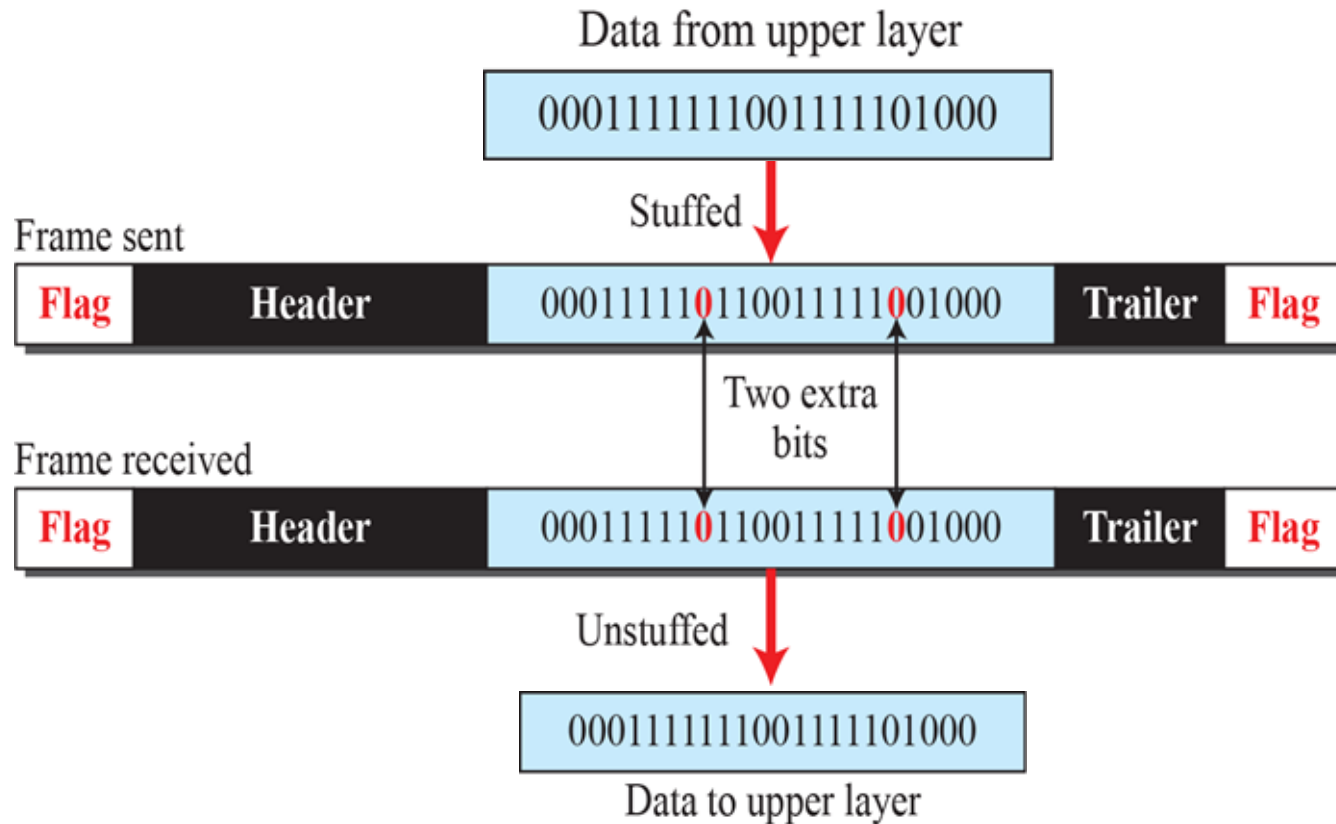
- If flag appears in the data to be carried by the frame, Byte stuffing is used.
- Byte stuffing is the process of adding one extra byte (ESC) whenever the flag character in the data. This is done at the Sender
- If (ESC) character also appears in the data, it is also preceded by ESC. This is done because ESC may be also sent by the application as part of the message.
- At the receiver, each time ESC appears in the data, it is removed and the following next character directly following it is treated as data not as flag.

Figure : A frame in a bit-oriented protocol



- To separate one frame from another an 8-bit flag is added at the beginning and end of the frame
- Flag is protocol dependent usually (01111110)

Figure : Bit stuffing and unstuffing



Sender:

11111 → 111110

Receiver:

111110 → 11111

- If flag appears in the data to be carried by the frame, Bit stuffing is used.
- Bit stuffing is the process of adding (stuff) one extra 0 **whenever 5 consecutive 1s. Appear in the data from upper layer** This is done at the Sender.
- The receiver, on seeing a sequence of five 1s, **checks the next bit**. If it is 0, the bit is simply discarded (unstuff); if it is 1, then it notes that an **end of data set has been flagged**.



Note

**Data can be corrupted
during transmission.**

**Some applications require that
errors be detected and corrected.**

Types of Error

Single-Bit Error

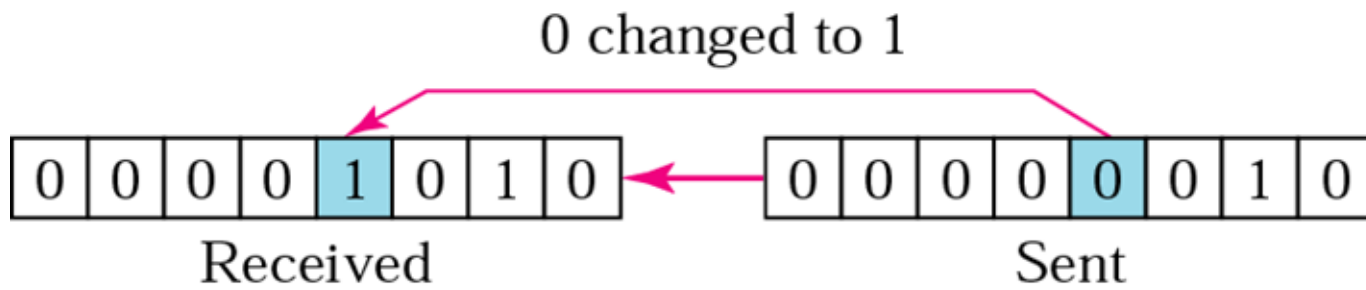
Burst Error



Note

In a single-bit error, only 1 bit in the data unit has changed.

