Coding and Error Control

Coping with Transmission Errors

- Error detection codes
  - Detects the presence of an error
- Error correction codes, or forward correction codes (FEC)
  - Designed to detect and correct errors
  - Widely used in wireless networks
- Automatic repeat request (ARQ) protocols
  - Used in combination with error detection/correction
  - Block of data with error is discarded
  - Transmitter retransmits that block of data

Error Detection Probabilities

- Definitions
  - P_b : Probability of single bit error (BER)
  - P_1 : Probability that a frame arrives with no bit errors
  - P_2 : While using error detection, the probability that a frame arrives with one or more undetected errors
  - P_3 : While using error detection, the probability that a frame arrives with one or more detected bit errors but no undetected bit errors

Error Detection Probabilities

- With no error detection

$$P_1 = (1 - P_b)^F$$

$$P_2 = 1 - P_1$$

$$P_3 = 0$$

  - F = Number of bits per frame

Error Detection Process

- Transmitter
  - For a given frame, an error-detecting code (check bits) is calculated from data bits
  - Check bits are appended to data bits
- Receiver
  - Separates incoming frame into data bits and check bits
  - Calculates check bits from received data bits
  - Compares calculated check bits against received check bits
  - Detected error occurs if mismatch

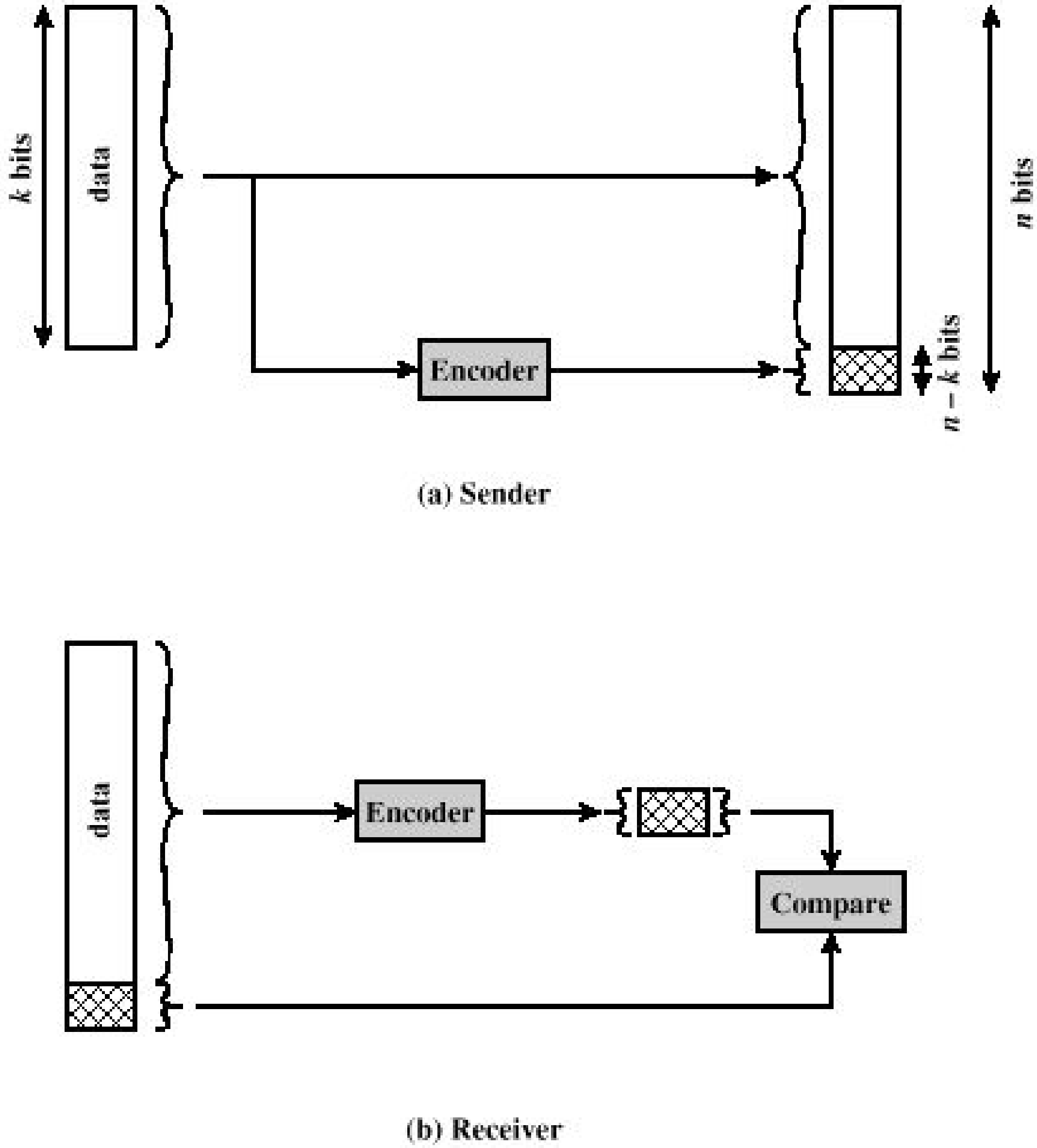

Figure 8.1 Error Detection Process

Parity Check

- Parity bit appended to a block of data
- Even parity
  - Added bit ensures an even number of 1s
- Odd parity
  - Added bit ensures an odd number of 1s
- Example, 7-bit character [1110001]
  - Even parity [11100010]
  - Odd parity [11100011]

Cyclic Redundancy Check (CRC)

- Transmitter
  - For a k-bit block, transmitter generates an $(n-k)$-bit frame check sequence (FCS)
  - Resulting frame of n bits is exactly divisible by predetermined number
- Receiver
