Computer Networks

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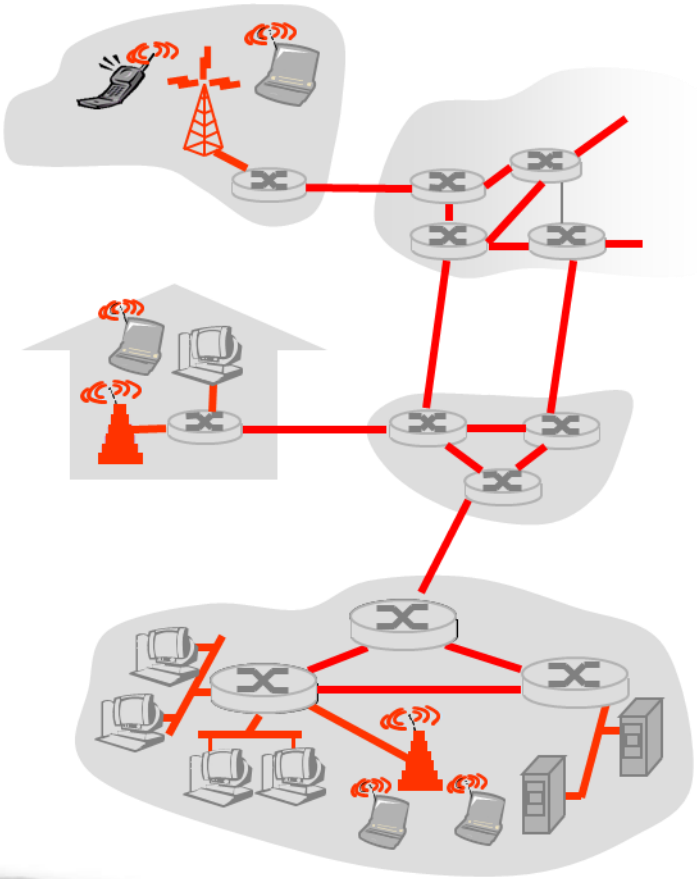
Chapter 2. Direct Link Networks

- Link Service and Framing
- Error Detection and Reliable Transmission
- HDLC, PPP, and SONET
- Token Ring
- Ethernet
- Bridges and Layer-2 switch
- Wireless Networks
- Network Performance

Link Service and Framing

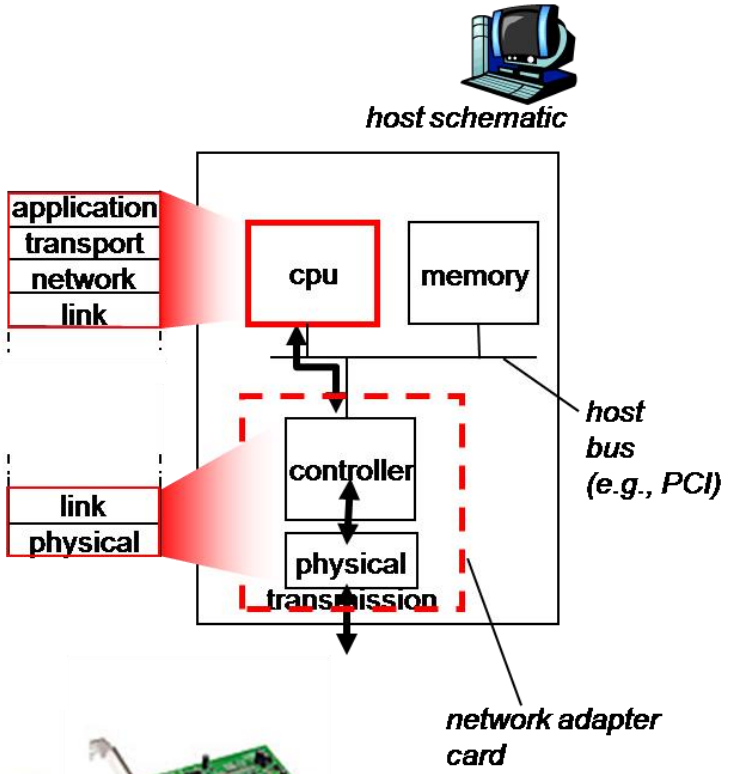
Direct Links

- Hosts and routers are nodes
- Communication channels that connect adjacent nodes are links
- Different types of links
  - Wired point-to-point links
  - Wired multiple access links (LANs)
  - Wireless links (WiFi)



Implement the Link Layer

- In host and router (switch)
- Link layer implemented in "adaptor"
  - i.e. network interface card (NIC)
  - Ethernet card, 802.11 card
- Implements link, physical layer
- Attaches into host's system buses
- Combination of hardware, software, firmware



Link Layer Services

- Data-link layer has the responsibility of transferring data over the links
- Framing
  - Encapsulate upper-level data into frame, adding header and trailer
- Link access
  - Coordinate access for shared multiple access medium
  - "MAC" addresses used in frame headers to identify source and destination
  - Half-duplex and full-duplex: Whether transmit and receive at the same time

Link Layer Services

- Reliable delivery over the link
  - Seldom used on low bit-error link (e.g. fiber)
  - Wireless links: high error rates
  - Flow control： Pacing between adjacent sending and receiving nodes
- Error detection and correction
  - Handling errors caused by signal attenuation or noise
  - Receiver detects presence of errors
  - Signals sender for retransmission or drops frame

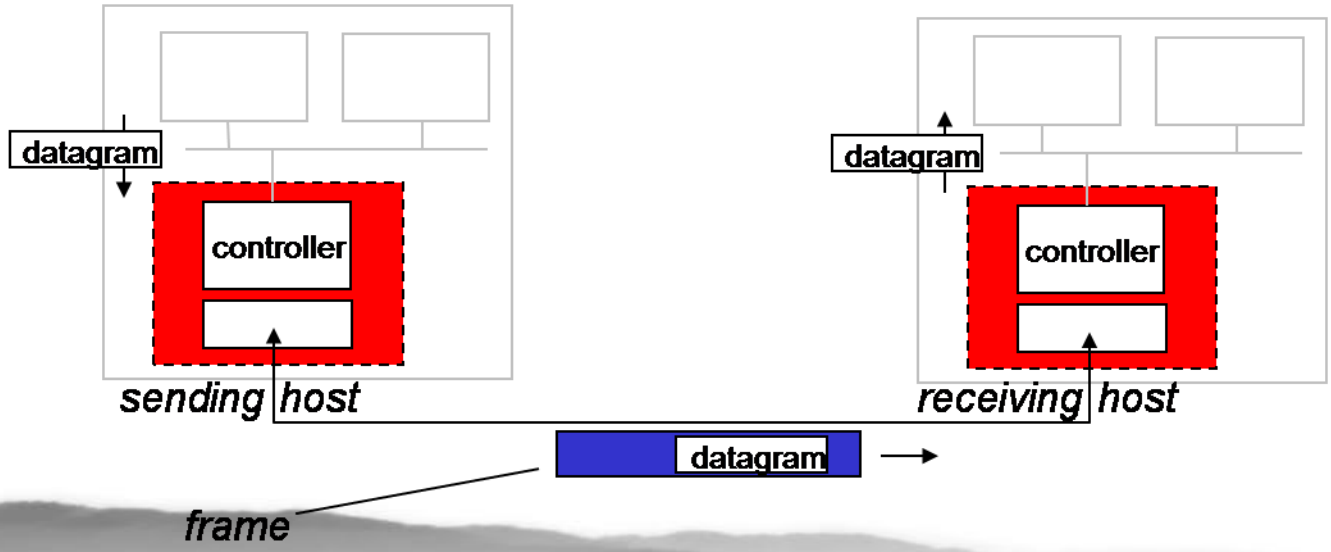
Link Layer Framing

Sending side

- Encapsulates datagram in frame
- Adds error checking bits, flow control, etc.

Receiving side

- Looks for errors, flow control, etc.
- Extracts datagram, passes to upper layer



Reliable delivery over the link

- Flow Control
- Ensuring the sender not overwhelm the receiver
  - Preventing buffer overflow
- Methods
  - Stop and Wait
  - Sliding window

Stop and Wait

- Source: transmits frame
- Destination: receives frame and replies with ACK
- Source: waits for ACK before sending next frame

- Destination can stop flow by not send ACK

- Work well for large frames

Sliding Window

- Allow multiple frames to be in transit
- Receiver has buffer (window) sized *Win*
- Sender can send up to *Win* frames without ACK
- Each frame is numbered
- ACK includes number of next frame expected
- Sequence number bounded by field of size (k)
  - Frames are numbered modulo 2^k
- Question: how to set k given *Win*

