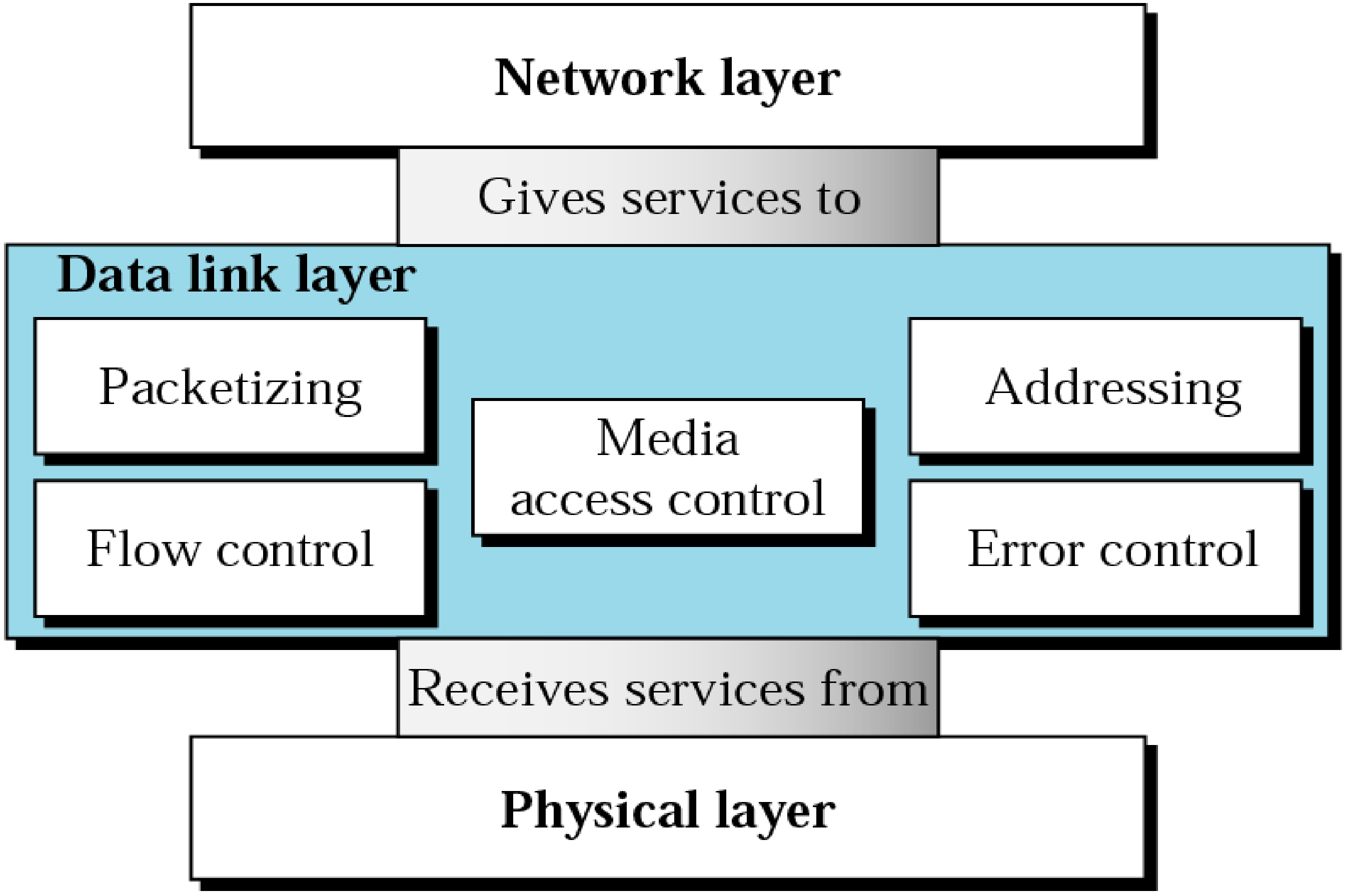
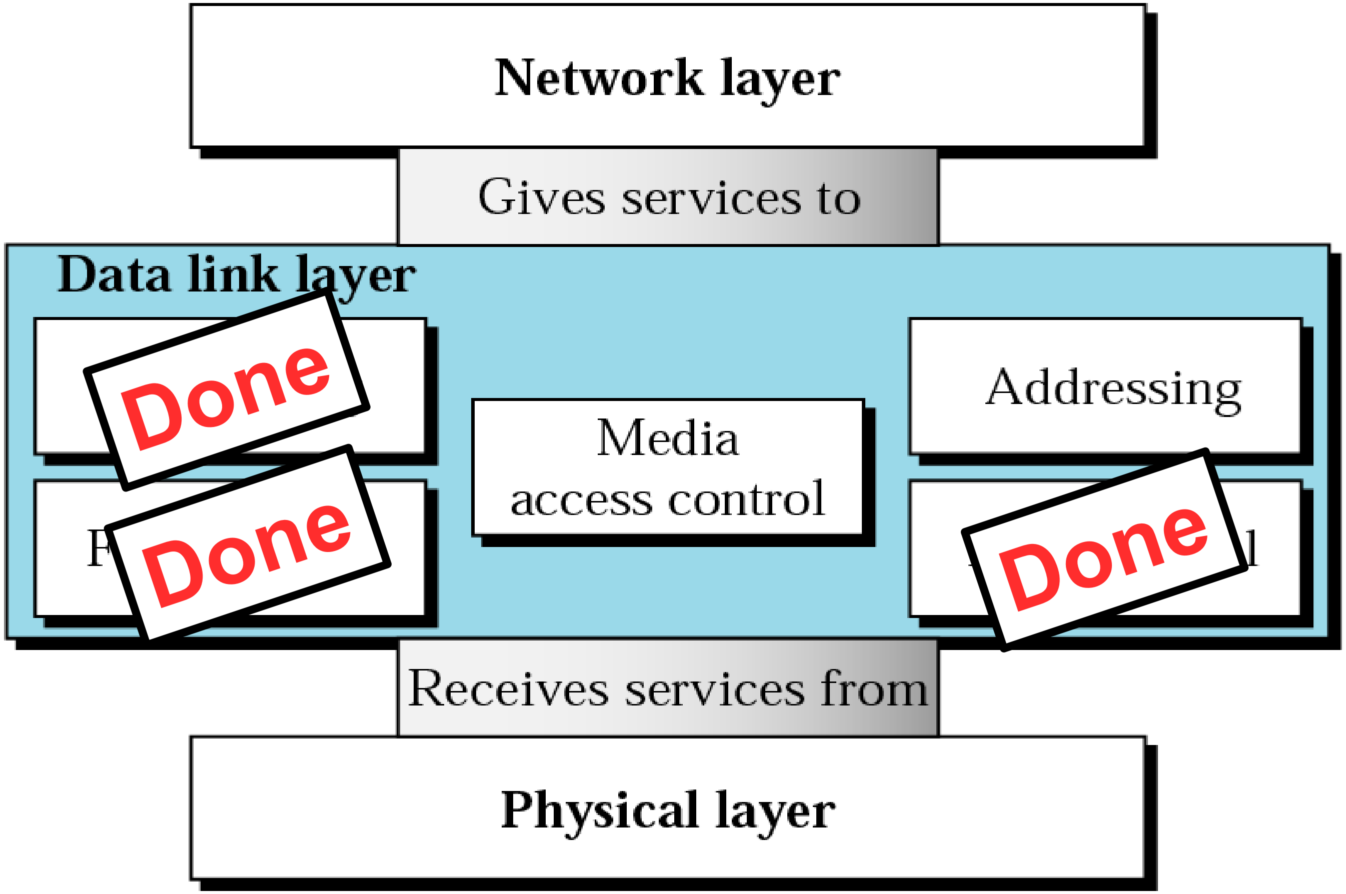
# Link Layer