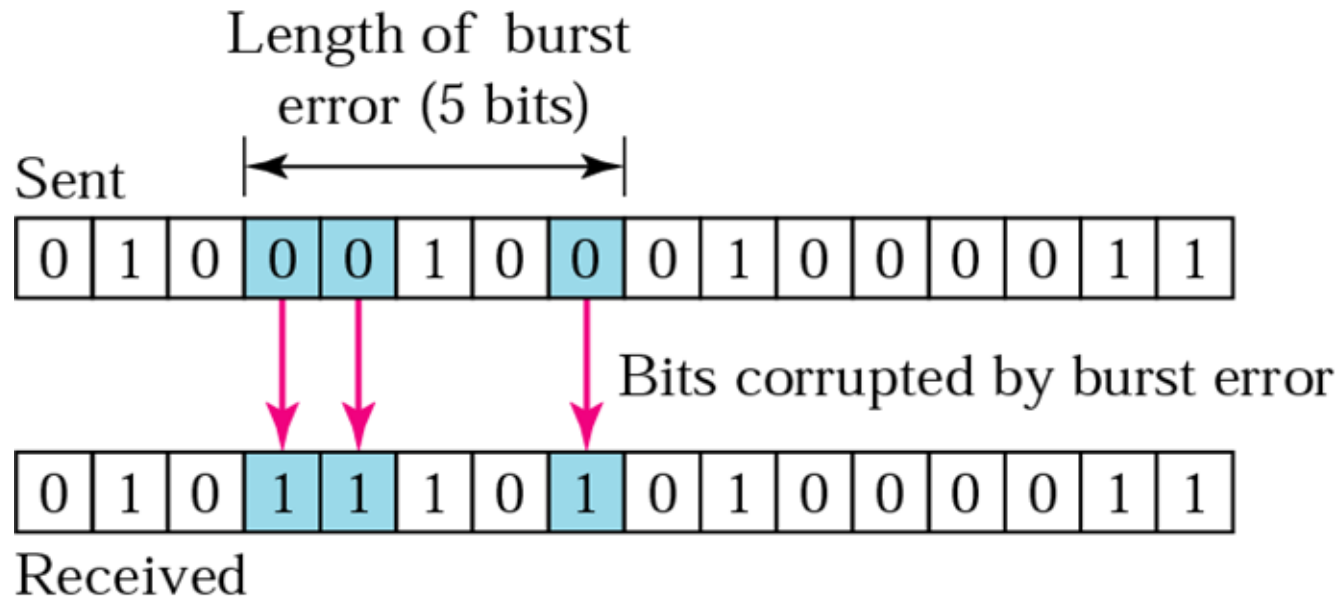
Single-bit error



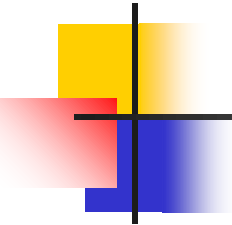
Note

A burst error means that 2 or more bits in the data unit have changed.

Burst error of length 5



- Burst error does NOT necessarily mean that the errors occur in **consecutive bits**
- **Length of the burst:** number of bits from the **first corrupted** bit to the **last corrupted** bit
- Effect of burst error is **higher at high data rates**



Example

How many bits are affected by 2 ms burst error if:

- a) The bandwidth is 1 Kbps*
- b) The bandwidth is 1 Gbps*

$$\text{Number of affected bits} = \text{Bandwidth} \times \text{Error duration}$$

Solution

- a) $1 \times 10^3 \times 2 \times 10^{-3} = 2 \text{ bits}$*
- b) $1 \times 10^9 \times 2 \times 10^{-3} = 2000000 \text{ bits}$*



Note

To detect or correct errors, we need to send extra (redundant) bits with data.

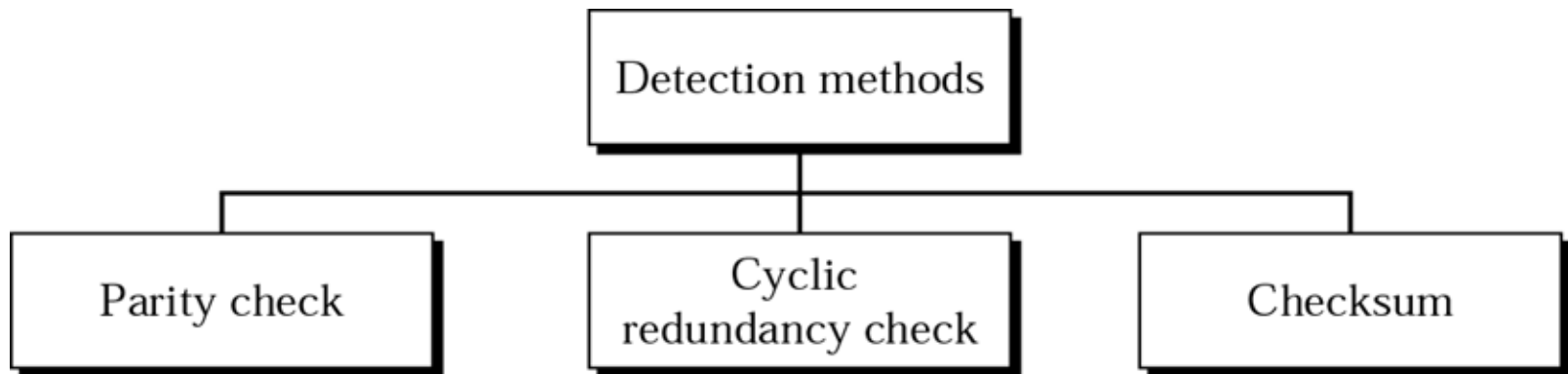


Figure *The structure of encoder and decoder*

A **parity bit** is an extra bit added to binary data to help **detect errors** during data transmission or storage.