Illustration of Sliding Window

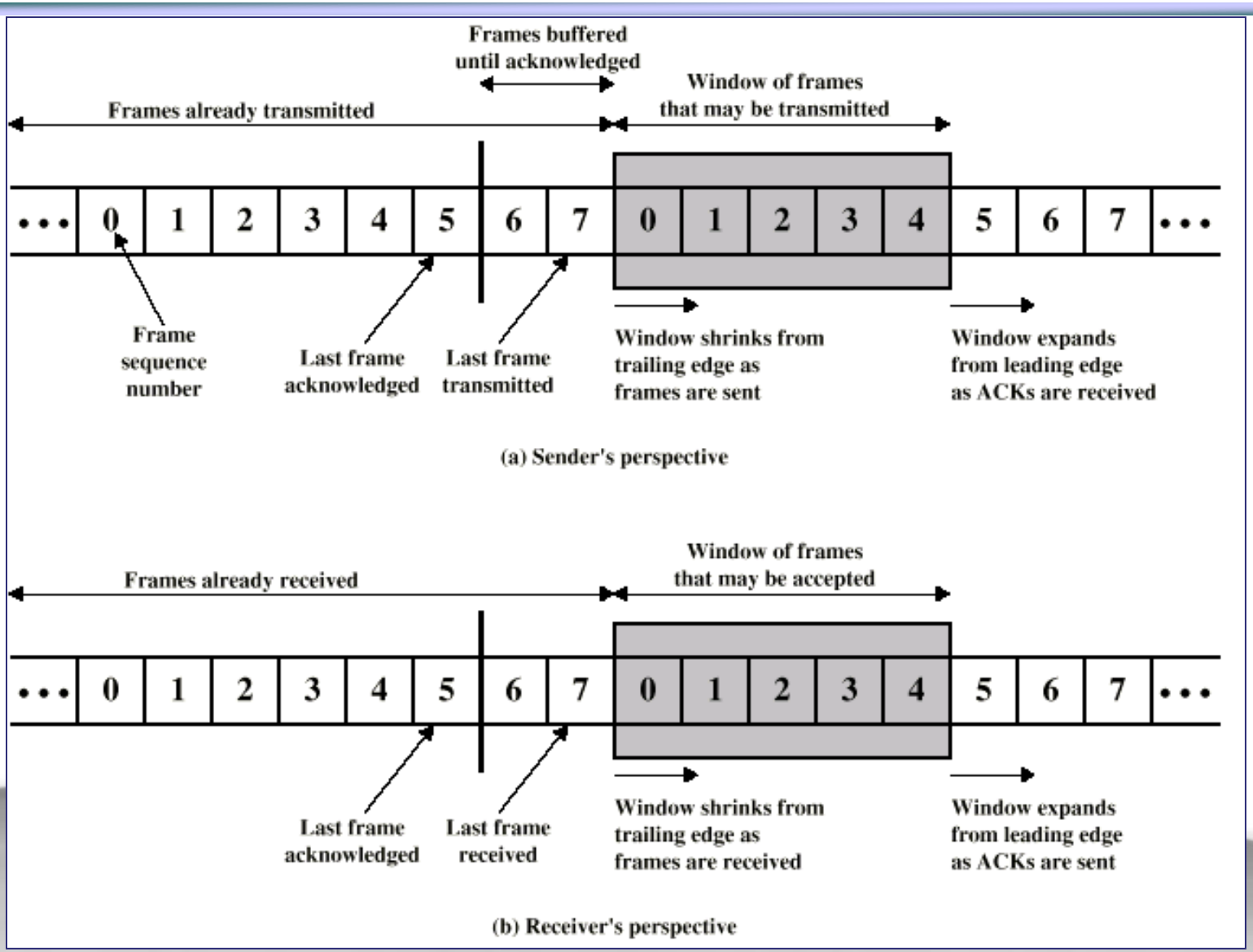
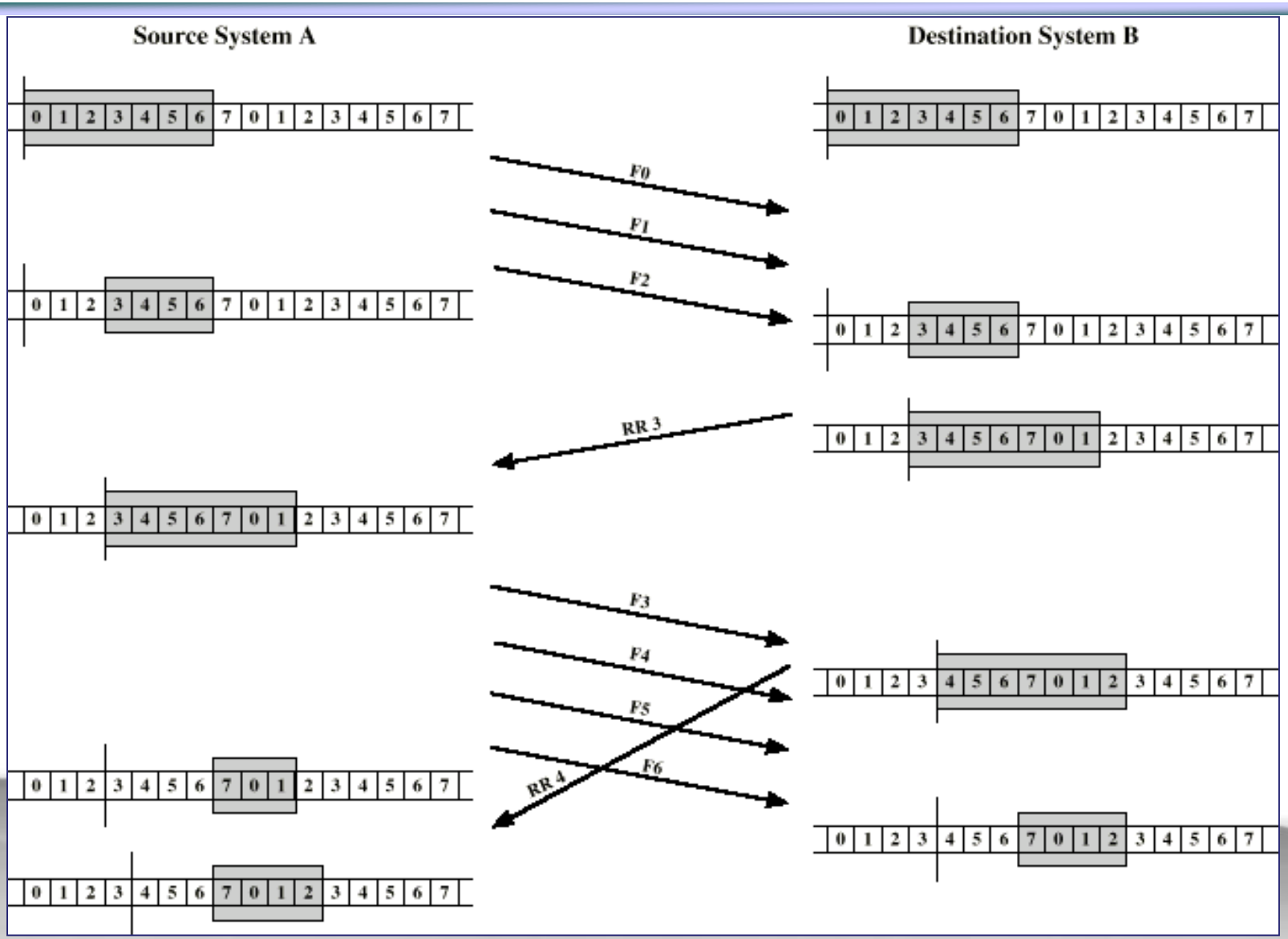


Illustration of Sliding Window

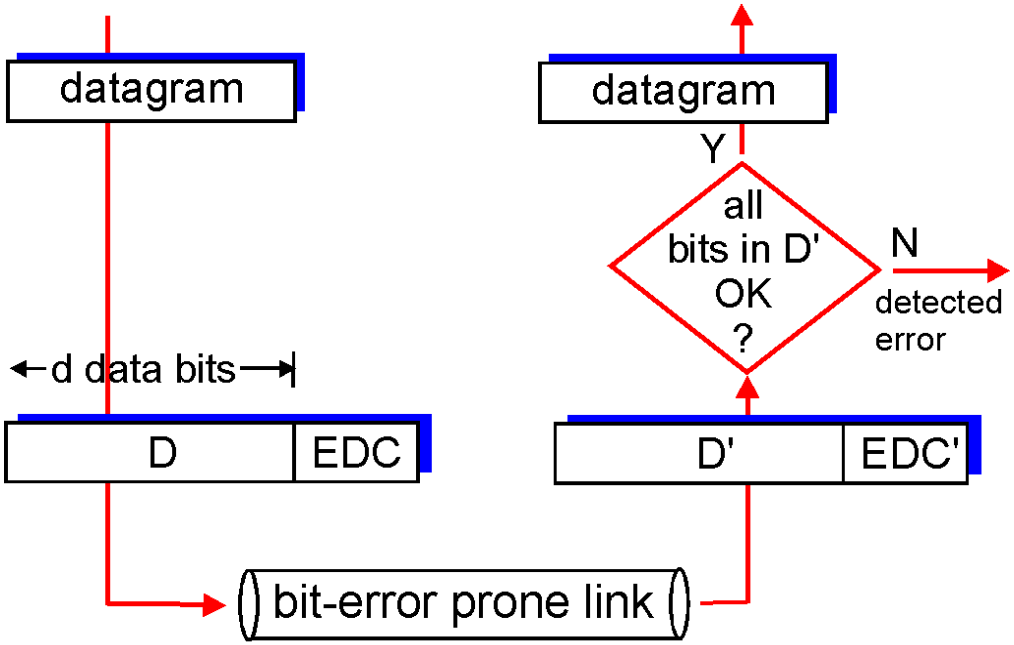


Error Handling in Sliding Window

- Go Back N
  - If error, reply with rejection (NAK)
  - The error frame and all future frames need be retransmitted
- Selective Reject
  - Only rejected error frames need be retransmitted
  - Receiver must maintain large enough buffer

Error Detection and Reliable Transmission

Error Detection and Correction



- EDC= Error Detection and Correction bits (redundancy)
- D = Data protected by error checking, may include header fields

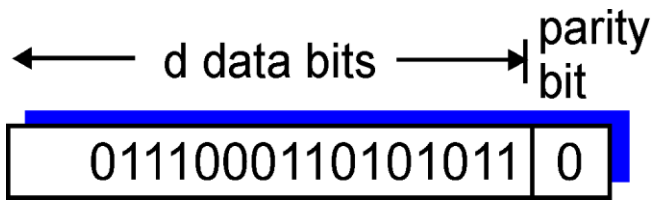
Note: error detection not 100% reliable!