* Figure is courtesy of B. Forouzan

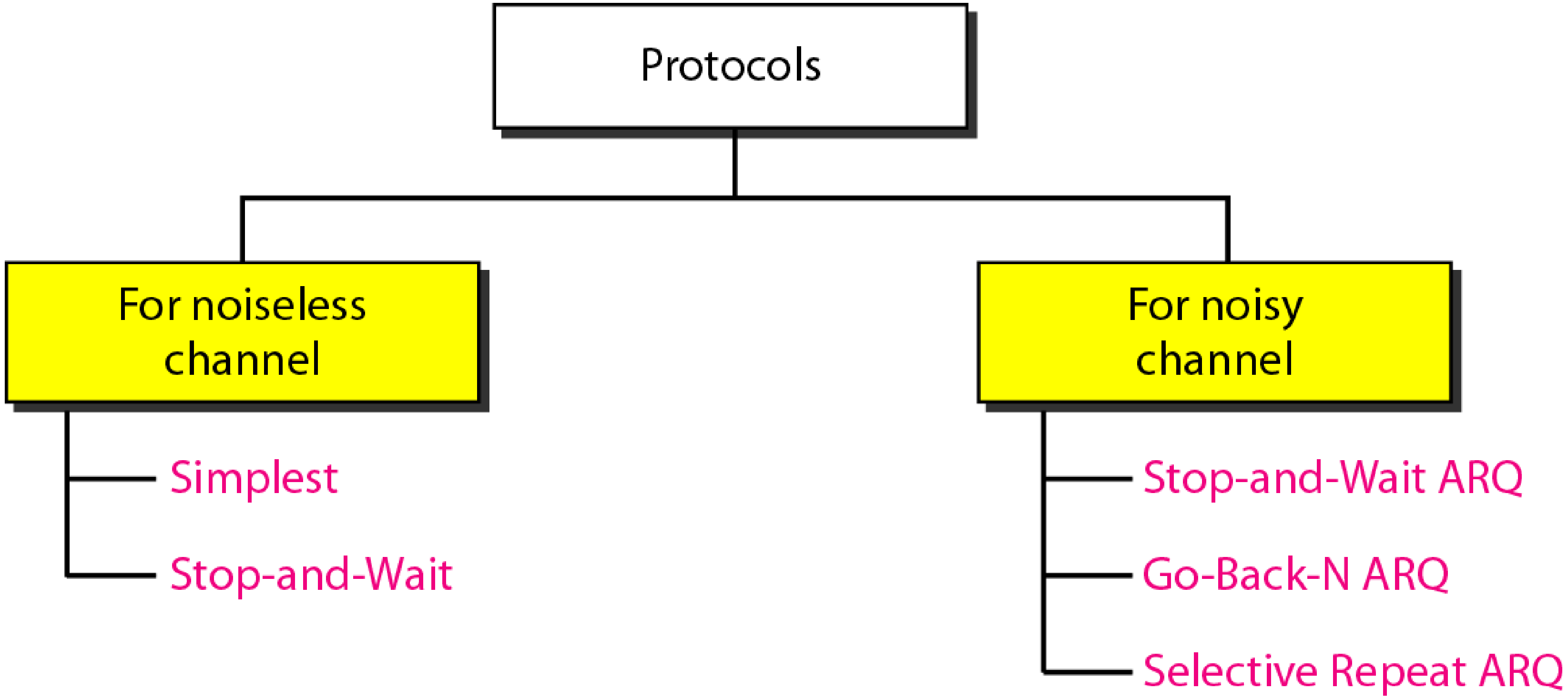
# Link Layer



* Figure is courtesy of B. Forouzan

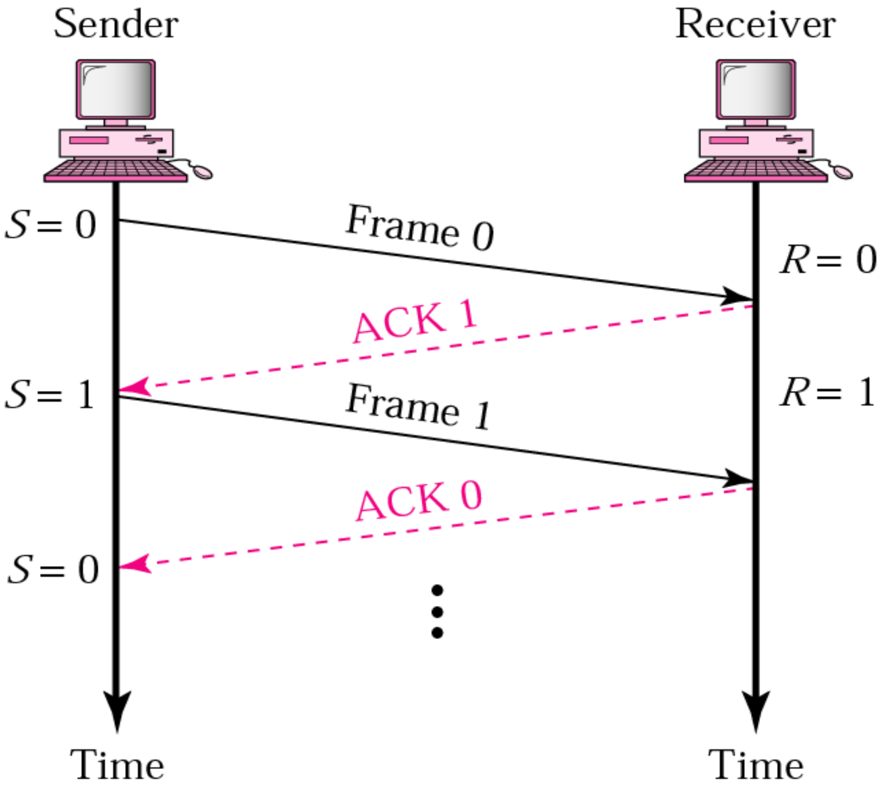
# Review: Flow Control

Flow Control: Refers to the control of the amount of data that a sender can transmit **without overflowing the receiver**.