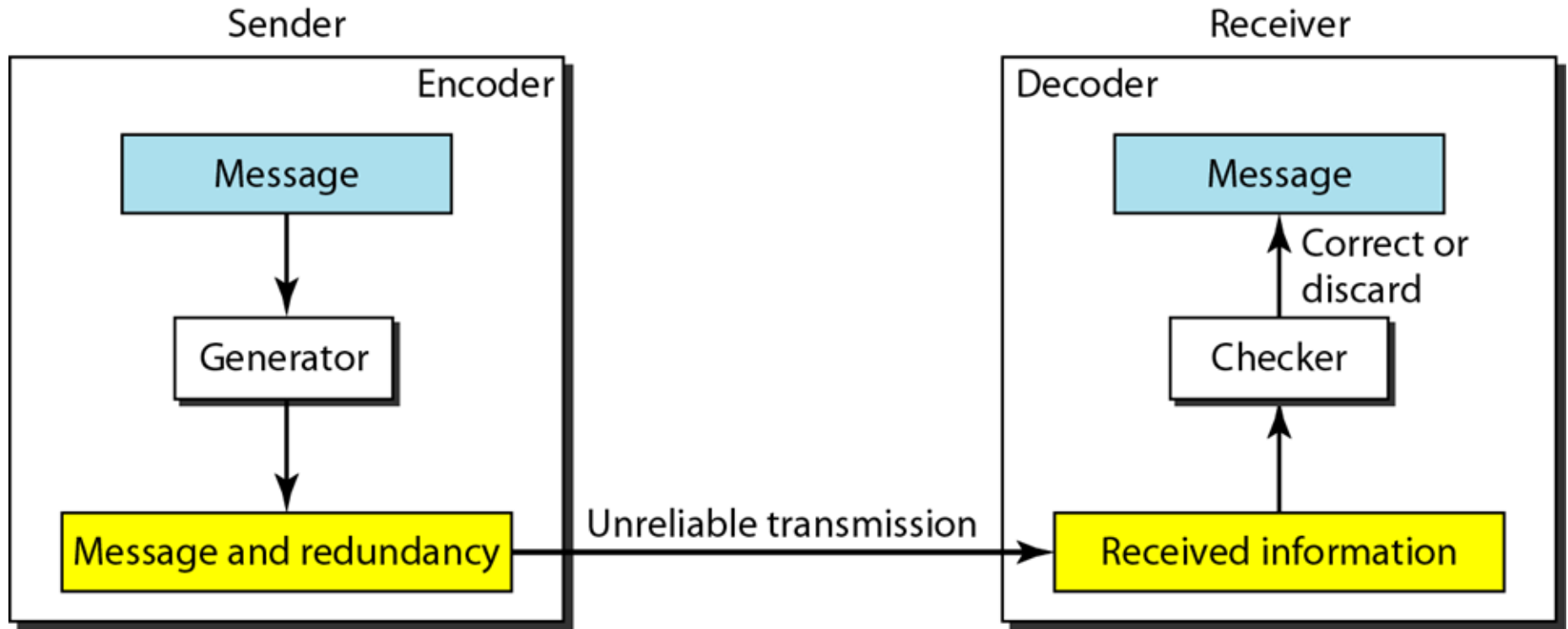
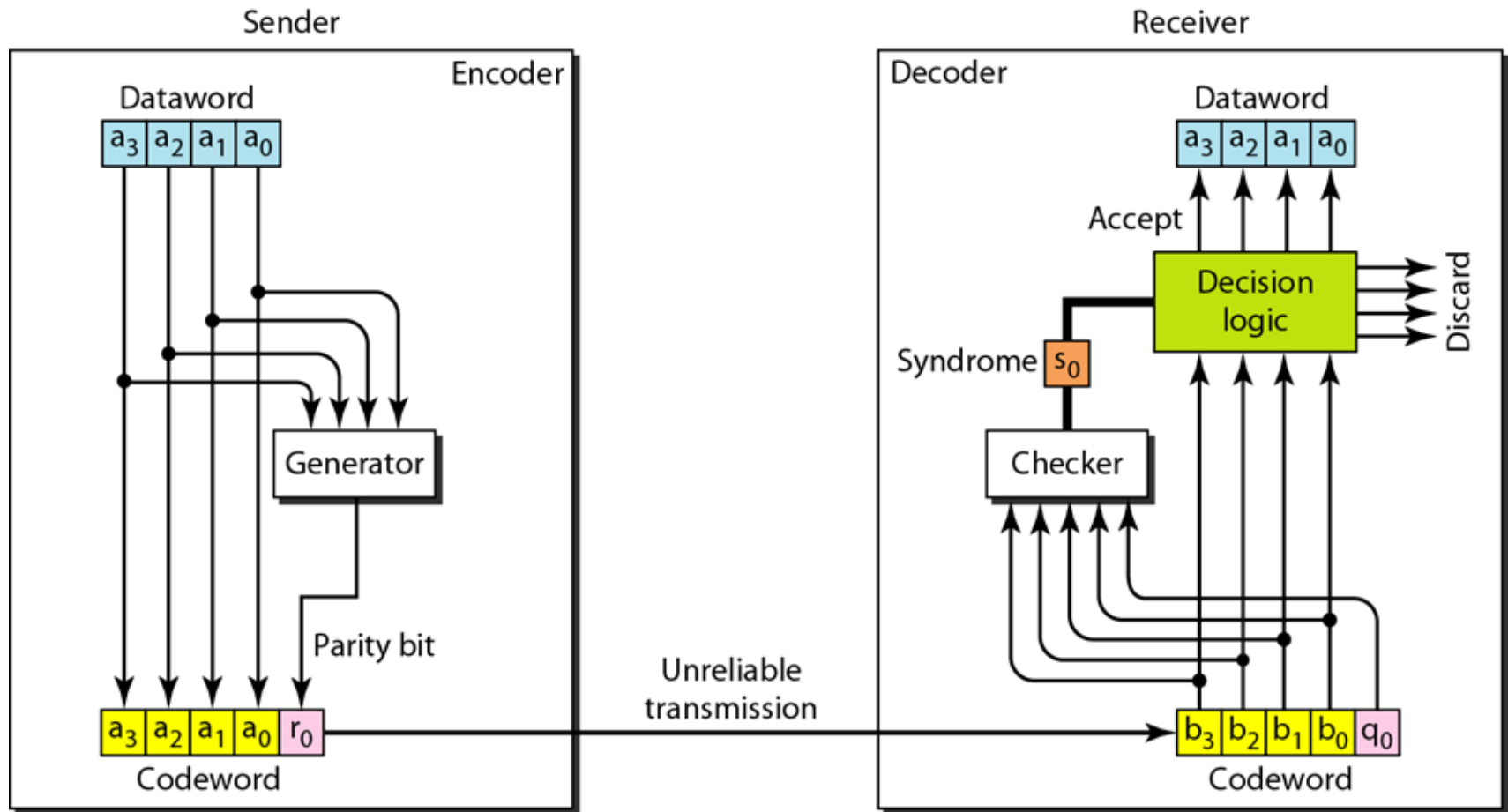


Figure *Encoder and decoder for simple parity-check code*





Note:

In parity check, a parity bit is added to every data unit so that the total number of 1s is even (or odd for odd-parity).

Table *Simple parity-check code C(5, 4)*

<i>Datawords</i>	<i>Codewords</i>	<i>Datawords</i>	<i>Codewords</i>
0000	00000	1000	10001
0001	00011	1001	10010
0010	00101	1010	10100
0011	00110	1011	10111
0100	01001	1100	11000
0101	01010	1101	11011
0110	01100	1110	11101
0111	01111	1111	11110

$C(n,k)$ = codeword that consists of n-bit for every k-bit data word

Example 1

Suppose the sender wants to send the word *world*. In ASCII the five characters are coded as

1110111 1101111 1110010 1101100 1100100

The following shows the actual bits sent in case **Even parity** is used:

11101110 11011110 11100100 11011000 11001001

Example 2

Now suppose the word world in Example 1 is received by the receiver without being corrupted in transmission.

11101110 11011110 11100100 11011000 11001001

The receiver counts the 1s in each character and comes up with even numbers (6, 6, 4, 4, 4). The data are **accepted**.

Example 3

Now suppose the word world in Example 1 is corrupted during transmission.

11111110 11011110 11101100 11011000 11001001

The receiver counts the 1s in each character and comes up with even and odd numbers (7, 6, 5, 4, 4). The receiver knows that the data are **corrupted**, discards them, and asks for retransmission.