- Larger EDC field yields better detection and correction

Parity Checking

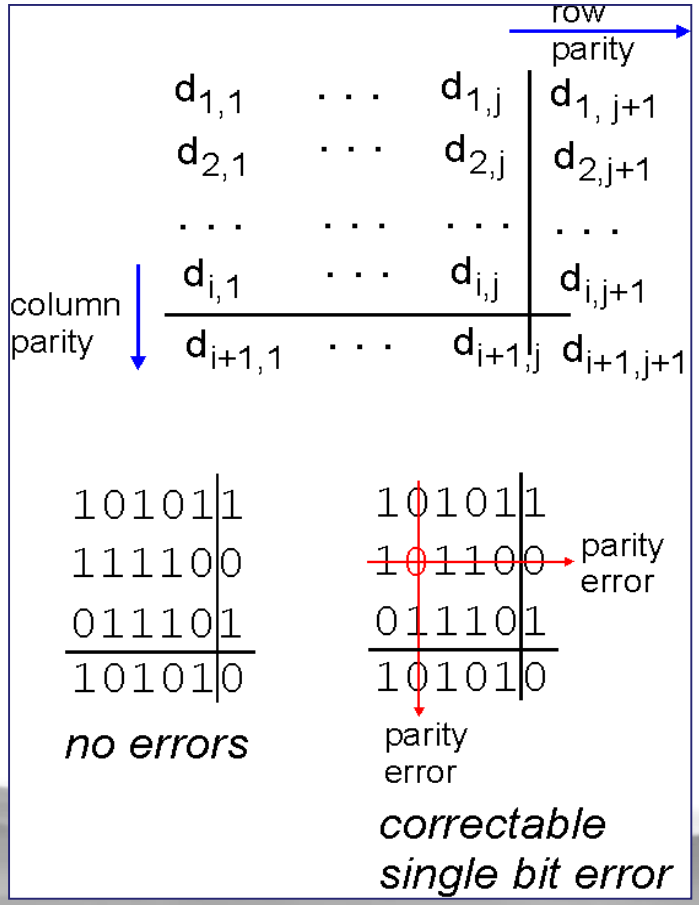
Single Bit Parity:

Detect single bit errors



Two Dimensional Bit Parity:

Detect and correct single bit errors



Can detect two-bit errors

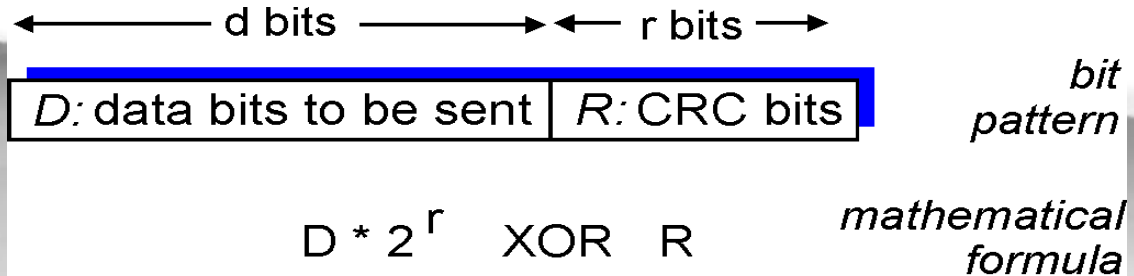
Cyclic Redundancy Check

- Widely used in hardware-based implementation

- View data bits, D, as a binary number
- Choose r+1 bit pattern (generator or polynomial), G
  - G is called a Key, which is known to both the sender and receiver ahead.
- Since $D * 2^r = a * G \oplus R$, so $D * 2^r \oplus R = a * G$

- Sender: send $D * 2^r \oplus R$, represented by <D,R>
- Receiver: when received <D,R>
  - If <D, R> exactly divisible by G (modulo 2) , no error
  - If divides <D,R> by G has non-zero remainder: error detected!

- Limit: Can detect burst errors less than r+1 bits

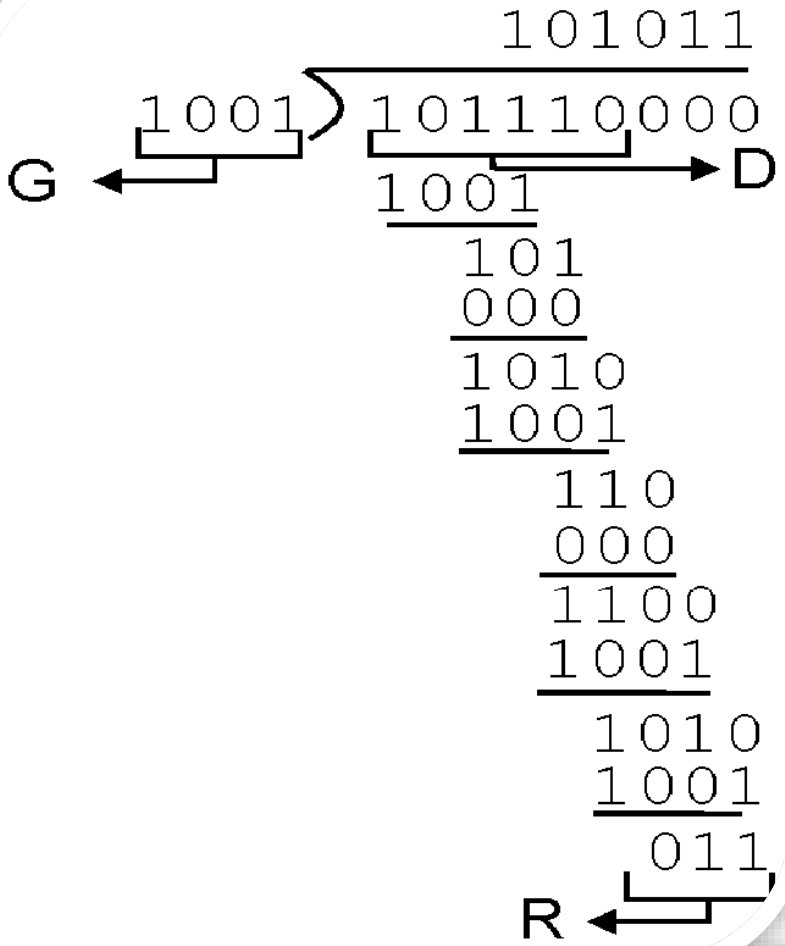


Example of CRC

- Since $D * 2^r = a * G \oplus R$, so $D * 2^r \oplus R = a * G$
- Obtain R by:

$$R = \text{remainder}\left[\frac{D \cdot 2^r}{G}\right]$$

- Question：
- D=101110, r=3, G=1001
- R=?

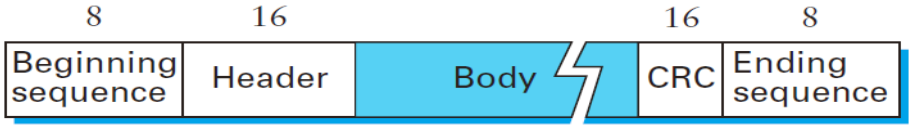


循环移位模2运算

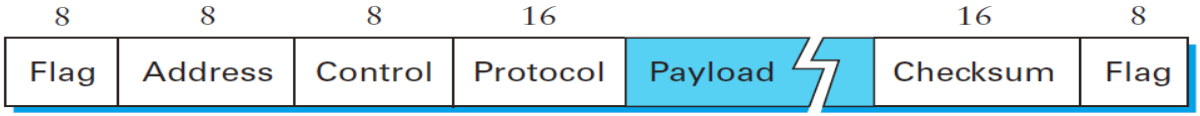
HDLC, PPP, and SONET

HDLC, PPP, and SONET

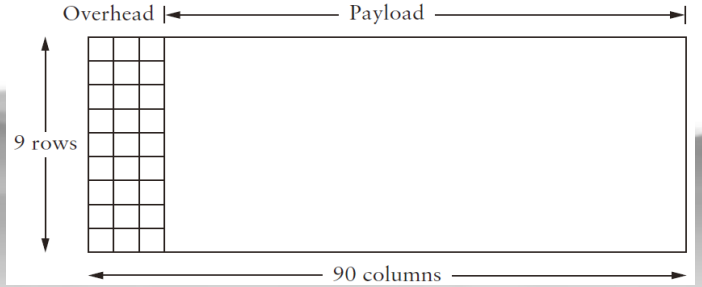
- HDLC (High-Level Data Link Control, 高级链路控制): Bit-Oriented Protocols
  - Sees the transmitted data as a stream of bits
  - Allows the data frames to contain an arbitrary number of bits
  - Frame separated by flag byte (01111110)