* Figure is courtesy of B. Forouzan

# Stop-and-Wait ARQ

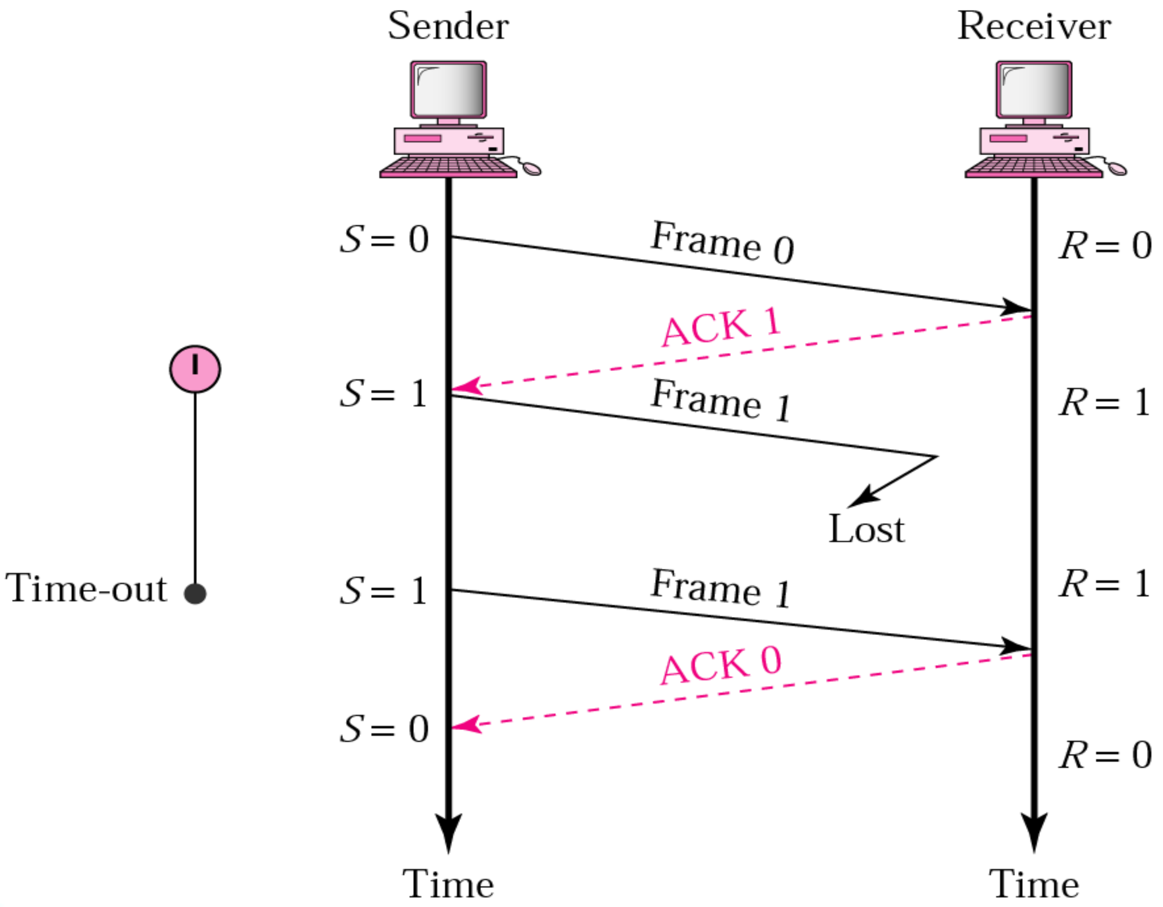


- ACK = received packet, ready to receive packet #

* Figure is courtesy of B. Forouzan

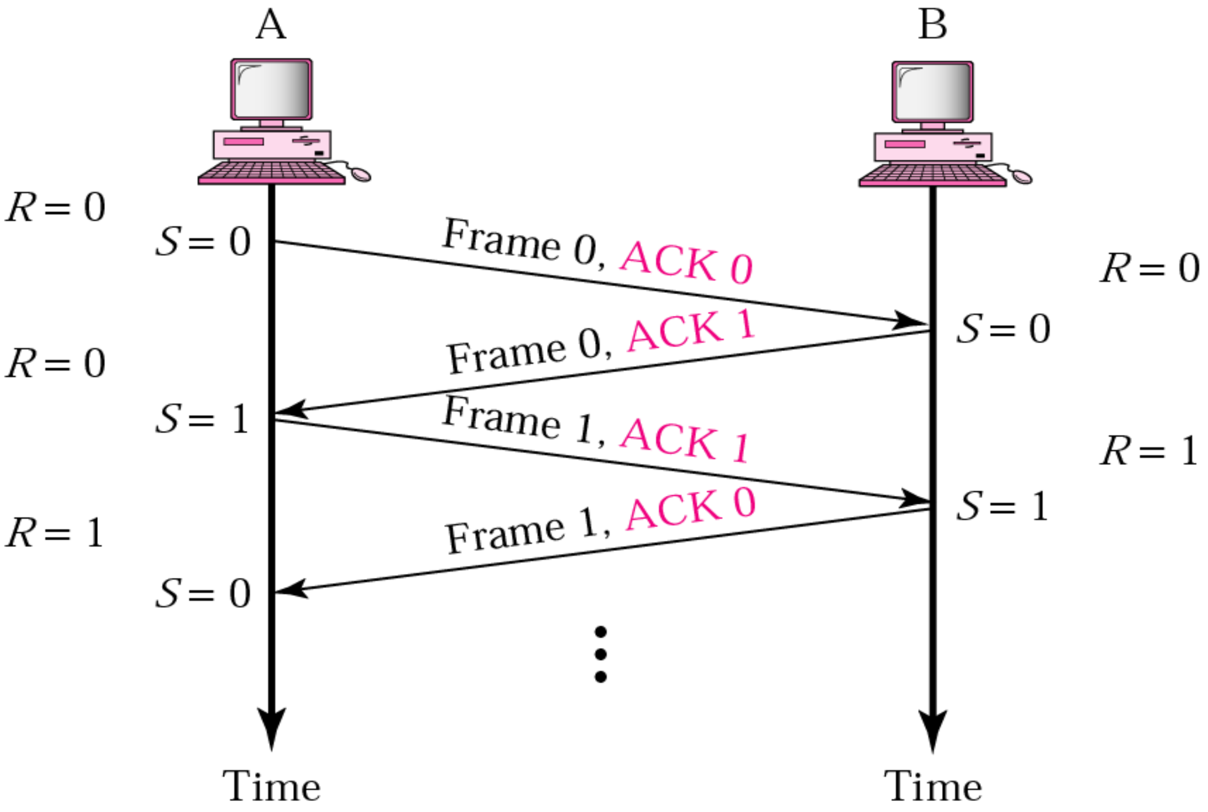
# Stop-and-Wait ARQ: Time-Out

- Frame is lost during transmission



* Figure is courtesy of B. Forouzan

# Piggybacking ACKs

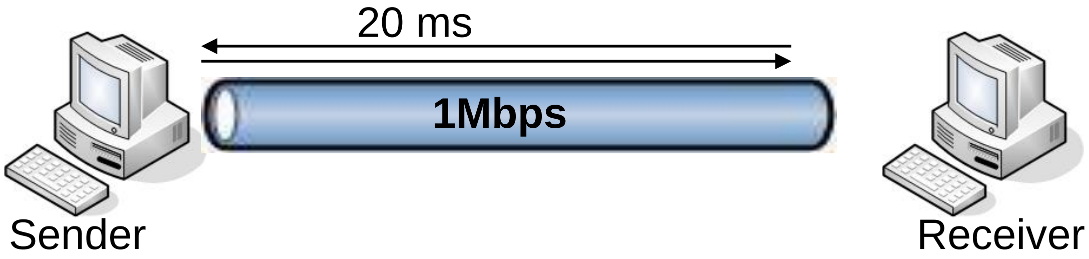


- Next data frame send carries acknowledgement for last frame received

* Figure is courtesy of B. Forouzan

# Bandwidth-Delay Product: Example

- Bandwidth × Round-Trip-Time
  - gives indication of amount of data that can be send while waiting for ACK