Note:

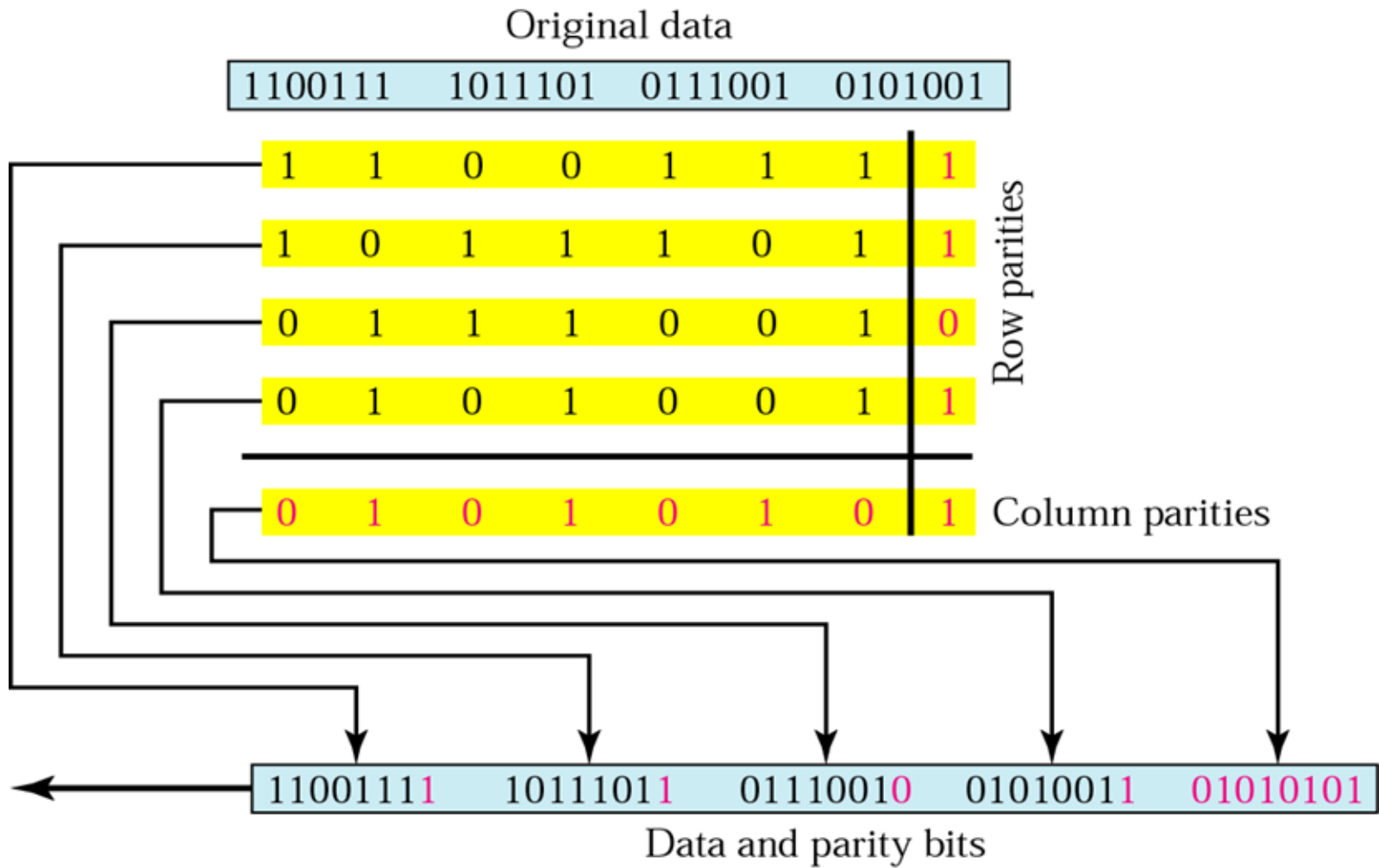
*Simple parity check can detect all single-bit errors. It can detect burst errors only if the total number of bits changed in each data unit is **odd**.*



Note:

In two-dimensional parity check, a block of bits is divided into rows and a redundant row of bits is added to the whole block.

Two-dimensional parity



Two-dimension parity

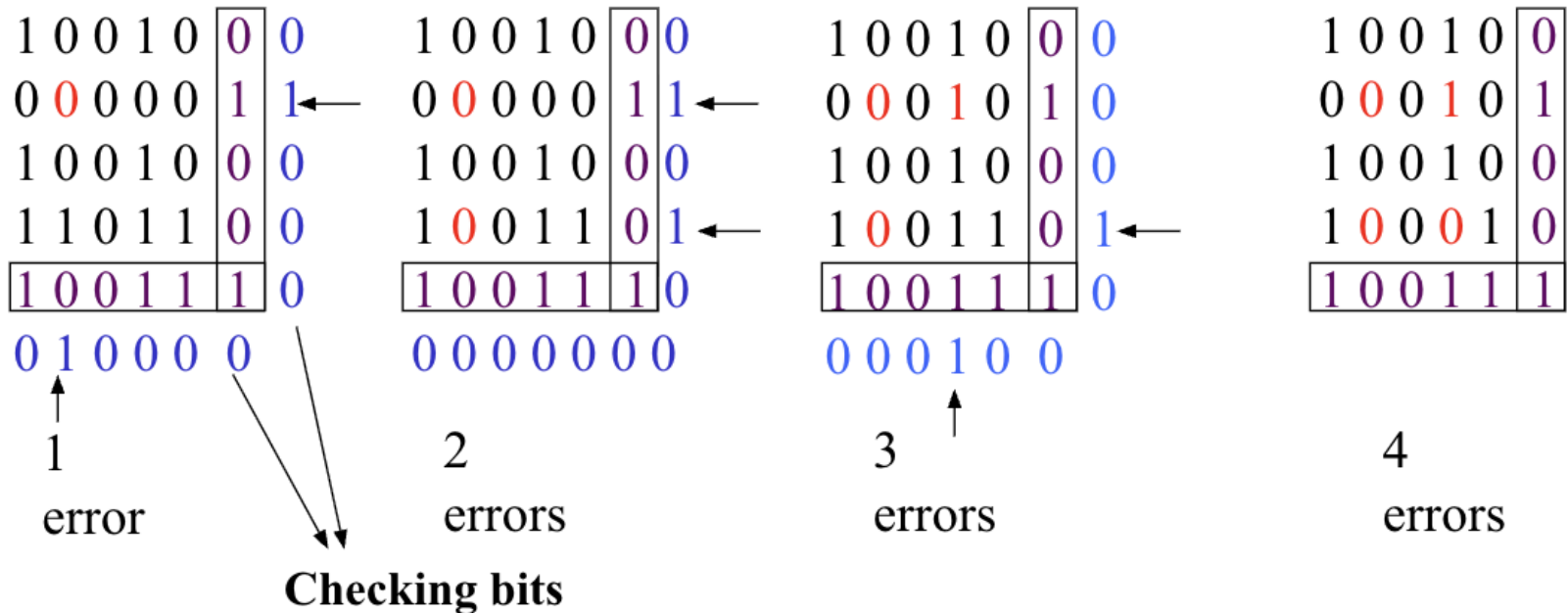
1. Data blocks are organized into table
2. Last column: check bits for rows
3. Last row: check bits for columns
4. Can **detect** and **correct single** bit error