- PPP (Point-to-Point Protocol, 点对点协议): Byte-Oriented Protocols
  - Sees the transmitted data as a stream of bytes



- SONET (Synchronous Optical Network, 同步光纤网) : Clock-Based Framing (per 125us)

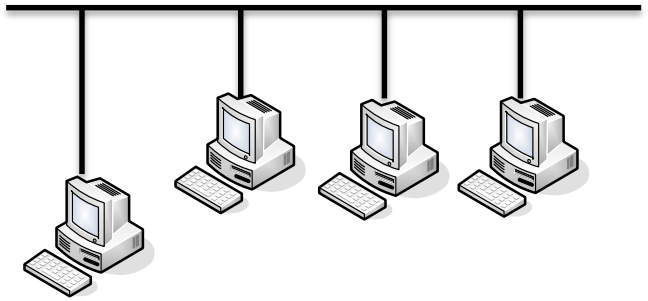


HDLC

- High level data link control

Station Types

- Primary station (主站)
  - Controls operation of link, issues commands
- Secondary station (从站)
  - Under control of primary station, issues responses
- Combined (peer) station (混合站)



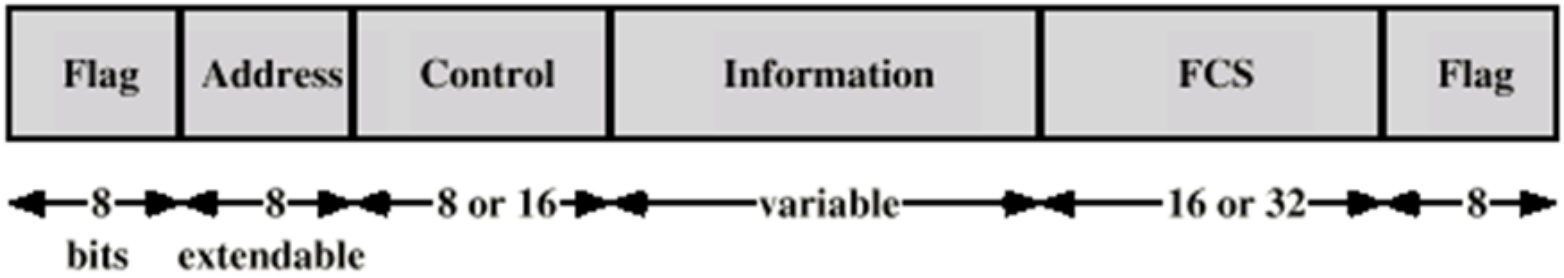
Link Configurations

- Unbalanced：One primary and several secondary stations
- Balanced：Between 2 combined stations

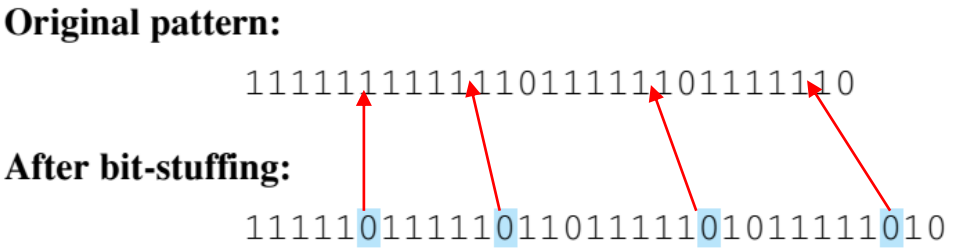
HDLC Transfer Modes

- Normal Response Mode (NRM)
  - Unbalanced
  - Secondary may only transmit data in response to command from primary
  - Host computer with many Terminals
- Asynchronous Response Mode (ARM)
  - Unbalanced
  - Initiated by secondary, mainly for retransmission
- Asynchronous Balanced Mode (ABM)
  - Balanced
  - Either station can initiate transmission

HDLC Frame Format

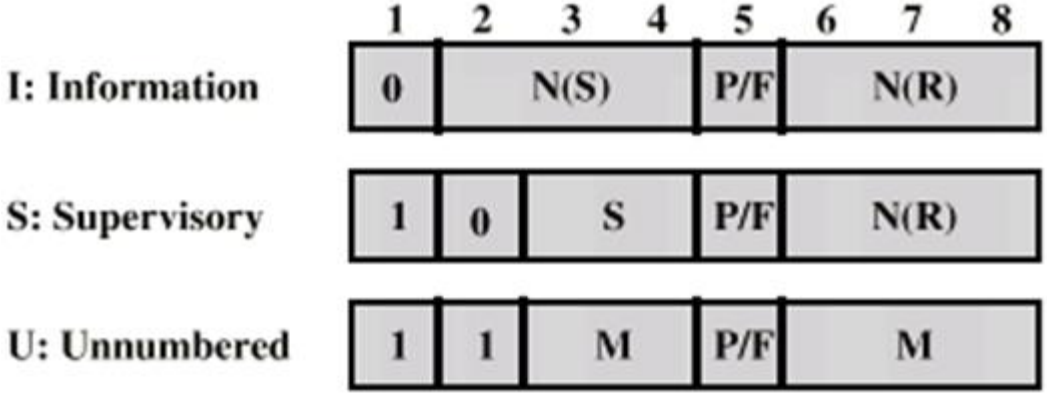


- Flag
  - 01111110, delimit frame at both ends
- Bit Stuffing
  - Sending: 0 inserted after every sequence of five 1s in other fields
  - Receiving: after five 1s, if sixth is 0, delete 0; if sixth starts with 10, delimiter



- Address
  - Identifies secondary stations, all 1s means broadcast

The Control Field



N(S): send sequence number
N(R): receive sequence number

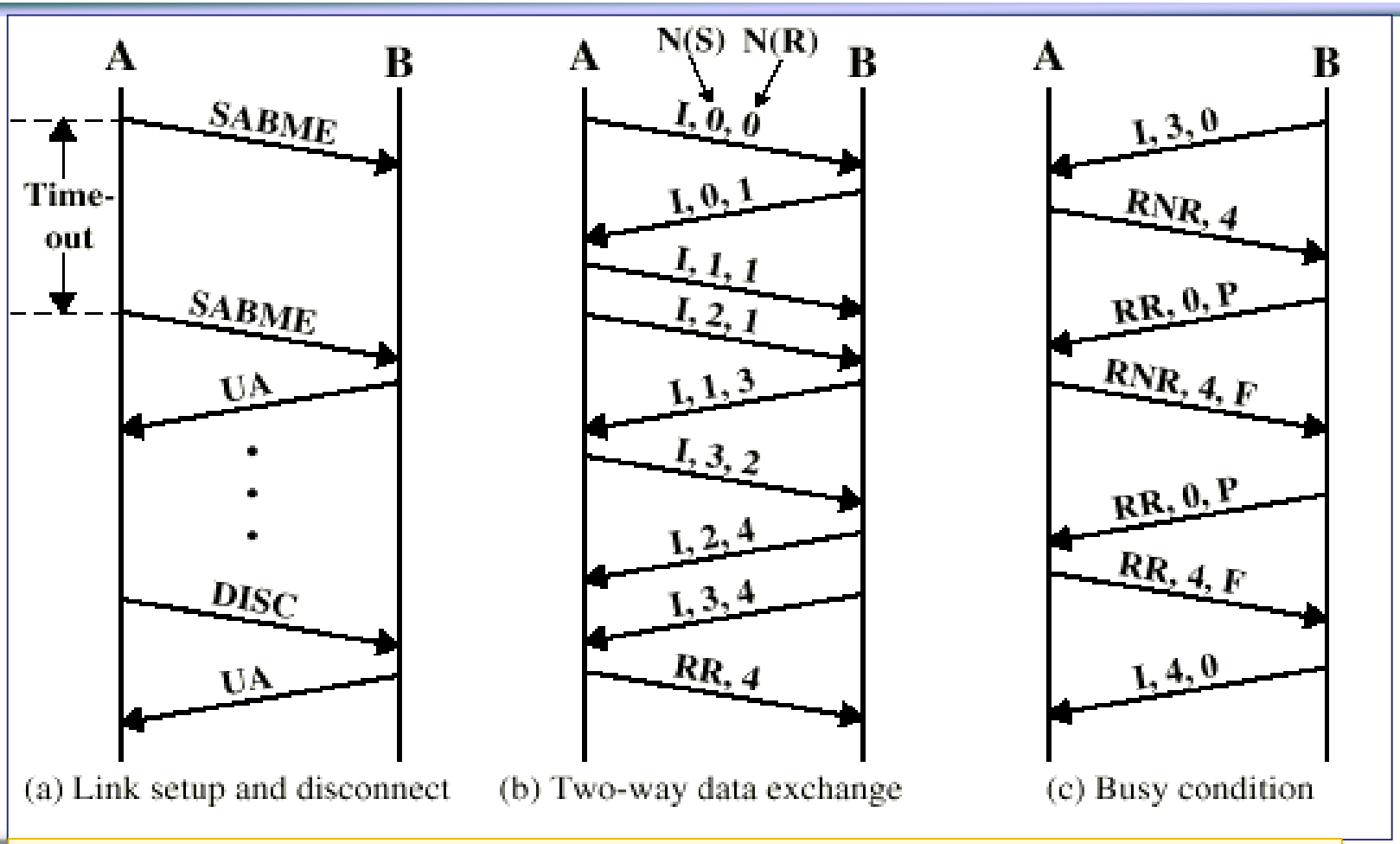
S: supervisory function bits
M: unnumbered function bits
P/F: poll/final bit