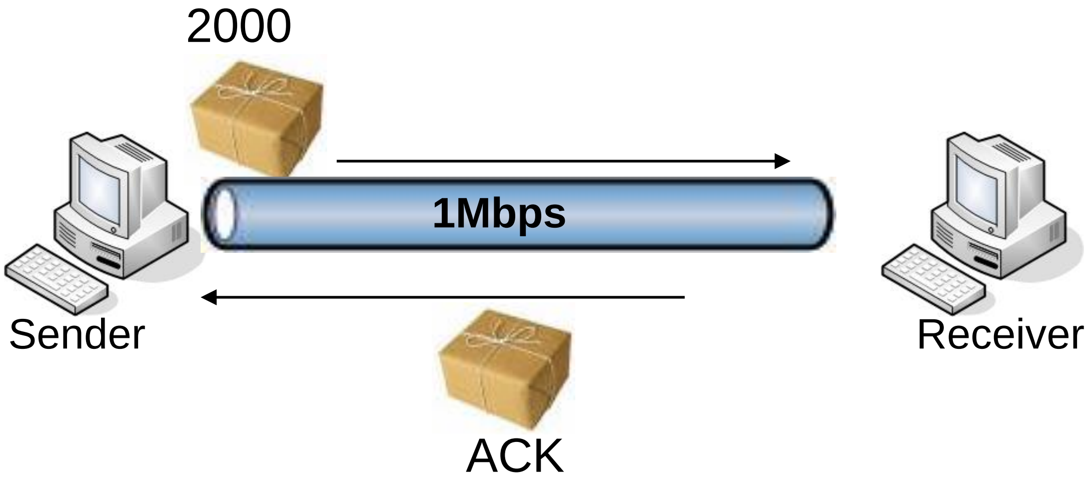


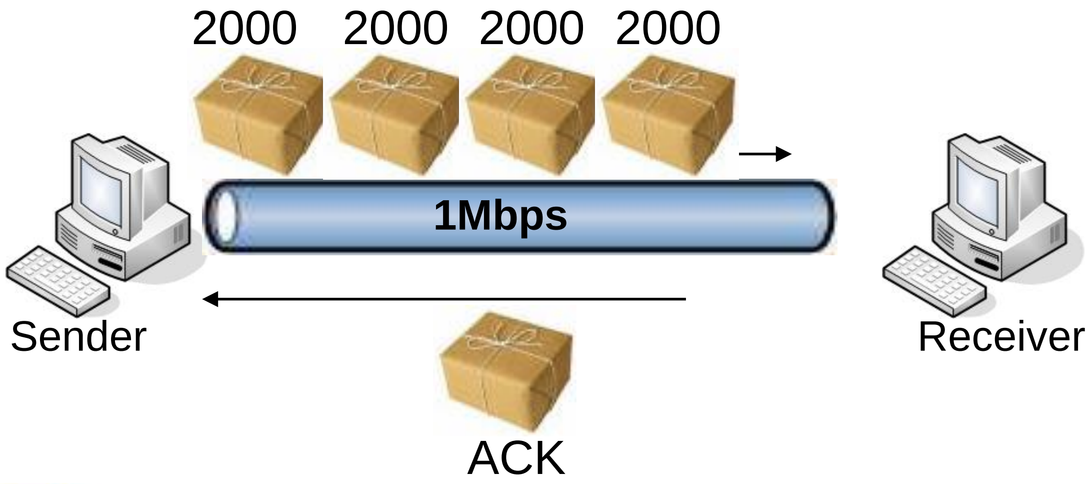
- Communication link with 1Mb/s
- Round-Trip time: 20 ms = 20*10$^{-3}$ s

- How much data can you send during the time it takes for 1 bit to
- 20*10$^{-3}$ s * 1*10$^{6}$ b/s = 20.000 bits

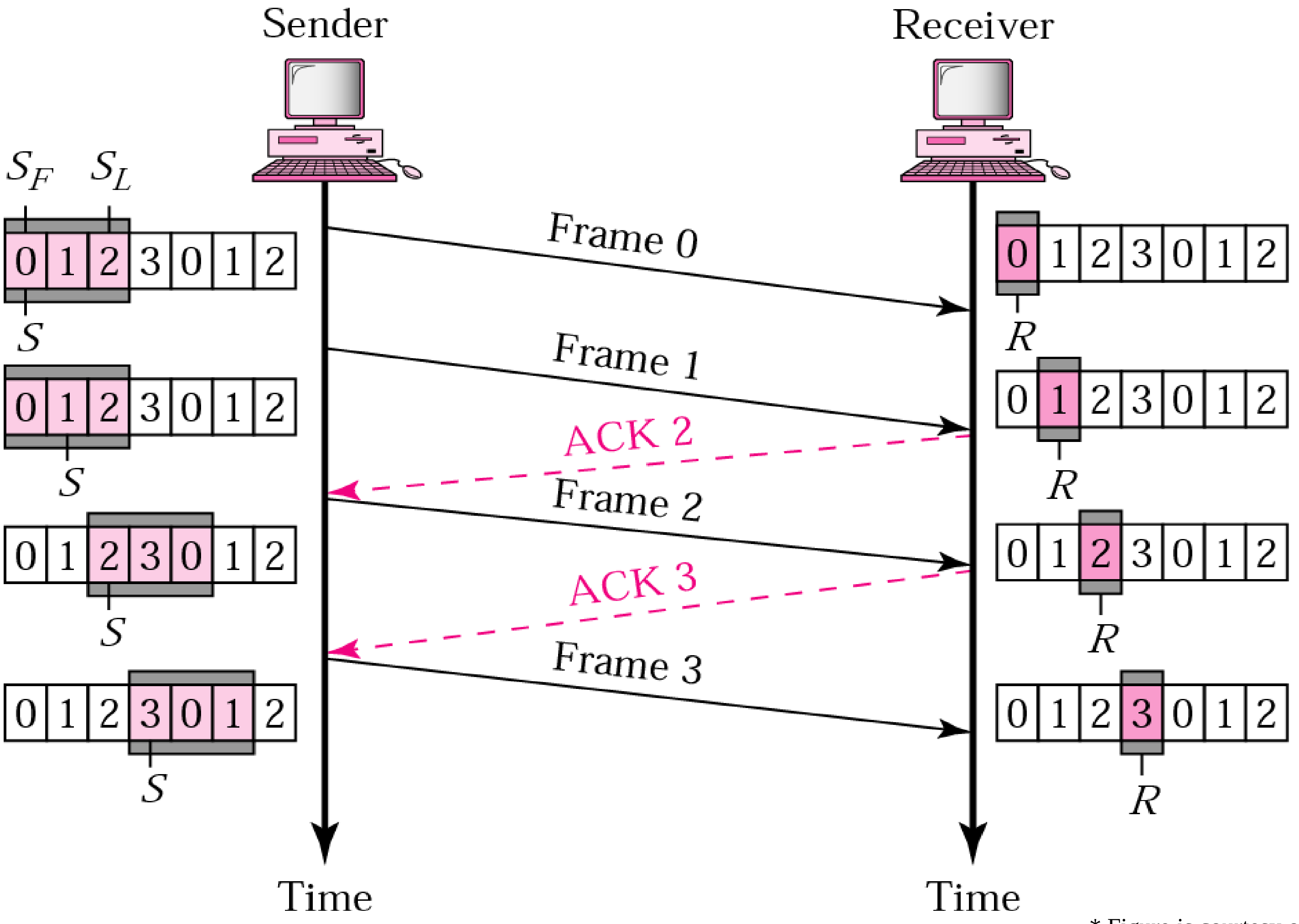
- Frame of 2000 bit ⇒ 10% of bandwidth used