Data →

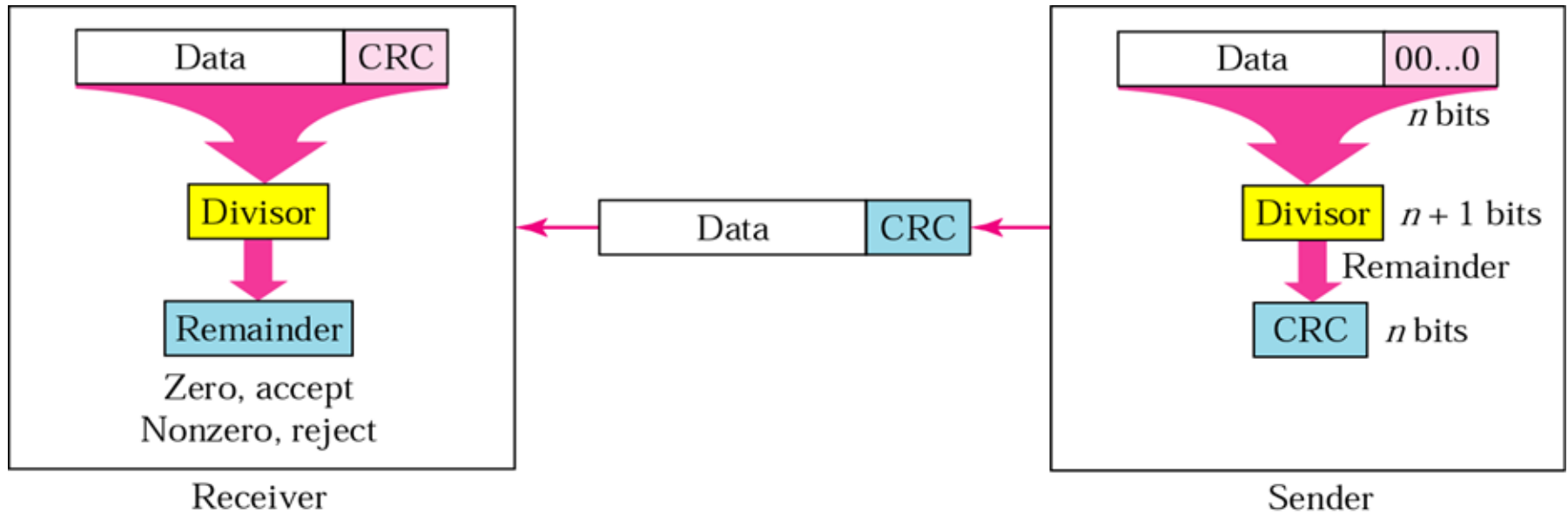
1	0	0	1	0	0
0	1	0	0	0	1
1	0	0	1	0	0
1	1	0	1	1	0
1	0	0	1	1	1

→ **Parity bits**

Can detect one, two, three errors, (Red bits are errors)
 But **NOT** all four errors.



Cyclic Redundancy Check (CRC)

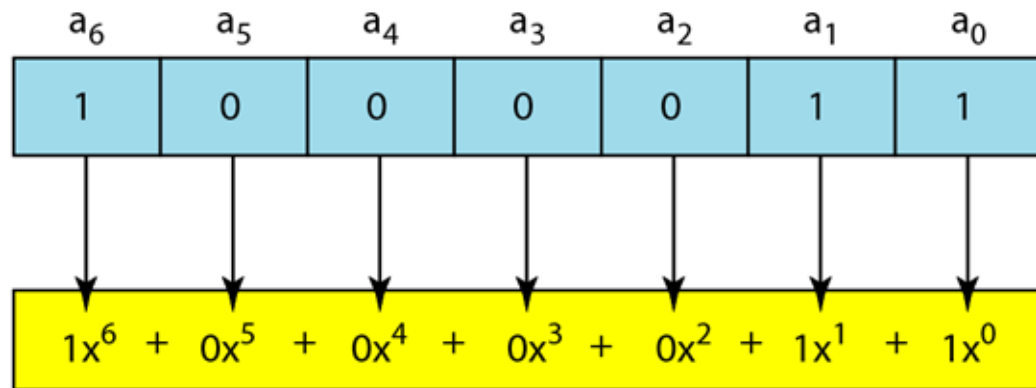


Note

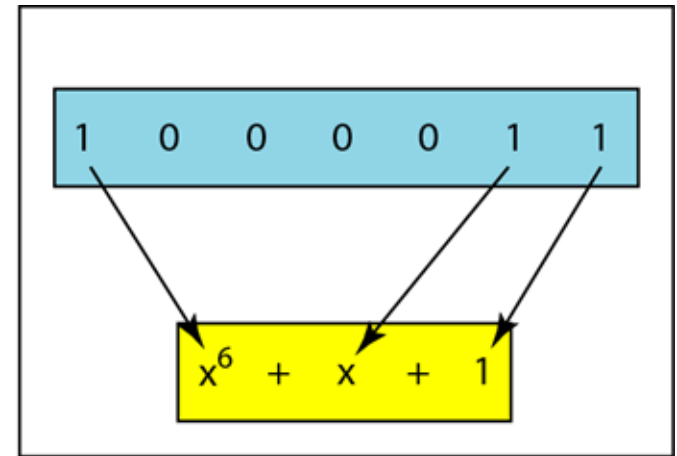
The divisor in a cyclic code is normally called the generator polynomial or simply the generator.

Because this divisor is used to **generate the CRC bits** (the remainder).