- Supervisory
  - Flow and error control (no sending data)
  - Receive Ready (RR), Receive Not Ready (RNR); Reject (REJ), Selective Reject (SREJ)
- Unnumbered
  - Supplementary link control: setting modes, reset link
- Poll/Final
  - If solicits response; and does be the (end of) response

I帧：information，信息帧
S帧：supervisory，监控帧
U帧：unnumbered，无编号帧

P/F比特：在命令帧中，P比特=1时，请求一个响应帧；在响应帧中，F比特=1时，表示是对一个请求命令的响应

Examples of HDLC Operation



SABME: Set asynchronous balanced extended mode
UA: Unnumbered Acknowledgment
DISC: Disconnect
RR: Receive ready
RNR: Receive not ready

PPP

- Point-to-Point Protocol

Design requirements

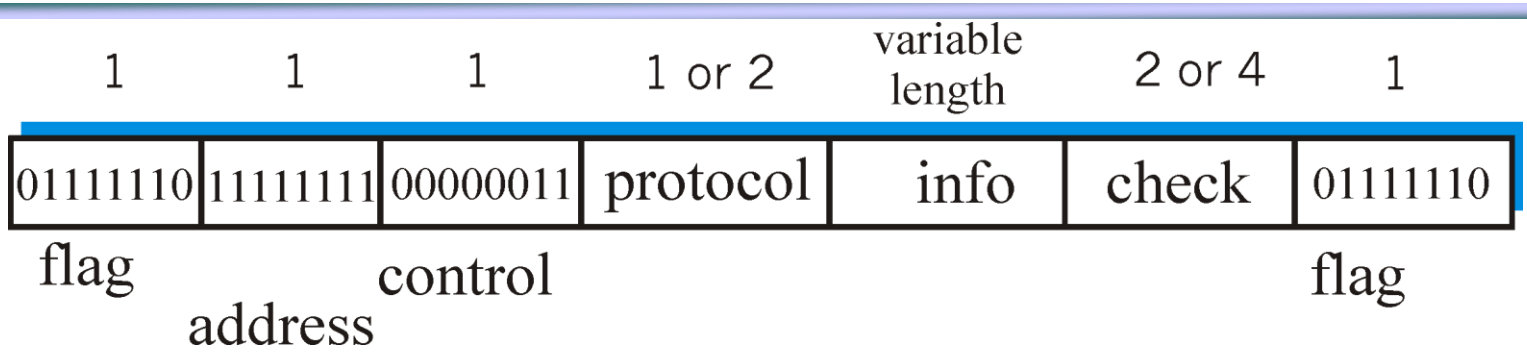
- Packet framing: encapsulation of network-layer datagram in data link frame
- Bit transparency: carry any bit pattern in the data field
- Connection liveness: detect, signal link failure to network layer
- Network layer address negotiation: endpoint can learn/configure each other's network address
- Error detection

Non-requirements

- No error recovery
- No flow control
- May delivery out of order
- No need to support multipoint links

- Working upon different physical networks: PPPoE (Ethernet), PPPoA (ATM)

PPP Data Frame



- Flag: delimiter
- Address, Control: does nothing
- Protocol: upper layer protocol (e.g. PPP-LCP, IP, IPCP)
- Check: cyclic redundancy check

LCP: Link Control Protocol for PPP
IPCP: Internet Protocol Control Protocol, a special LCP for IP

Byte Stuffing

- Q: How to include flag pattern <01111110> in other fields

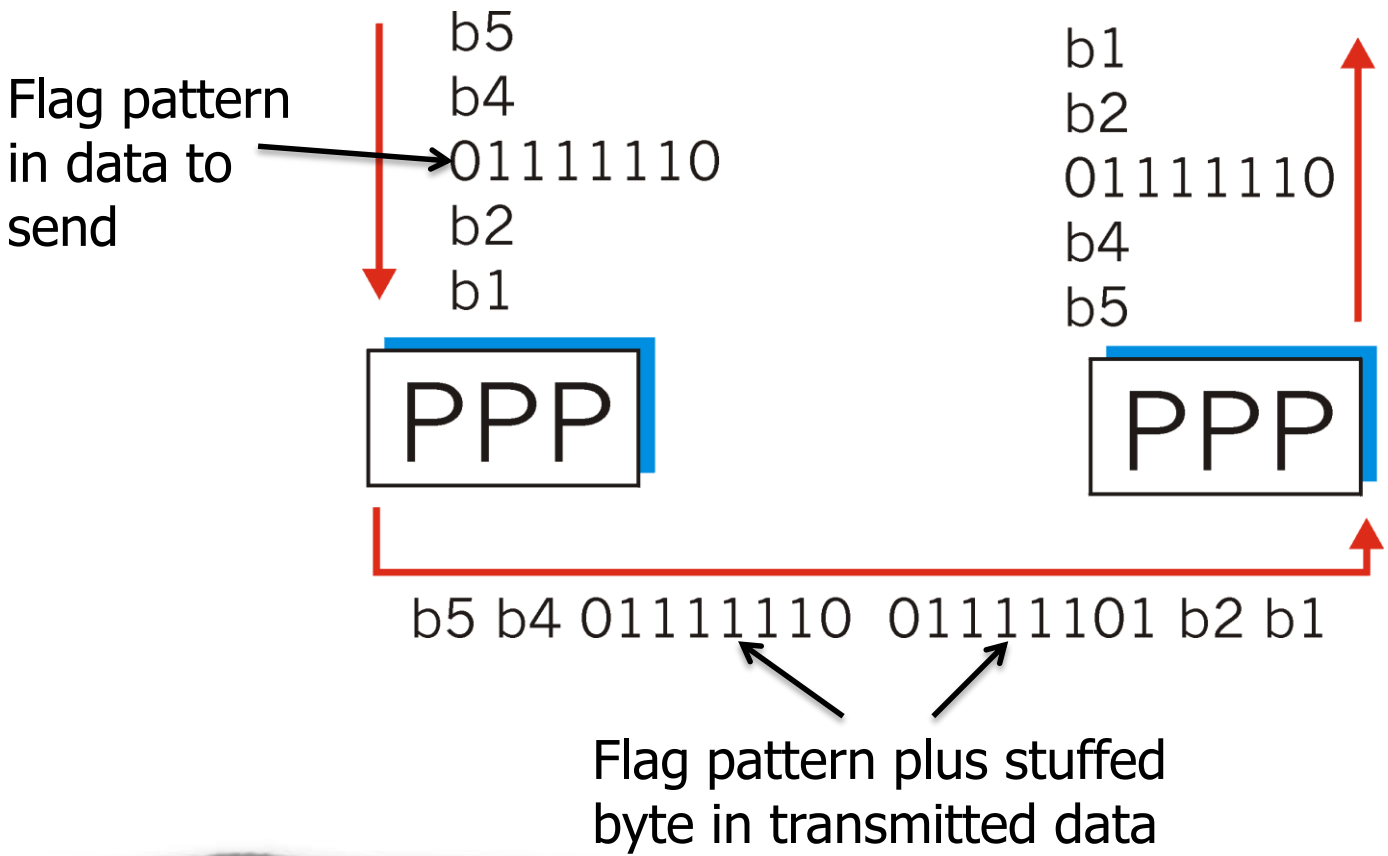
Sender:

- Adds extra <01111101> (stuffs) before <01111110> (byte)

Receiver:

- When receives < 01111101, 01111110>: discard first byte, continue data reception
- If two < 01111101, 01111101> in a row: discard first byte, continue data reception
- Single <01111110>: delimiter

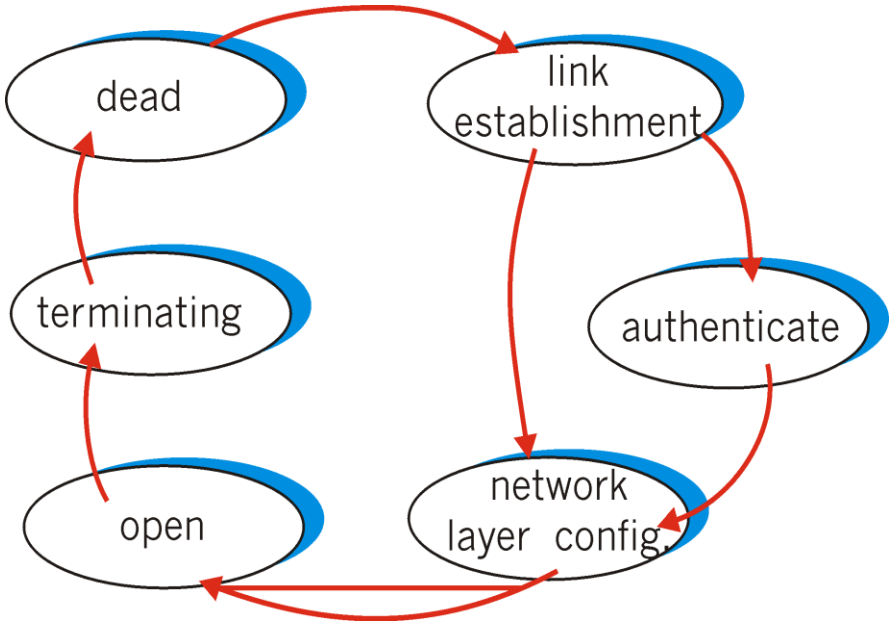
Byte Stuffing



PPP Link Control Protocol

Before exchanging network-layer data, data link peers must

- Configure PPP link (max. frame length, authentication)
- Learn/configure network layer information