# Bandwidth-Delay Product: Example



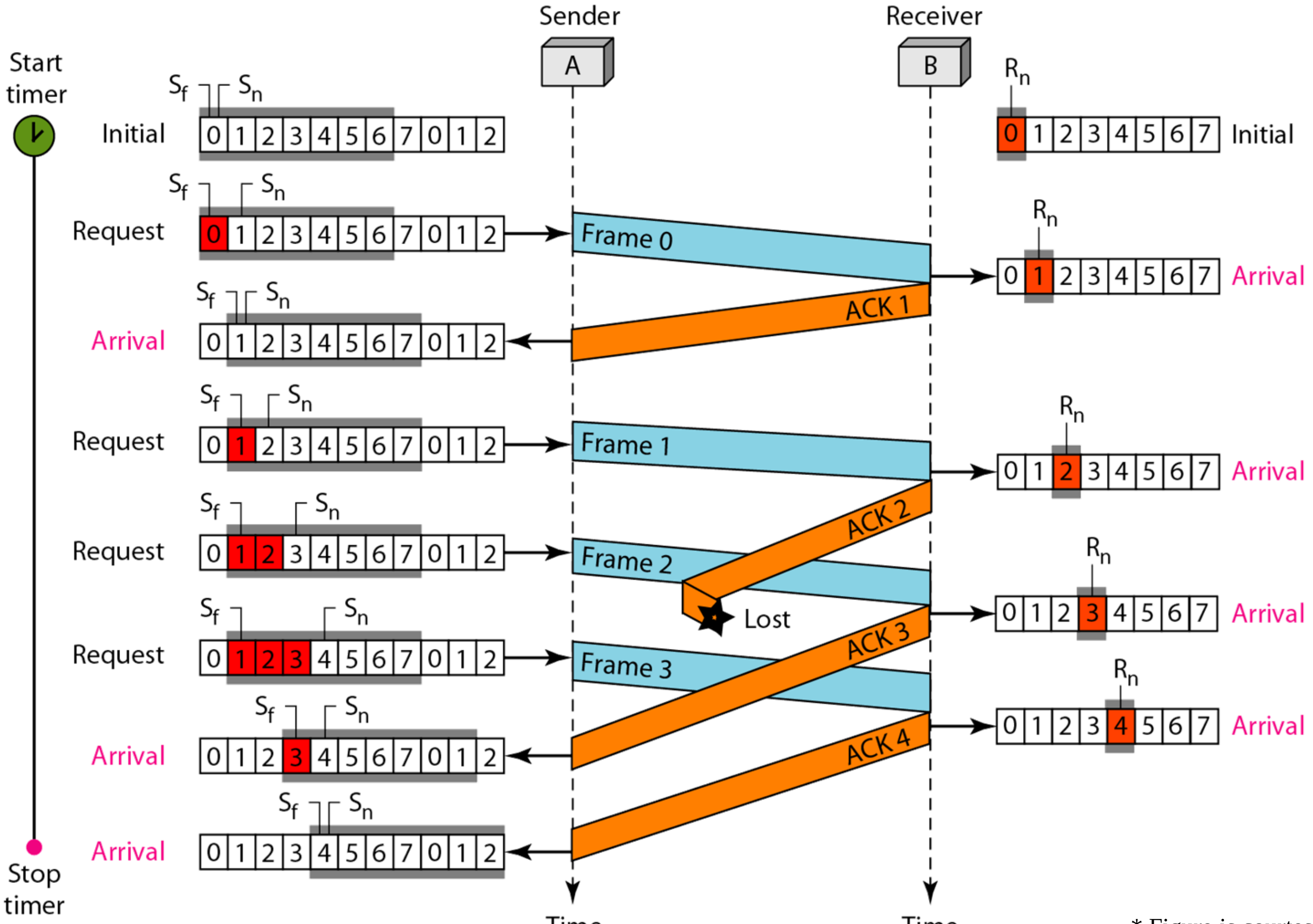


# Go-Back-N ARQ



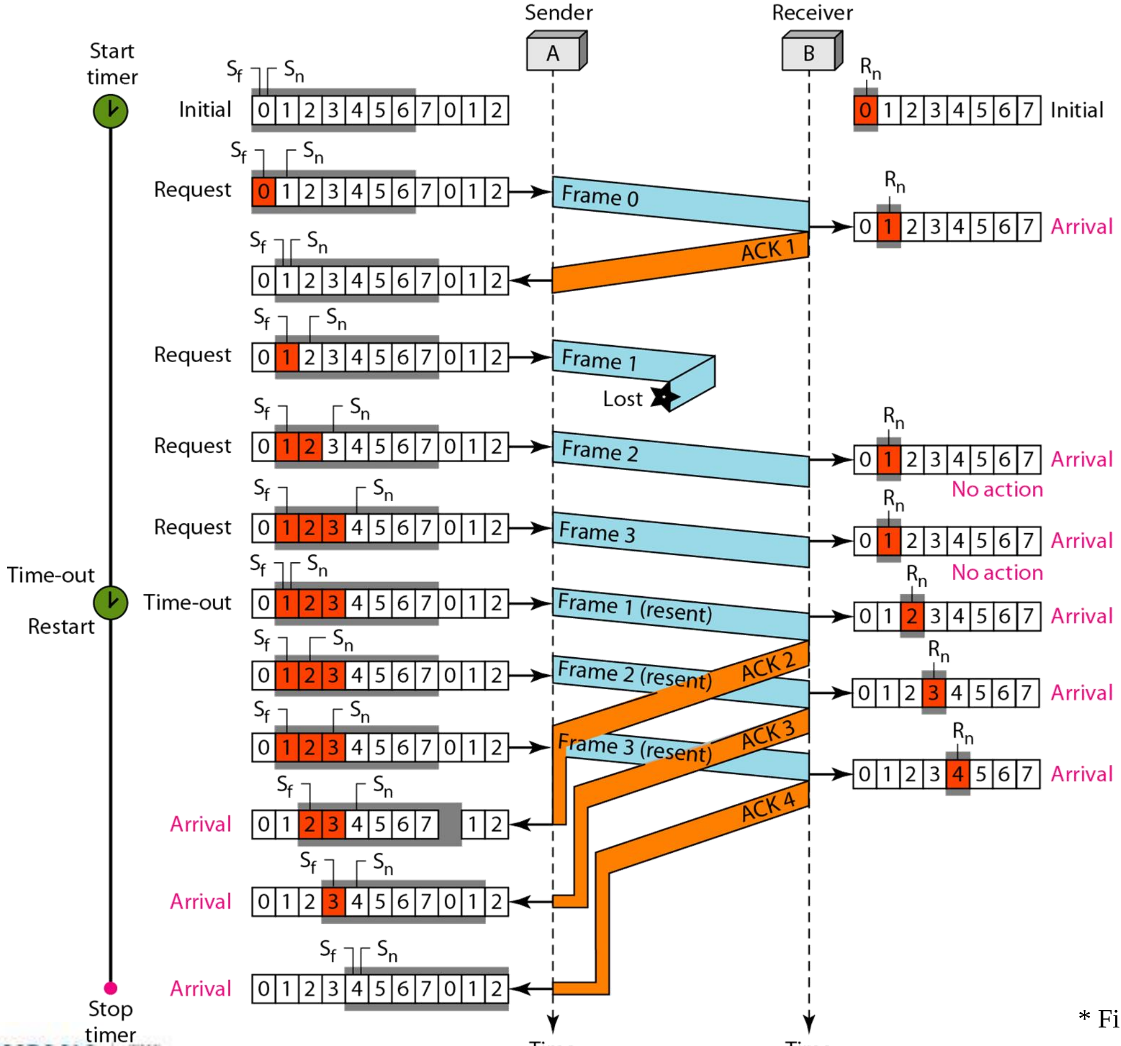
* Figure is courtesy of B. Forouzan

# Go-Back-N: Lost ACK



* Figure is courtesy of B. Forouzan

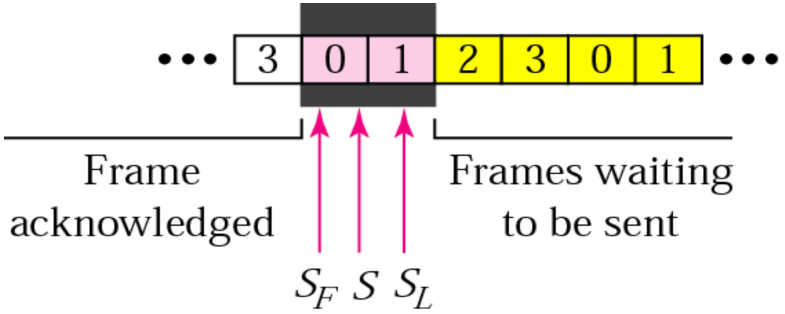
# Go-Back-N ARQ: Bad Behaviour



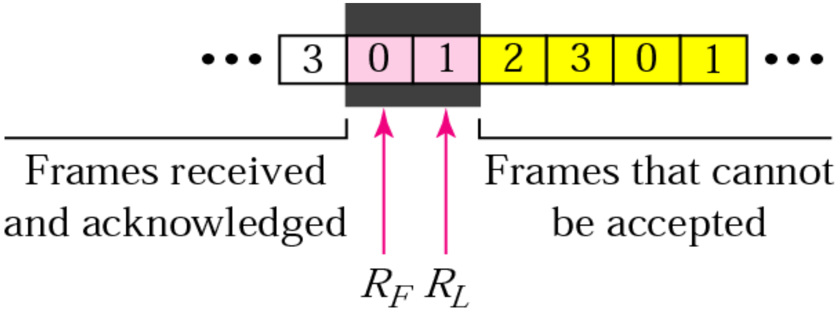
* Figure is courtesy of B. Forouzan

# Selective Repeat

- Two Windows:
  - 1 Sender Window – 1 Receiver Window



a. Sender window

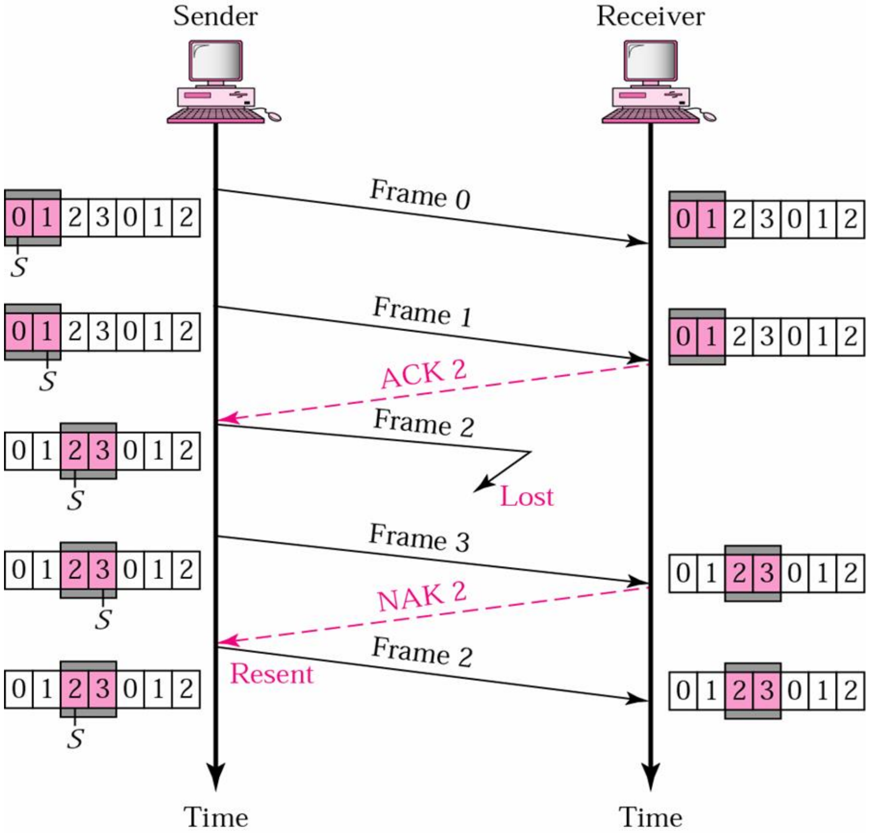


3
0
1
2
3
0
1
Frames received and acknowledged
Frames that cannot be accepted
$R_F$
$R_L$

b. Receiver window

* Figure is courtesy of B. Forouzan

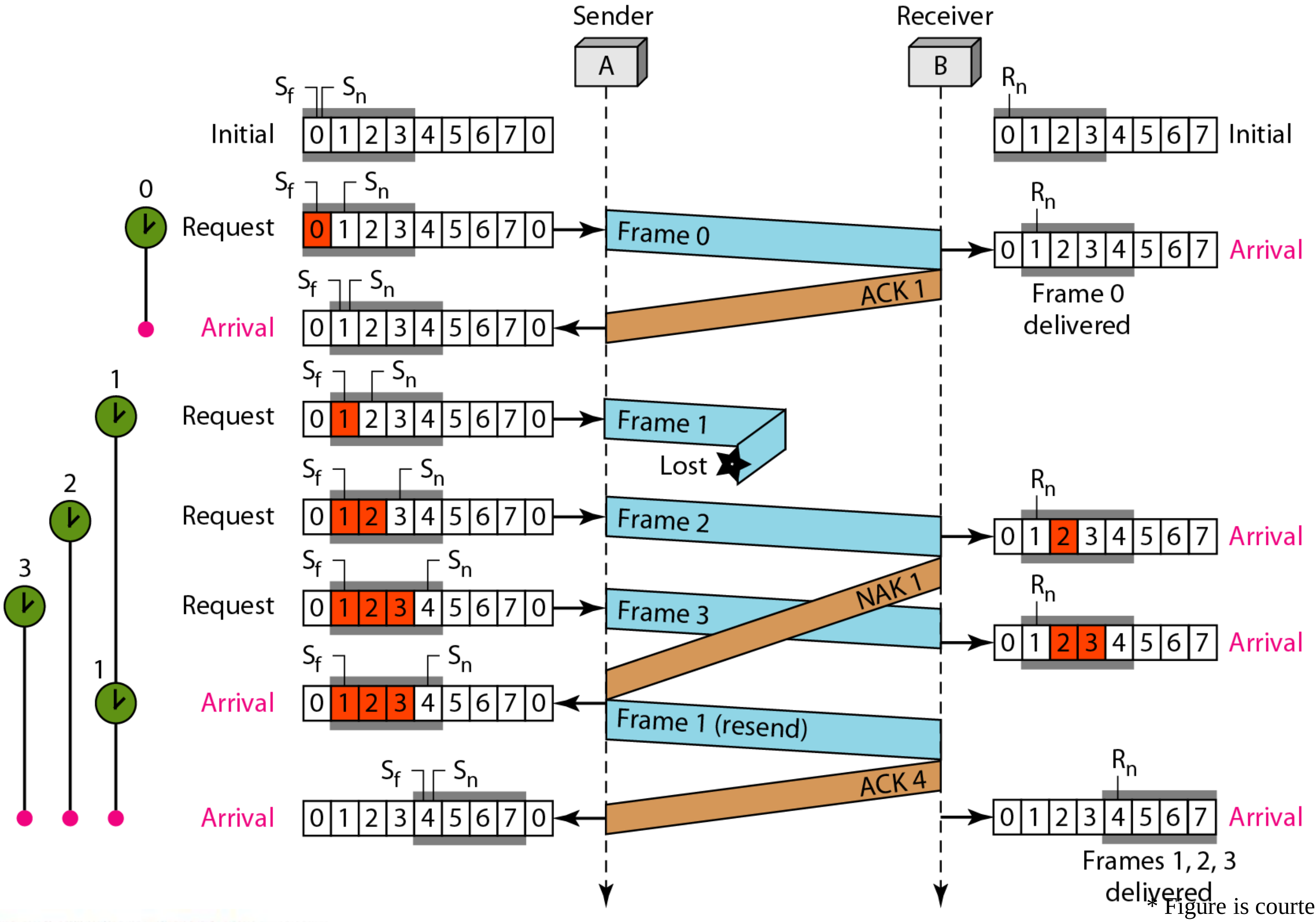
# Selective Repeat ARQ: Lost Frame



- NAK = Negative Acknowledgement
- Sender still maintains timers for packets in case NAK gets lost

* Figure is courtesy of B. Forouzan