Figure *A polynomial to represent a binary word*



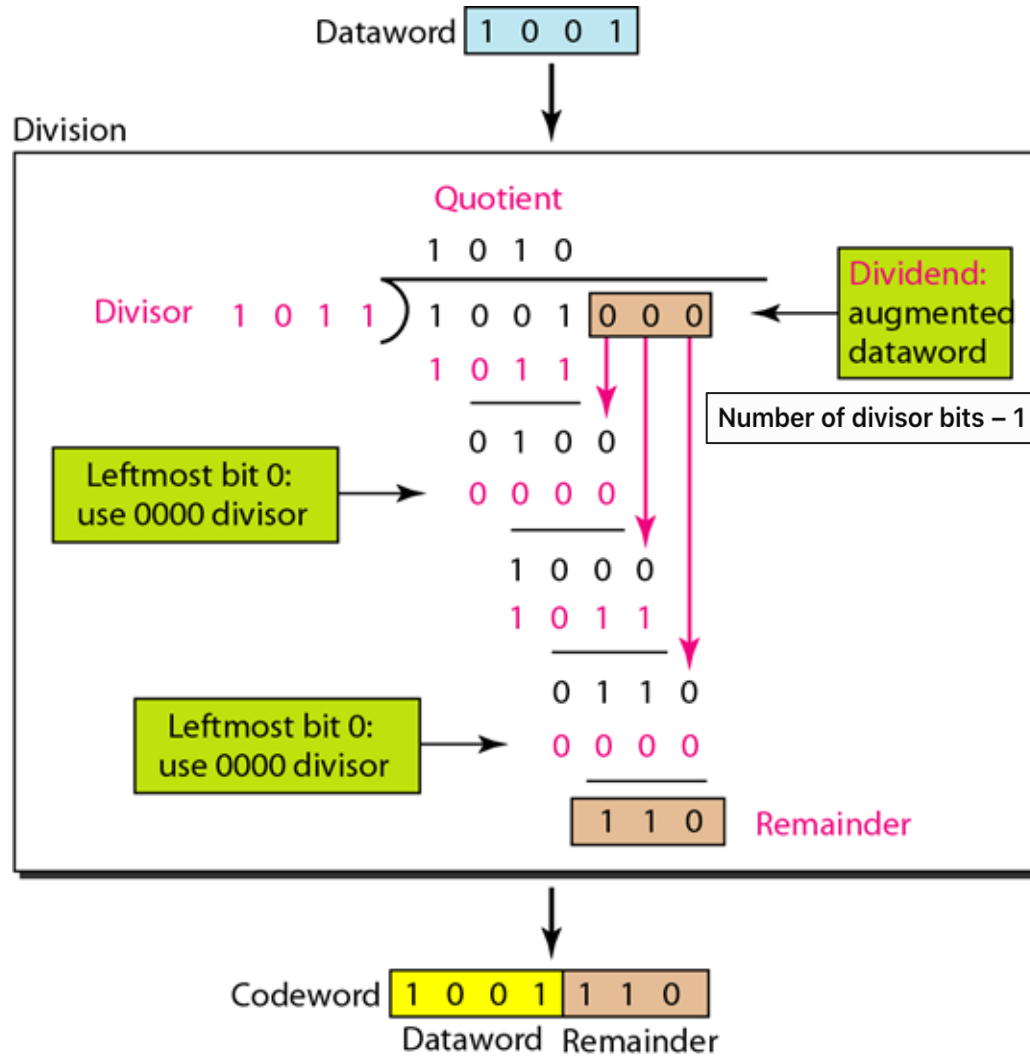
a. Binary pattern and polynomial



b. Short form

In CRC, a sequence of bits is represented as a polynomial so that we can use polynomial division to calculate the remainder. In binary, this division is performed using XOR.

Figure Division in CRC encoder



XOR Rules:

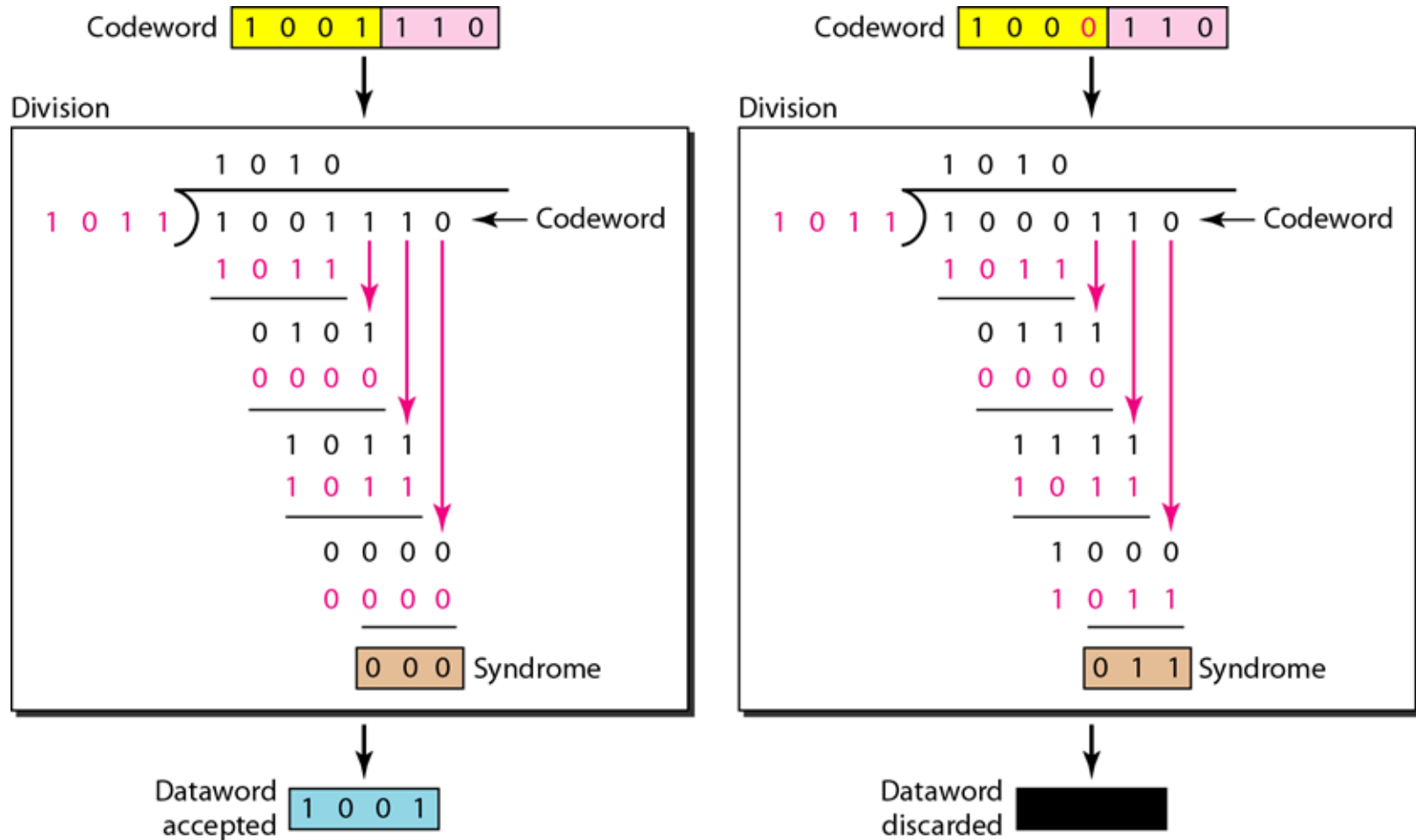
$$0 \oplus 0 = 0$$

$$0 \oplus 1 = 1$$

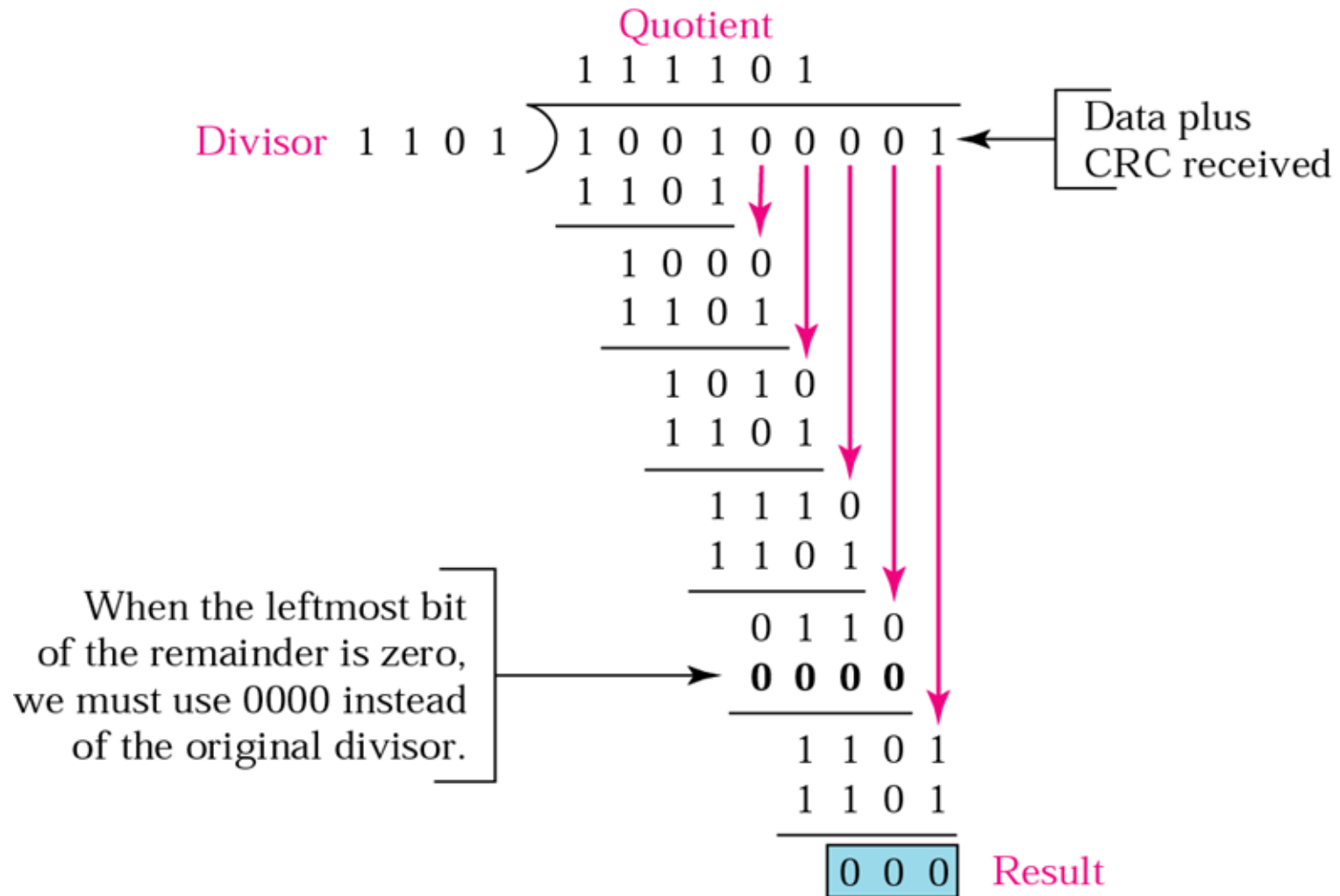
$$1 \oplus 0 = 1$$

$$1 \oplus 1 = 0$$

Figure *Division in the CRC decoder for two cases*



Binary division in CRC checker



Binary division in CRC checker

SENDER:

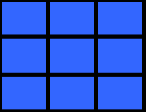
Data → append zeros → divide → get CRC → Data + CRC

RECEIVER:

Data + CRC → divide by same divisor

↓

Remainder 0	→ No error detected
Remainder $\neq 0$	→ Error detected



Standard polynomials

<i>Name</i>	<i>Polynomial</i>	<i>Used in</i>
CRC-8	$x^8 + x^2 + x + 1$ 100000111	ATM header
CRC-10	$x^{10} + x^9 + x^5 + x^4 + x^2 + 1$ 11000110101	ATM AAL
CRC-16	$x^{16} + x^{12} + x^5 + 1$ 10001000000100001	HDLC
CRC-32	$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$ 100000100110000010001110110110111	LANs



Advantages of Cyclic Codes

We have seen that cyclic codes have:

- a very good performance in detecting **single-bit errors, double errors, an odd number of errors, and burst errors.***
- They can easily be **implemented in hardware** and software. They are especially fast when implemented in hardware.*
- This has made cyclic codes a **good candidate for many networks.***



Example

Find the suitability of the following generators in relation to burst errors of different lengths.

- a. $x^6 + 1$ b. $x^{18} + x^7 + x + 1$ c. $x^{32} + x^{23} + x^7 + 1$*

Solution

*a. $x^6 + 1$ generator can detect all burst errors with a length **less than or equal** to 6 bits; $(1/2^5 = 0.03)$ 3 out of 100 burst errors with **length 7** will not be detected; $(1/2^6 = 0.016)$ 16 out of 1000 burst errors of **length 8 or more** will not be detected.*