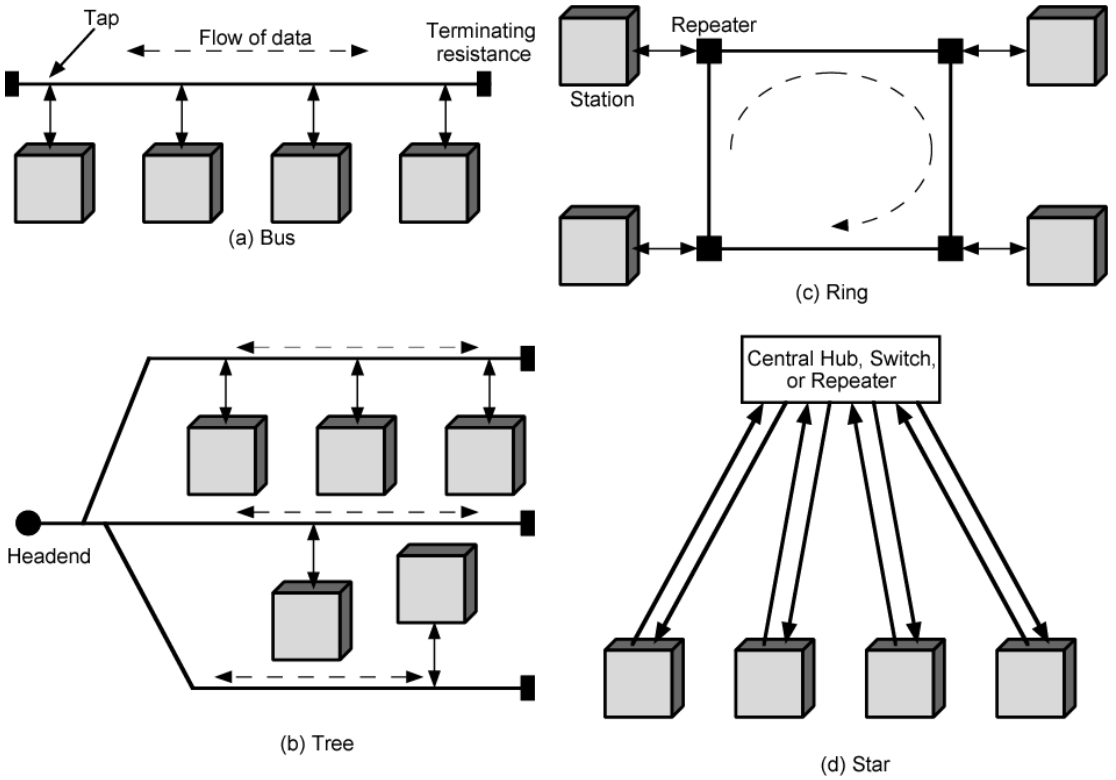
SONET/SDH

- SONET: Synchronous optical networking, used in USA and Canada
- SDH: synchronous digital hierarchy, used in the rest of the world

SONET:同步光纤网，STS-1
SDH:同步数字系列，STM-1

Token Ring

Different Topologies of LAN

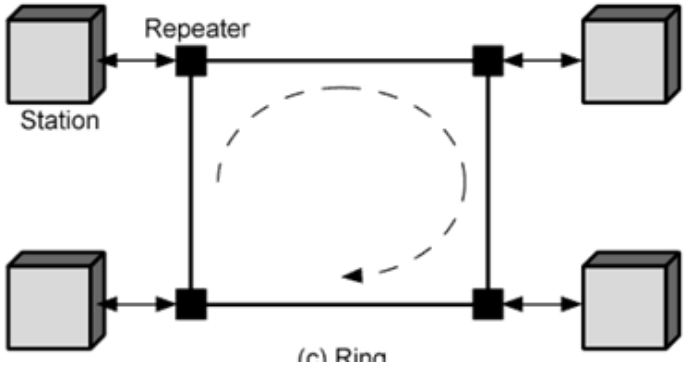


Token Ring

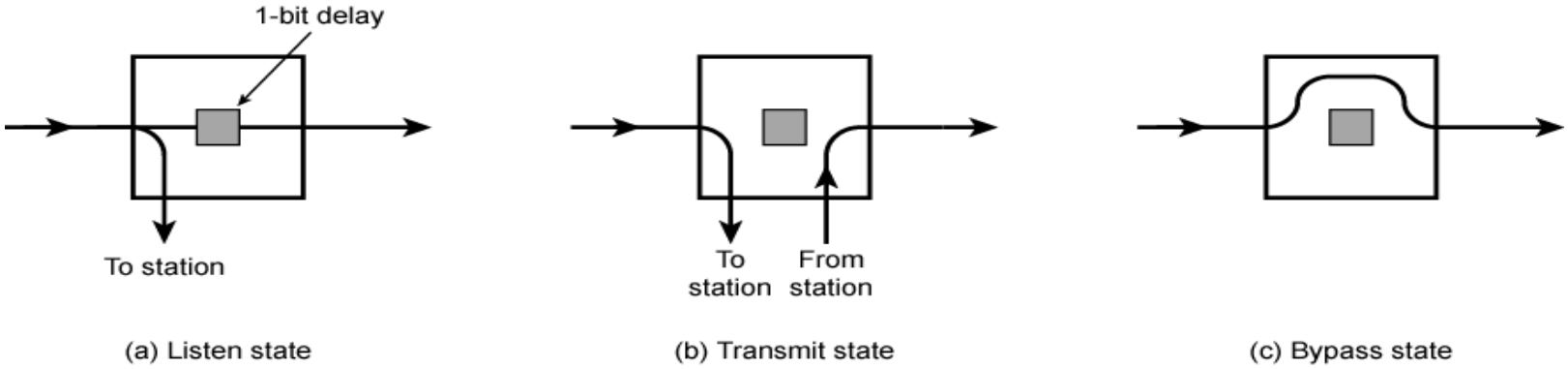
- A protocol for LAN, IEEE 802.5
- Developed from IBM's commercial token ring
- Because of IBM's presence, token ring has gained broad acceptance
- Never achieved popularity of Ethernet

Ring Operation

- Each repeater connects to two others via unidirectional transmission links
- Repeater acts as attachment point



- Data transferred bit by bit from one repeater to the next
  - Repeater regenerates and retransmits each bit
  - Repeater performs data insertion, data reception, data removal
- Frame removed by transmitter after one trip round ring

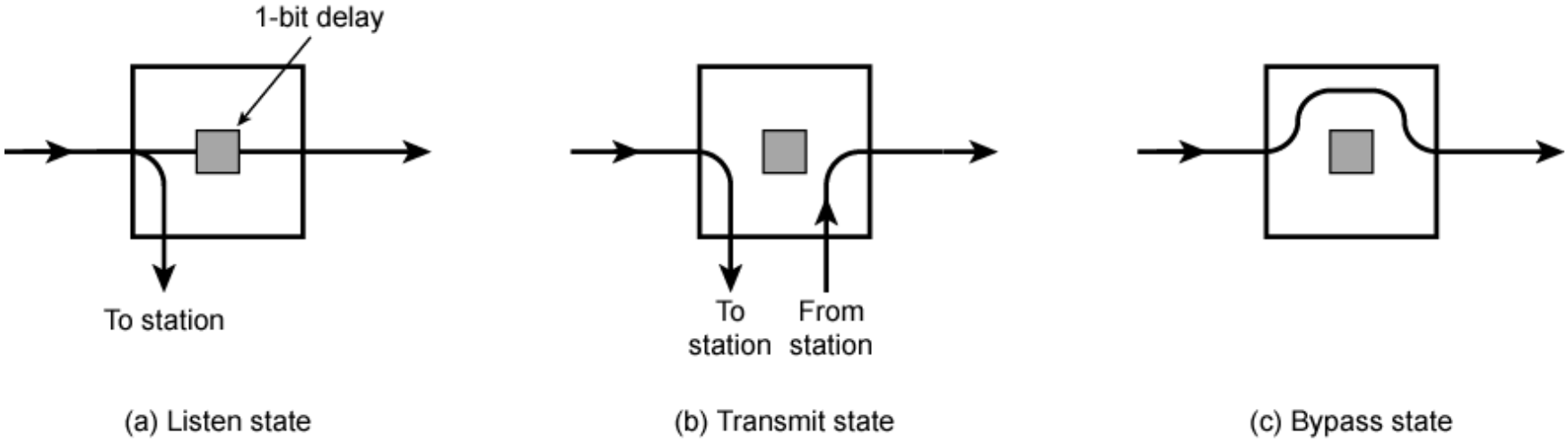


(a) Listen state (b) Transmit state (c) Bypass state

Listen State

- Scan passing bit stream for patterns
  - Address of attached station vs. destination address
  - Token permission to transmit
- Copy incoming bit and send to attached station
  - If destination address matched
  - Whilst forwarding each bit
- Modify bit as it passes
  - e.g. to indicate a packet has been copied (ACK)
  - Or make reservation