# Selective Repeat ARQ



* Figure is courtesy of B. Forouzan

# Sliding Windows

- Allow multiple frames to be in transit

- Receiver has buffer w long
- Transmitter can send up to w frames
  - without ACK

- Each frame is numbered
- ACK includes number of next frame expected

# Window Size for Go-Back-N

- Depends on size of max. frame number
  - Frame # needs to be included in every frame
  - e.g. 4 bits – $2^4$ = 16 frame numbers

- Trade-off between window size and frame size

# CS2031
# Telecommunications II

## High-level Data Link Control (HDLC)

# HDLC

- ISO 33009, ISO 4335, Used initially in X.25

**1979**, ISO 3309

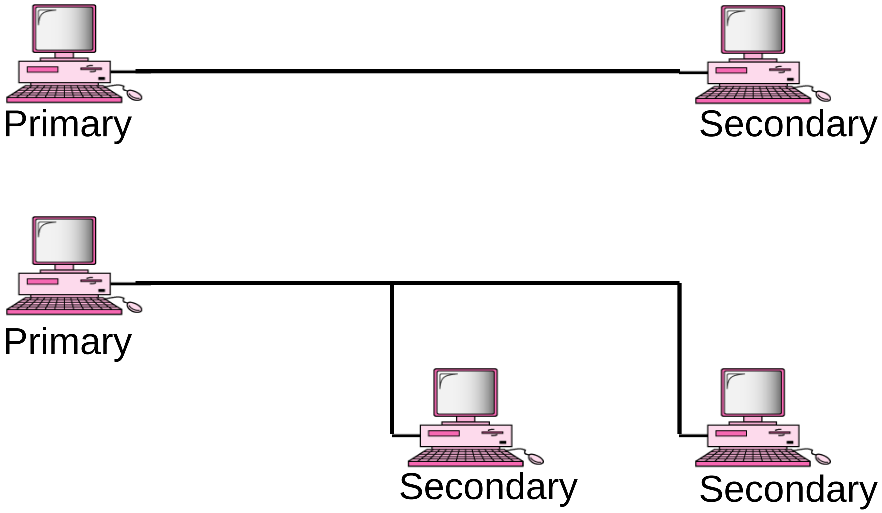
- It’s old – so, why should we care?
  - Implements framing, addressing
  - Implements flow control mechanisms

- Do we have to learn it by heart?
  - **No** – learn the principles – not the frames layout!