  - Divides incoming frame by predetermined number
  - If no remainder, assumes no error

CRC using Modulo 2 Arithmetic

- Exclusive-OR (XOR) operation
- Parameters:
  - T = n–bit frame to be transmitted
  - D = k–bit block of data; the first k bits of T
  - F = $(n - k)$–bit FCS; the last $(n - k)$ bits of T
  - P = pattern of $n-k+1$ bits; this is the predetermined divisor
  - Q = Quotient
  - R = Remainder

CRC using Modulo 2 Arithmetic

- For T/P to have no remainder, start with

$$T = 2^{n-k} D + F$$

- Divide $2^{n-k}D$ by P gives quotient and remainder

$$\frac{2^{n-k} D}{P} = Q + \frac{R}{P}$$

- Use remainder as FCS

$$T = 2^{n-k} D + R$$

CRC using Modulo 2 Arithmetic

- Does R cause T/P have no remainder?

$$\frac{T}{P} = \frac{2^{n-k}D + R}{P} = \frac{2^{n-k}D}{P} + \frac{R}{P}$$

- Substituting,

$$\frac{T}{P} = Q + \frac{R}{P} + \frac{R}{P} = Q + \frac{R+R}{P} = Q$$

  - No remainder, so T is exactly divisible by P

CRC using Polynomials

- All values expressed as polynomials
  - Dummy variable *X* with binary coefficients

$$\frac{X^{n-k}D(X)}{P(X)} = Q(X) + \frac{R(X)}{P(X)}$$

$$T(X) = X^{n-k}D(X) + R(X)$$

CRC using Polynomials

- Widely used versions of $P(X)$
  - CRC–12
    - $X^{12} + X^{11} + X^3 + X^2 + X + 1$
  - CRC–16
    - $X^{16} + X^{15} + X^2 + 1$
  - CRC – CCITT
    - $X^{16} + X^{12} + X^5 + 1$
  - CRC – 32
    - $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$

Wireless Transmission Errors

- Error detection requires retransmission
- Detection inadequate for wireless applications
  - Error rate on wireless link can be high, results in a large number of retransmissions
  - Long propagation delay compared to transmission time

Block Error Correction Codes

- Transmitter
  - Forward error correction (FEC) encoder maps each k-bit block into an n-bit block codeword
  - Codeword is transmitted; analog for wireless transmission
- Receiver
  - Incoming signal is demodulated
  - Block passed through an FEC decoder