Ring Repeater States



(a) Listen state (b) Transmit state (c) Bypass state

Transmit state

- Reclaim frame and pass back to station for checking (ACK)
- May buffer other's frame for retransmission later

Bypass state

- Do nothing more than a connector

802.5 MAC Protocol

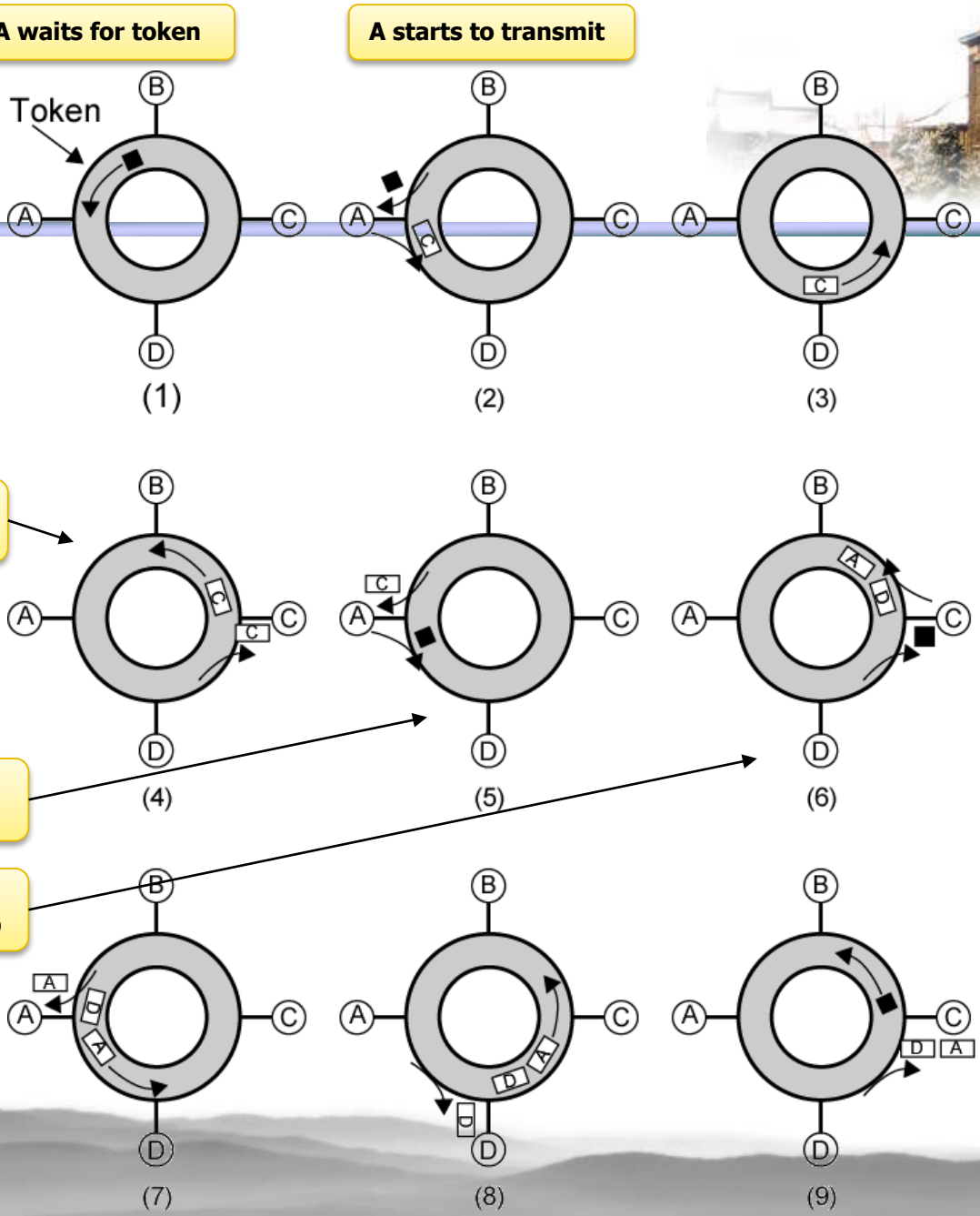
- Small frame (token) circulates when idle
- Station waits for token

- Changes one bit in token to make it SOF (Start of Frame) for data frame
- Append rest of data frame

- Frame makes round trip and is absorbed by transmitting station
- Station then inserts new token when transmission has finished (leading edge of returning frame arrives)

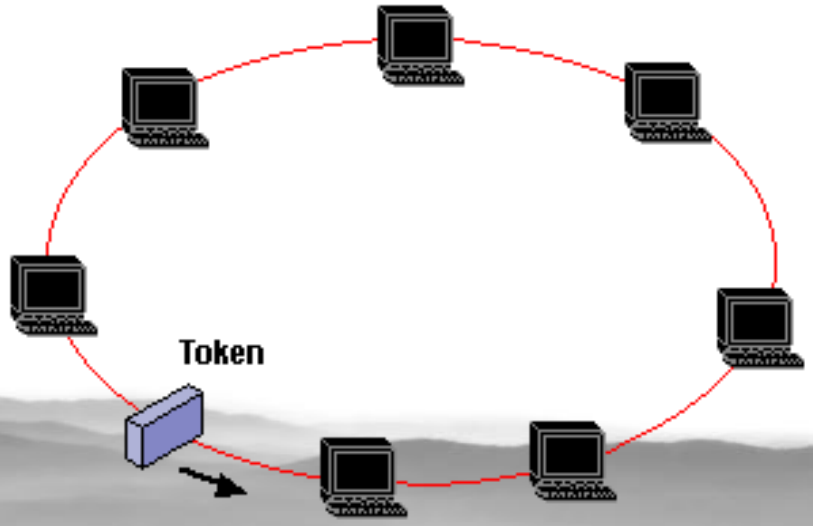
- Under light loads, some inefficiency
- Under heavy loads, round robin

Token Ring Operation



Example

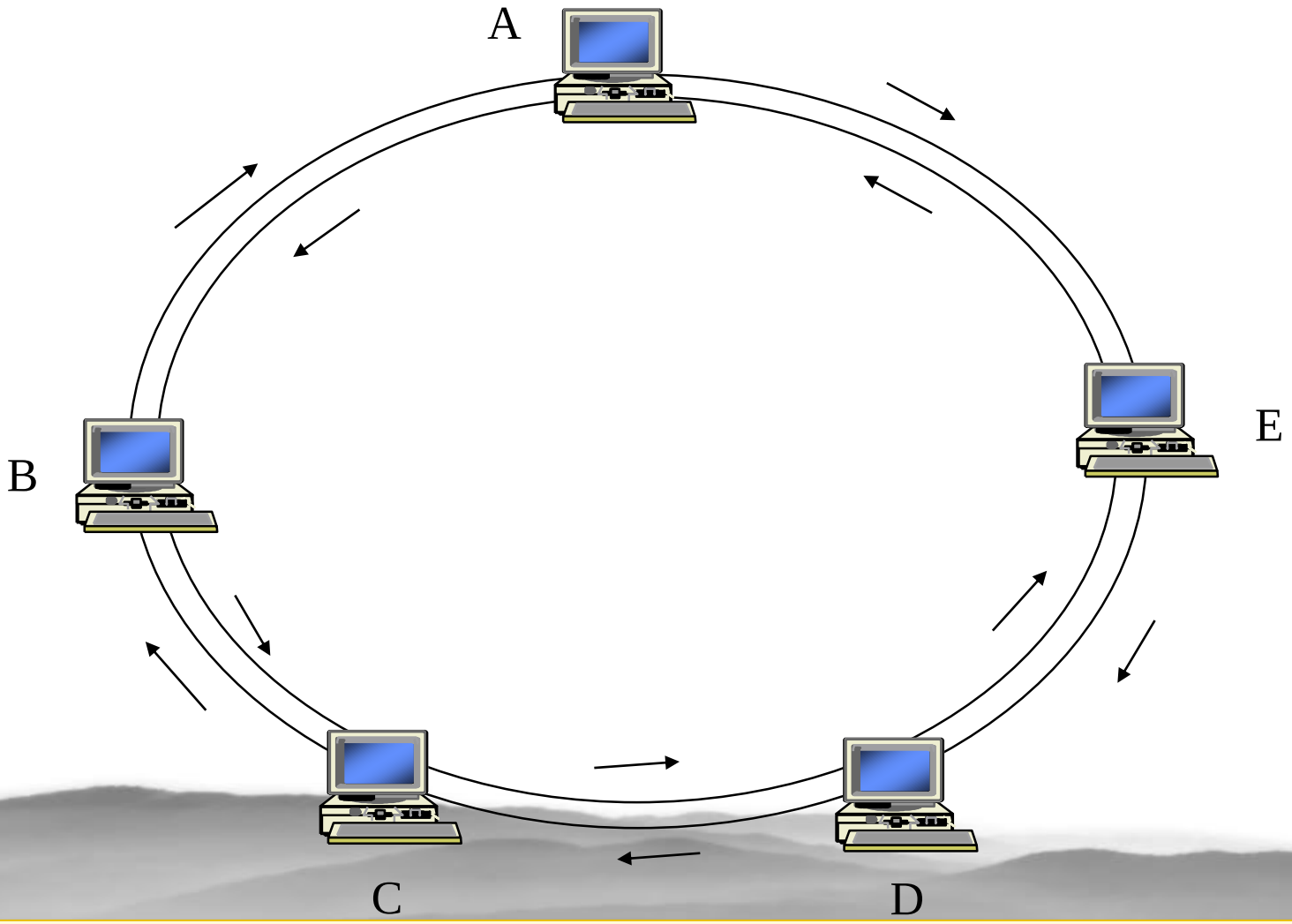
- Assume N nodes in a Token Ring:
  - There N nodes in the ring
  - The time that a token pass around a circle is T
  - Each node transmits data for time T' in average
- If a node want to transmit data, what is the average time that it should wait?