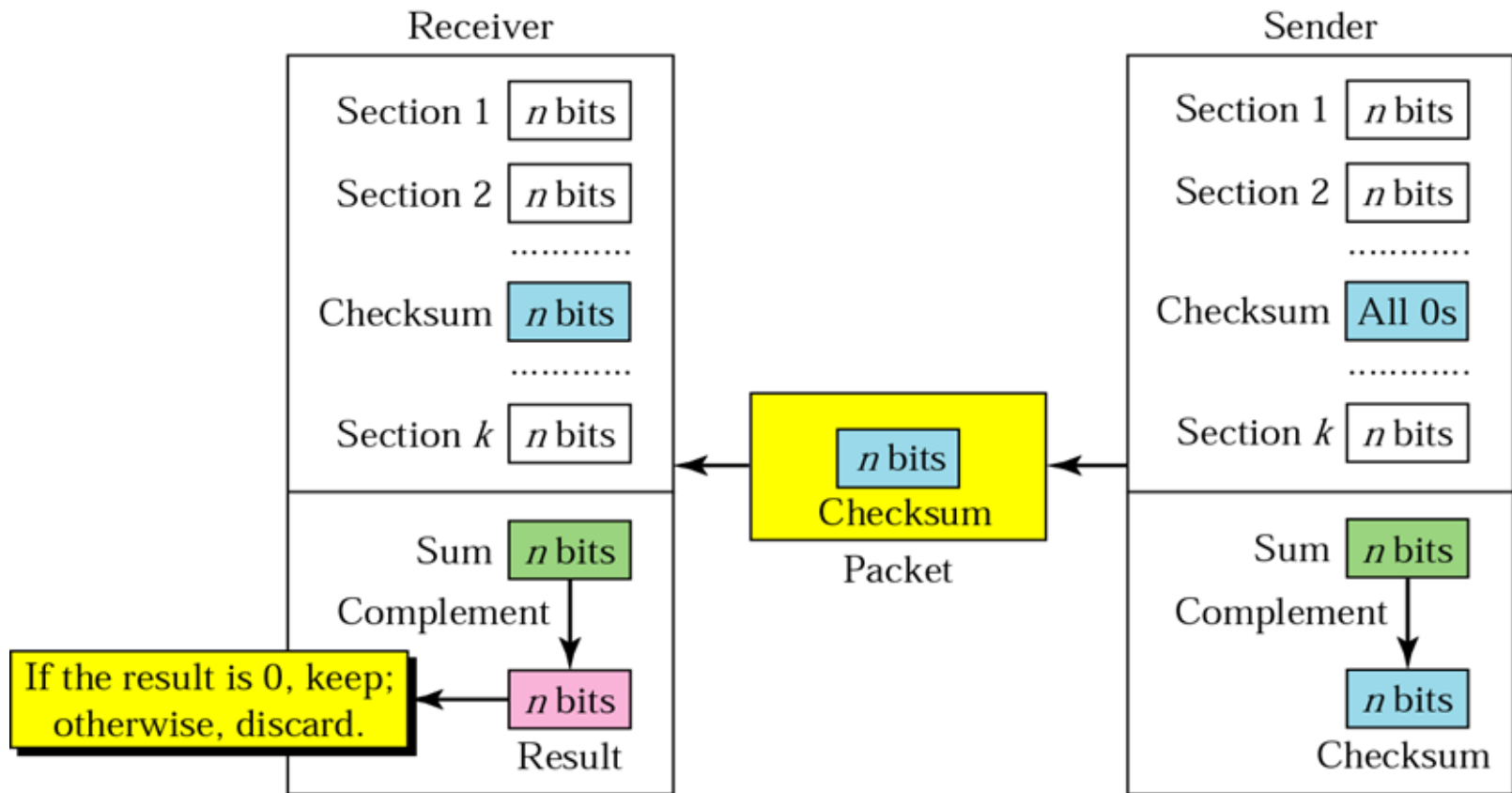


Example (continued)

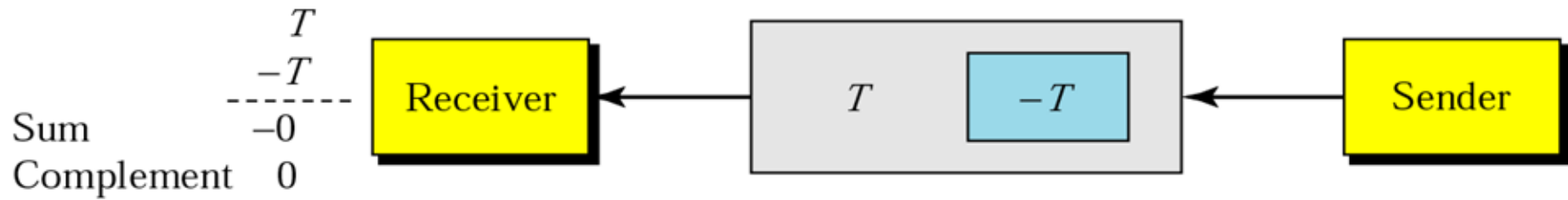
b. $x^{18} + x^7 + x + 1$ generator can detect all burst errors with a length less than or equal to 18 bits; 8 out of 1 million burst errors with length 19 will slip by; 4 out of 1 million burst errors of length 20 or more will slip by.

c. $x^{32} + x^{23} + x^7 + 1$ generator can detect all burst errors with a length less than or equal to 32 bits; 5 out of 10 billion burst errors with length 33 will slip by; 3 out of 10 billion burst errors of length 34 or more will slip by.

Checksum



Data unit and checksum





Note

Sender site:

- 1. The message is divided into 16-bit words.**
- 2. The value of the checksum word is set to 0.**
- 3. All words including the checksum are added using one's complement addition.**
- 4. The sum is complemented and becomes the checksum.**
- 5. The checksum is sent with the data.**



Note

Receiver site:

- 1. The message (including checksum) is divided into 16-bit words.**
- 2. All words are added using one's complement addition.**
- 3. The sum is complemented and becomes the new checksum.**
- 4. If the value of checksum is 0, the message is accepted; otherwise, it is rejected.**

Example 7

Suppose the following block of 16 bits is to be sent using a checksum of 8 bits.

10101001 00111001

The numbers are added using one's complement

10101001

00111001

Sum 11100010

Checksum **00011101**

The pattern sent is 10101001 00111001 **00011101**

Example 8

Now suppose the receiver receives the pattern sent in Example 7 and there is no error.

10101001 00111001 00011101

When the receiver adds the three sections, it will get all 1s, which, after complementing, is all 0s and shows that there is no error.

10101001

00111001

00011101

Sum 11111111

Complement **00000000** means that the pattern is OK.

Example 9

Now suppose there is a burst error of length 5 that affects 4 bits.

10101111 11111001 00011101

When the receiver adds the three sections, it gets

10101111

11111001

00011101

Partial Sum **1** 11000101

Carry **1**

Sum 11000110

Complement **00111001 the pattern is corrupted.**

Error Correction

Retransmission

Forward Error Correction

Error Correction- 1-Retransmission

- For Wireless applications error detection and retransmission is *inefficient*:
 - The bit error rate on a wireless link can be very high which would result in large number of retransmissions.
- For real-time Multimedia applications, retransmissions create unacceptable delay. The application has to wait until the corrupted packet is retransmitted.

Error Correction-

2-Forward Error Correction (FEC)

Forward error correction (FEC) is an error correction technique to detect and correct a limited number of errors in transmitted data without the need for retransmission.

- Two-dimensional Parity
- Using XOR property
 - After adding the error detection bits to the datawords and create the codewords blocks
 - XOR all codewords together. This will create block (R)
 - Transmit the codewords with the block (R)
 - $R = C_1 \oplus C_2 \oplus C_3 \oplus \dots \oplus C_n$
 - To recover any of the corrupted blocks, XOR all other blocks with the (R)
 - For example, if C_2 is missing:
$$C_2 = R \oplus C_1 \oplus C_3 \oplus C_4$$
- Burst error correction using chunk interleaving



Burst Error Correction

Chunk Interleaving

*Another way to achieve FEC in multimedia is to allow some small chunks to be missing at the receiver. We cannot afford to let all the chunks belonging to the same packet be missing; however, we can afford to let **one chunk be missing** in each packet.*

One chunk is missing from each packet is acceptable in multimedia applications

Figure : Interleaving

Chunks

Packet 1	05	04	03	02	01
Packet 2	10	09	08	07	06
Packet 3	15	14	13	12	11
Packet 4	20	19	18	17	16
Packet 5	25	24	23	22	21

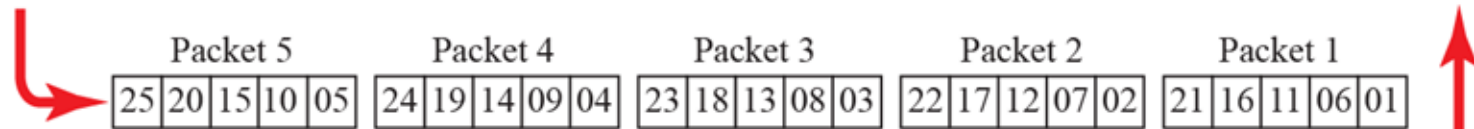
Sending
column by column

a. Packet creation at sender

Packet 1	05	04		02	01
Packet 2	10	09		07	06
Packet 3	15	14		12	11
Packet 4	20	19		17	16
Packet 5	25	24		22	21

Receiving
column by column

d. Packet recreation at receiver



b. Packets sent



c. Packets received