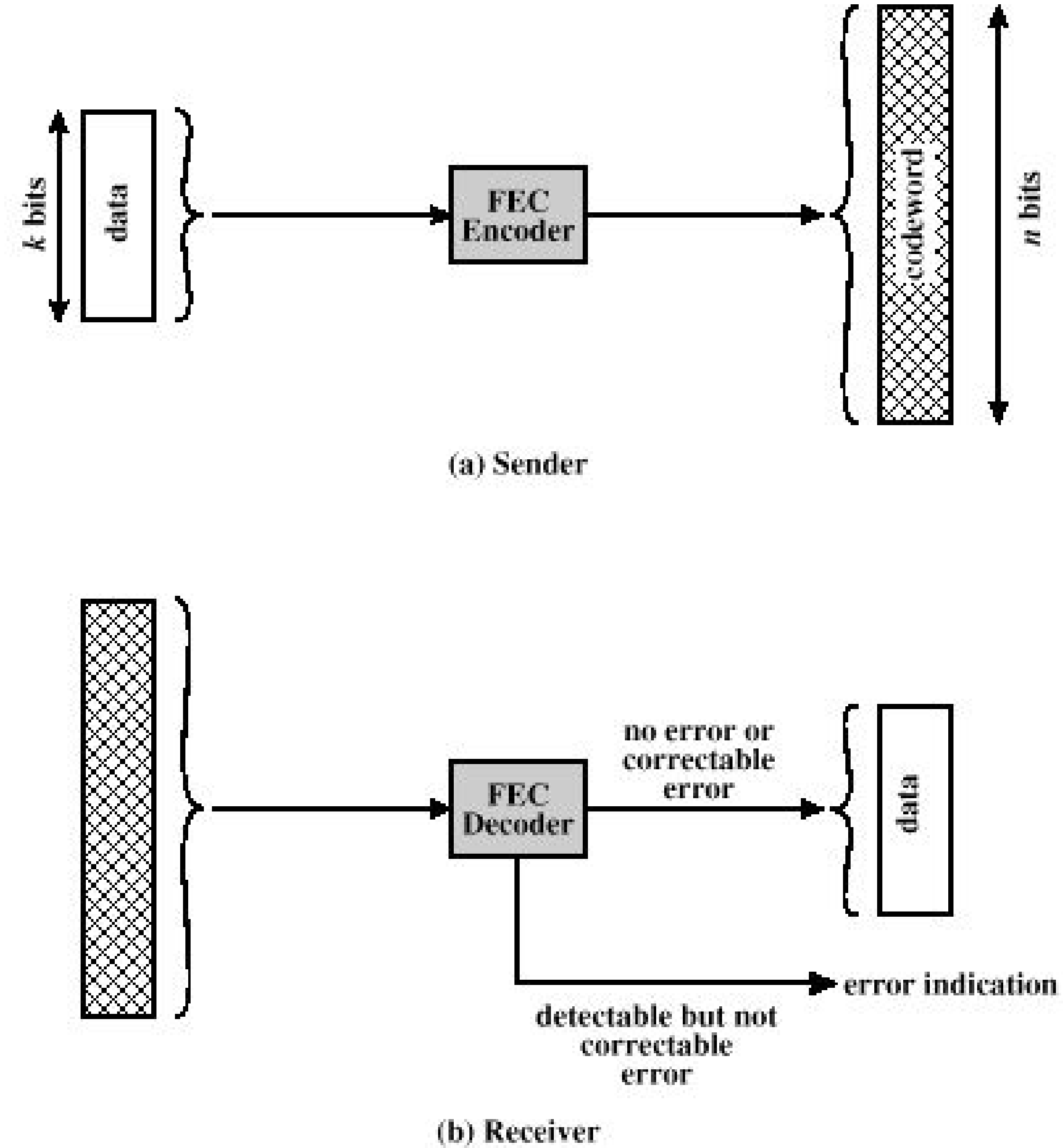

Figure 8.5 Forward Error Correction Process

FEC Decoder Outcomes

- No errors present
  - Codeword produced by decoder matches original codeword
- Decoder detects and corrects bit errors
- Decoder detects but cannot correct bit errors; reports uncorrectable error
- Decoder detects no bit errors, though errors are present

Automatic Repeat Request

- Mechanism used in data link control and transport protocols
- Relies on use of an error detection code (such as CRC)
- Flow Control
- Error Control

Flow Control

- Assures that transmitting entity does not overwhelm a receiving entity with data
- Protocols with flow control mechanism allow multiple PDUs in transit at the same time
- PDUs arrive in same order they're sent
- Sliding-window flow control
  - Transmitter maintains list (window) of sequence numbers allowed to send
  - Receiver maintains list allowed to receive

Flow Control

- Reasons for breaking up a block of data before transmitting:
  - Limited buffer size of receiver
  - Retransmission of PDU due to error requires smaller amounts of data to be retransmitted
  - On shared medium, larger PDUs occupy medium for extended period, causing delays at other sending stations