FDDI

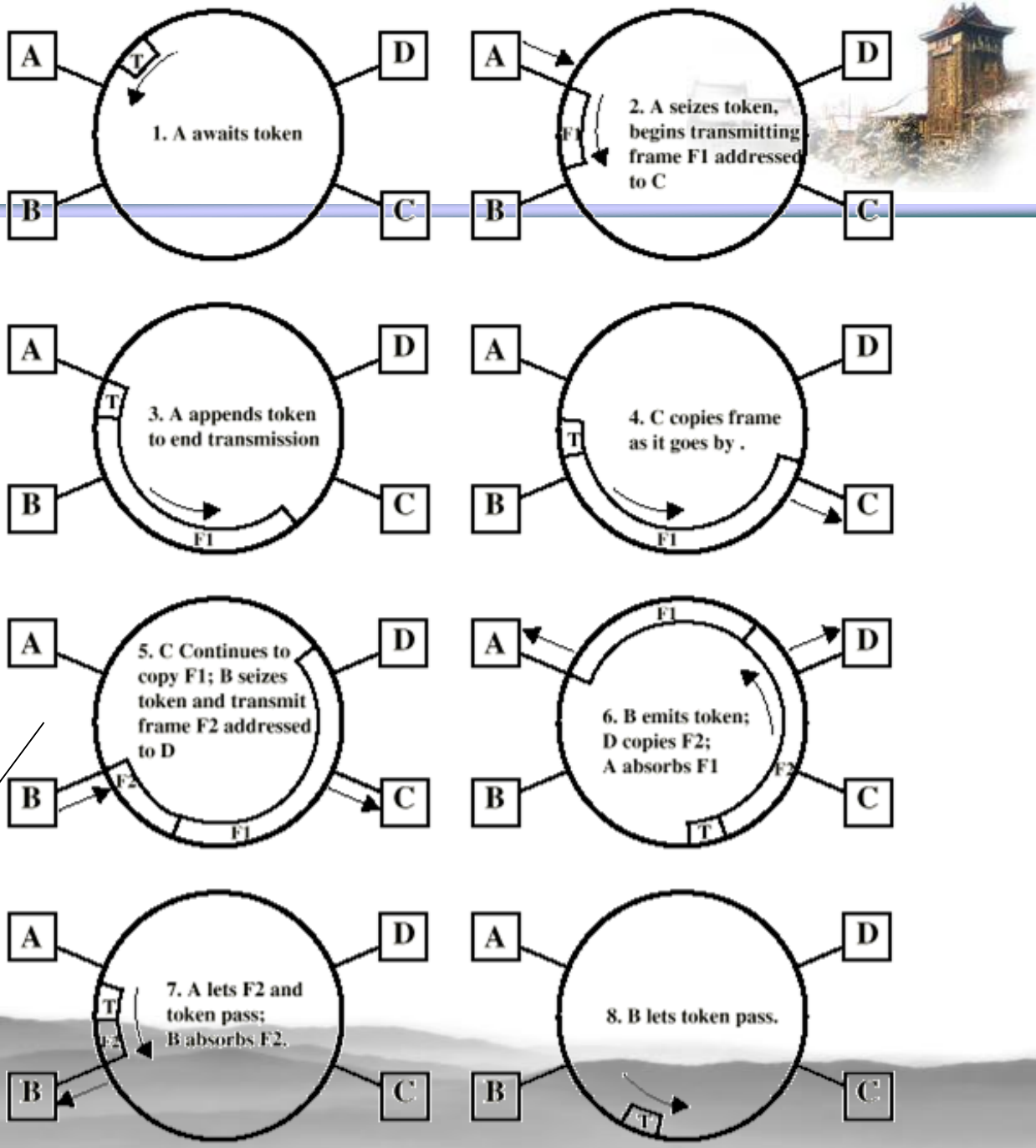
- FDDI: Fiber Distributed Data Interface（光纤分布式数据接口）
- 100 Mbps Token Ring
- Use multi-mode or single-mode optical fiber transmission links
- Span up to 200 kms and permits up to 500 stations

FDDI Token Ring: double ring architecture



双环结构，分别顺时针和逆时针传输；内环平时空闲，出错时切换到内环

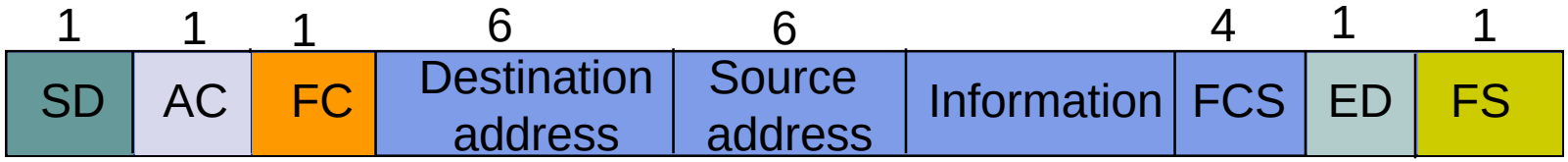
FDDI Operation



传输完成后，马上释放令牌，无需等待数据帧完成循环

Token Ring Frame Format (1)

Data frame format

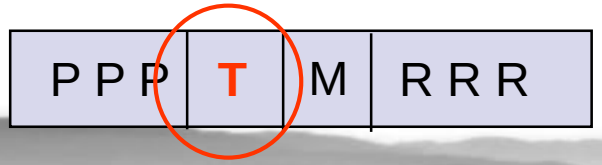


Token frame format

Starting delimiter

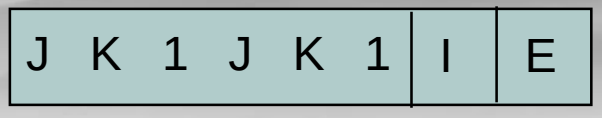
J, K non-data symbols (line code)
J begins as "0" but no transition
K begins as "1" but no transition

Access control



PPP=priority; **T=token bit**
M=monitor bit; RRR=reservation
T=0 token; T=1 data

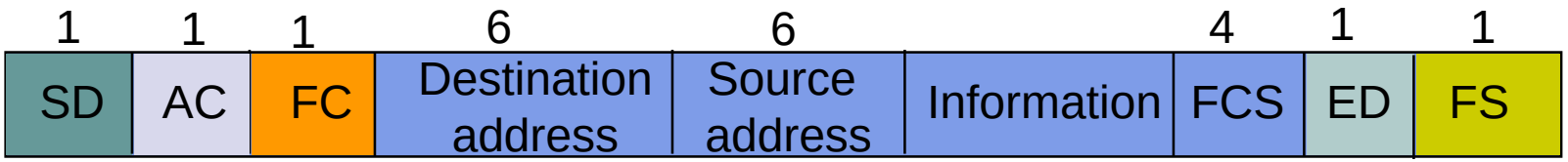
Ending delimiter



I = intermediate-frame bit
E = error-detection bit

Token Ring Frame Format (2)

Data frame format



Frame control

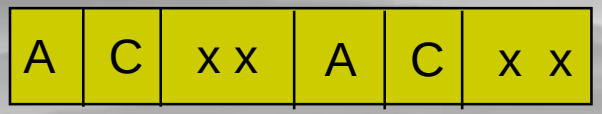
FF = frame type; FF=01 data frame
FF=00 MAC control frame
ZZZZZZ type of MAC control

Addressing — 48 bit format as in 802.3

Information — Length limited by allowable token holding time

FCS — CCITT-32 CRC

Frame status



A = address-recognized bit
xx = undefined
C = frame-copied bit

802.5 Physical Layer

Data Rate (Mbps)	4	16	100	100	1000
Medium	UTP, STP, Fiber	UTP, STP, Fiber	UTP, STP	Fiber	Fiber
Signaling	Differential Manchester	Differential Manchester	MLT-3	4B5B NRZI	8B/10B
Max Frame Len	4,550	18,200	18,200	18,200	18,200
Access Control	TR or DTR	TR or DTR	DTR	DTR	DTR

- Note: 1 Gbit specified in 2001
  - Uses 802.3 physical layer specification

Summary

- 链路层服务
- 错误检测：奇偶校验，CRC的计算
- 流控制：Stop and Wait，Sliding Window
- 三种直接相连技术
  - HDLC，PPP，SONET
- 局域网
  - 令牌环
  - 以太网
  - 无线局域网

Homework

- 第5章：R8, P2, P3, P5, P6