# HDLC Station Types

- Primary station
  - Controls operation of link
  - Frames issued are called commands
- Secondary station
  - Under control of primary station
  - Frames issued called responses
- Combined station
  - Combination of primary and secondary station
  - May issue commands and responses

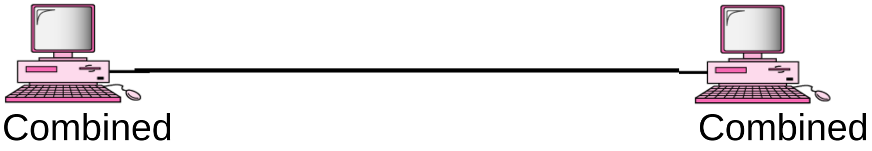
# HDLC Station Types



Unbalanced Configuration

Two types of stations:

- Primary station
- Secondary station



Balanced Configuration

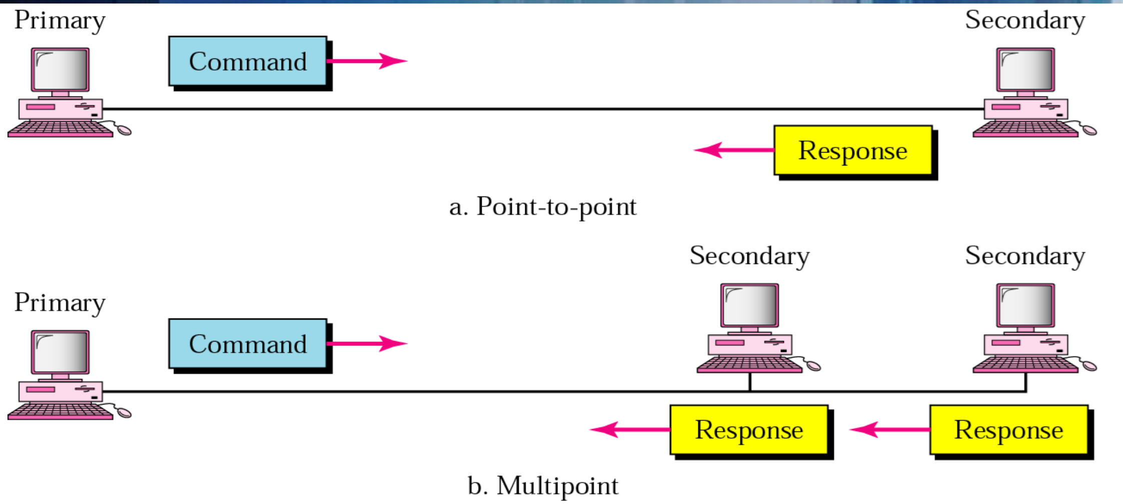
One type of stations:

- Combined station

# HDLC Modes

- Three modes:
  - – Normal Response Mode (NRM)
  - – Asynchronous Response Mode (ARM)
  - – Asynchronous Balanced Mode (ABM)

# Normal Response Mode (NRM)



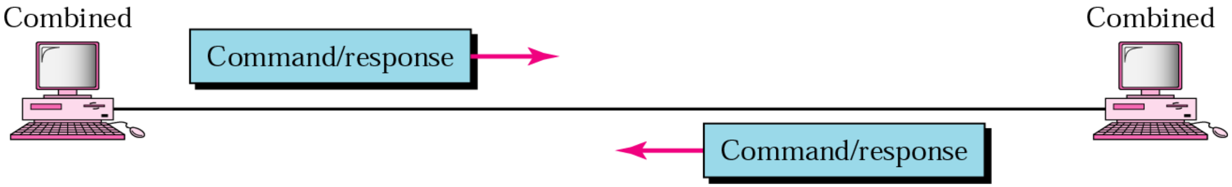
a. Point-to-point

b. Multipoint

- Master/Slave architecture
- Unbalanced configuration
- Primary initiates transfer to secondary
- Secondary may only transmit data in response to command from primary
- Used on multi-drop lines

* Figure is courtesy of B. Forouzan

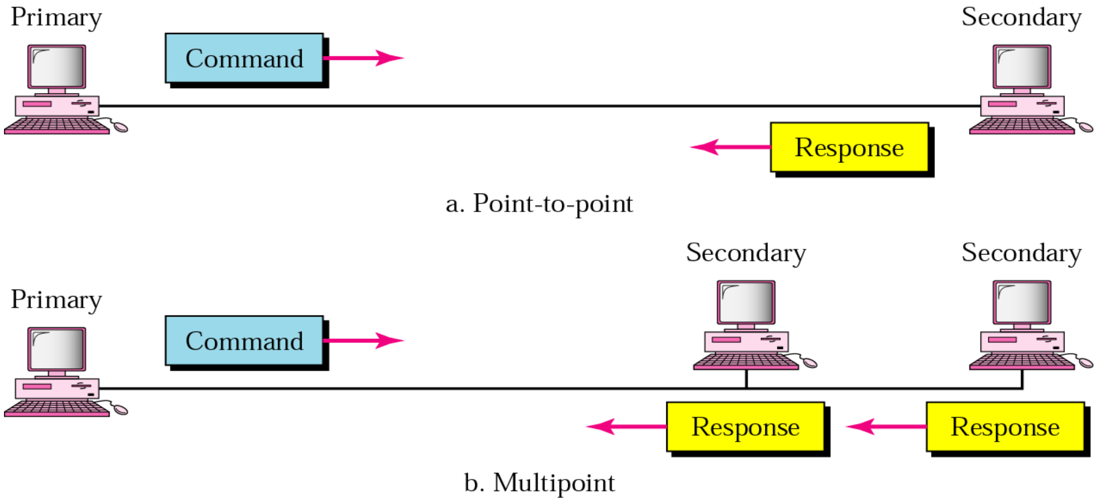
# Asynchronous Balanced Mode (ABM)



- Balanced configuration
- Either station may initiate transmission without receiving permission
- Most widely used
- No polling overhead

* Figure is courtesy of B. Forouzan

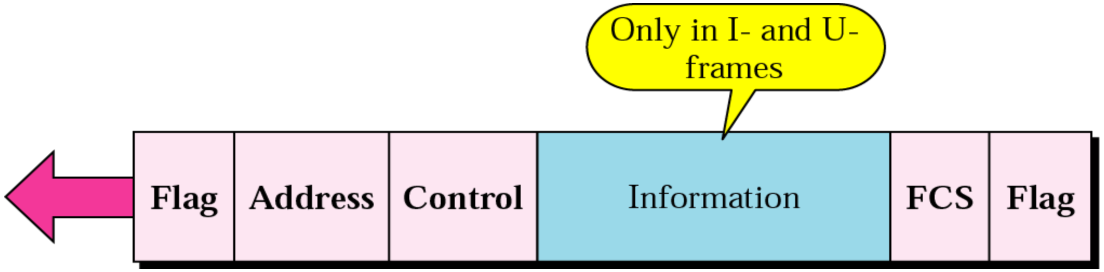
# Asynchronous Response Mode (ARM)



- Unbalanced configuration
- Secondary may initiate transmission without permission form primary
- Primary responsible for line
- Rarely used

* Figure is courtesy of B. Forouzan

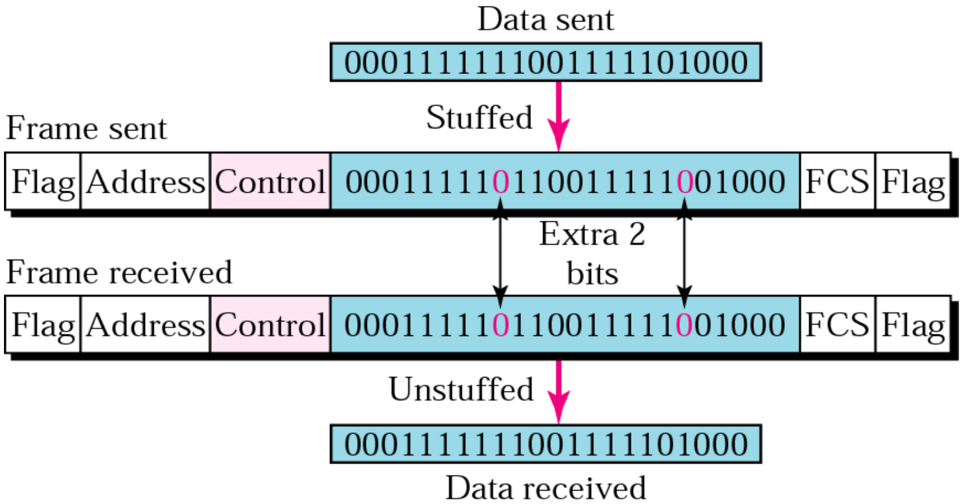
# HDLC frame



- Flag= 01111110
  - specifies beginning and end of frame
- Address
  - specifies secondary station
  - as either sender or receiver
- Control
  - specifies type of frame and seq.&ack. number
- Frame Check Sequence (FCS)
  - either 16- or 32-bit CRC