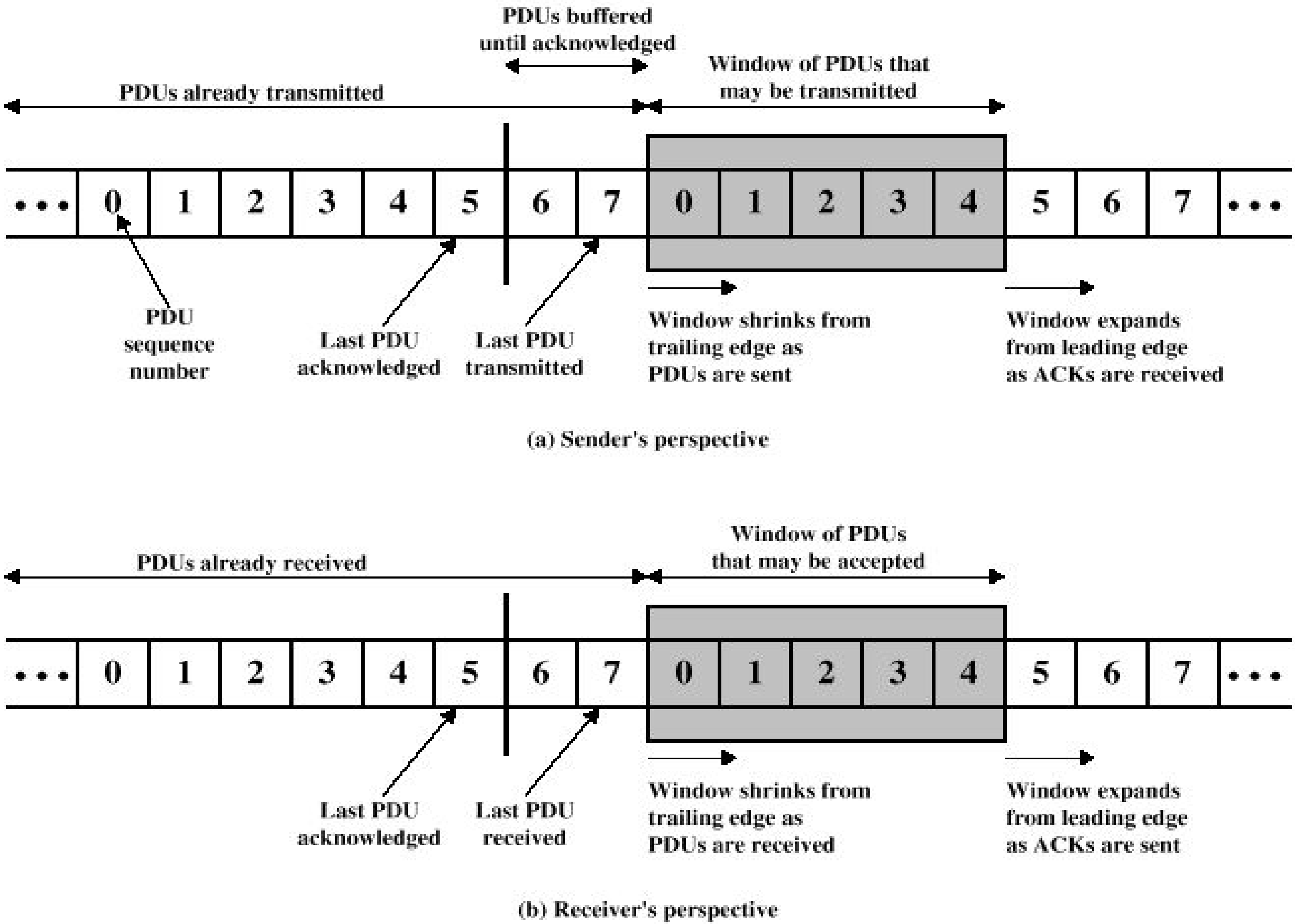

Figure 8.17 Sliding-Window Depiction

Error Control

- Mechanisms to detect and correct transmission errors
- Types of errors:
  - Lost PDU : a PDU fails to arrive
  - Damaged PDU : PDU arrives with errors
- Techniques:
  - Timeouts
  - Acknowledgments
  - Negative acknowledgments