* Figure is courtesy of B. Forouzan

# Bit-Stuffing



Data sent

0001111111001111101000

Stuffed

Frame sent

Flag | Address | Control | 000111110110011111001000 | FCS | Flag

Extra 2 bits

Frame received

Flag | Address | Control | 000111110110011111001000 | FCS | Flag

Unstuffed

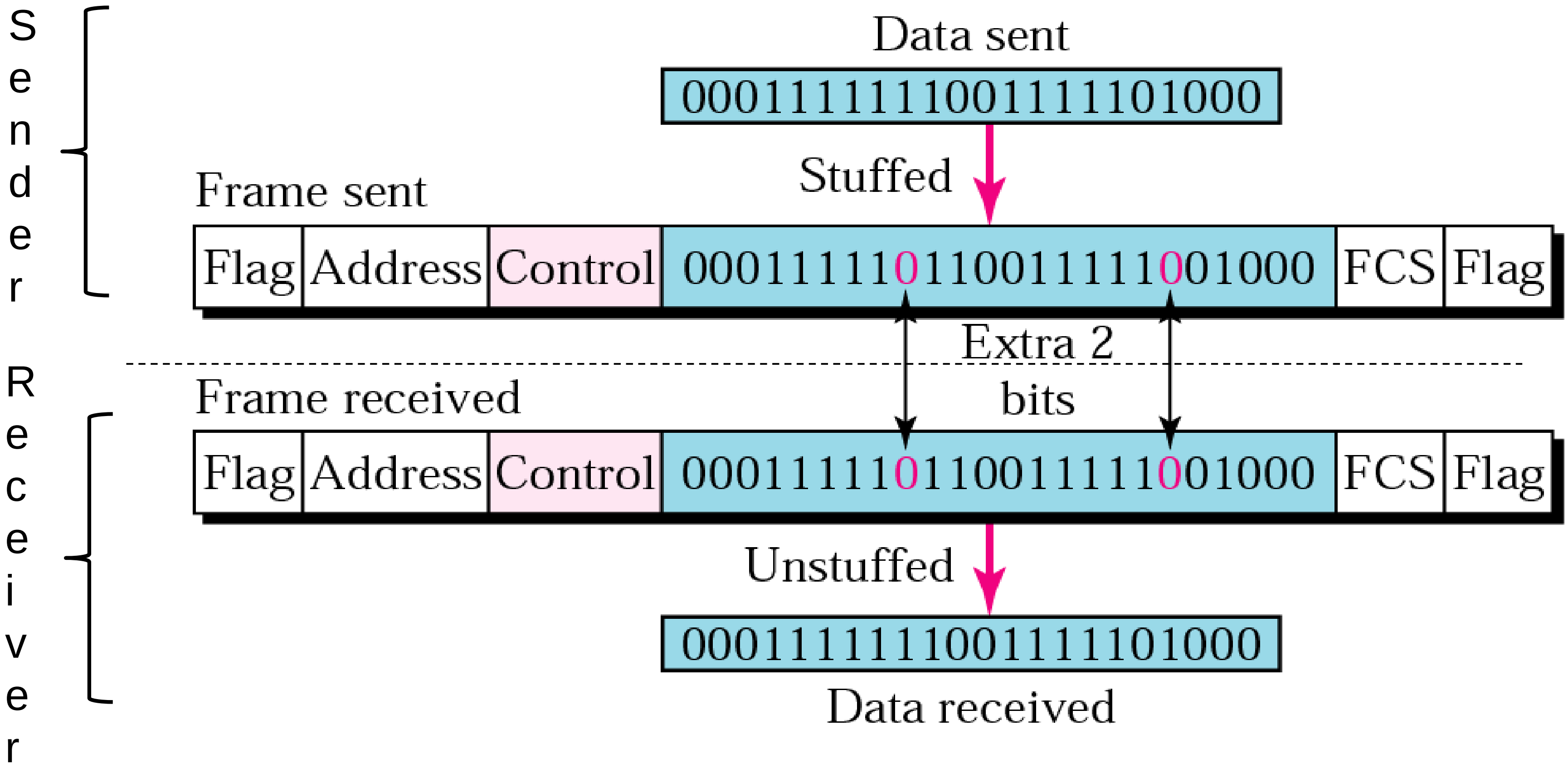
0001111111001111101000

Data received

- Bit stuffing used to avoid confusion with data containing same combination as flag 01111110
  - 0 inserted after every sequence of five 1s
  - If receiver detects five 1s
    - it checks next bit
    - If 0, it is deleted
    - If 1 and seventh bit is 0, accept as flag
    - If sixth and seventh bits 1, sender is indicating abort

* Figure is courtesy of B. Forouzan

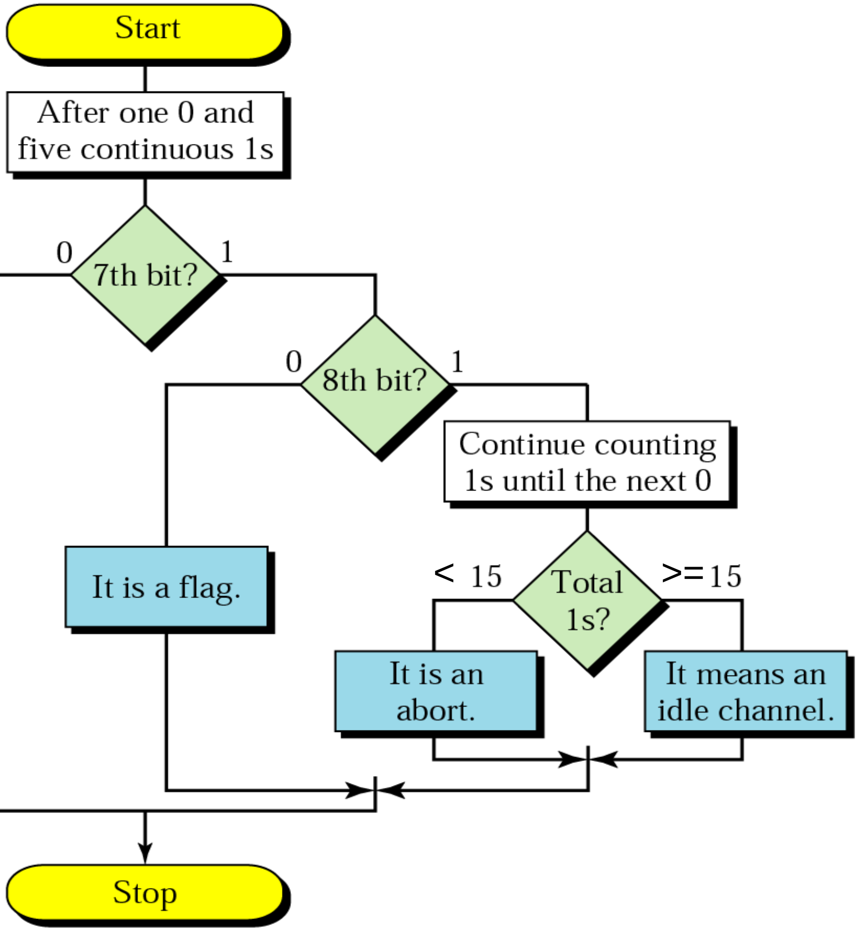
# Bit Stuffing



Process of adding 0 whenever there is a flag or escape sequence in the text.

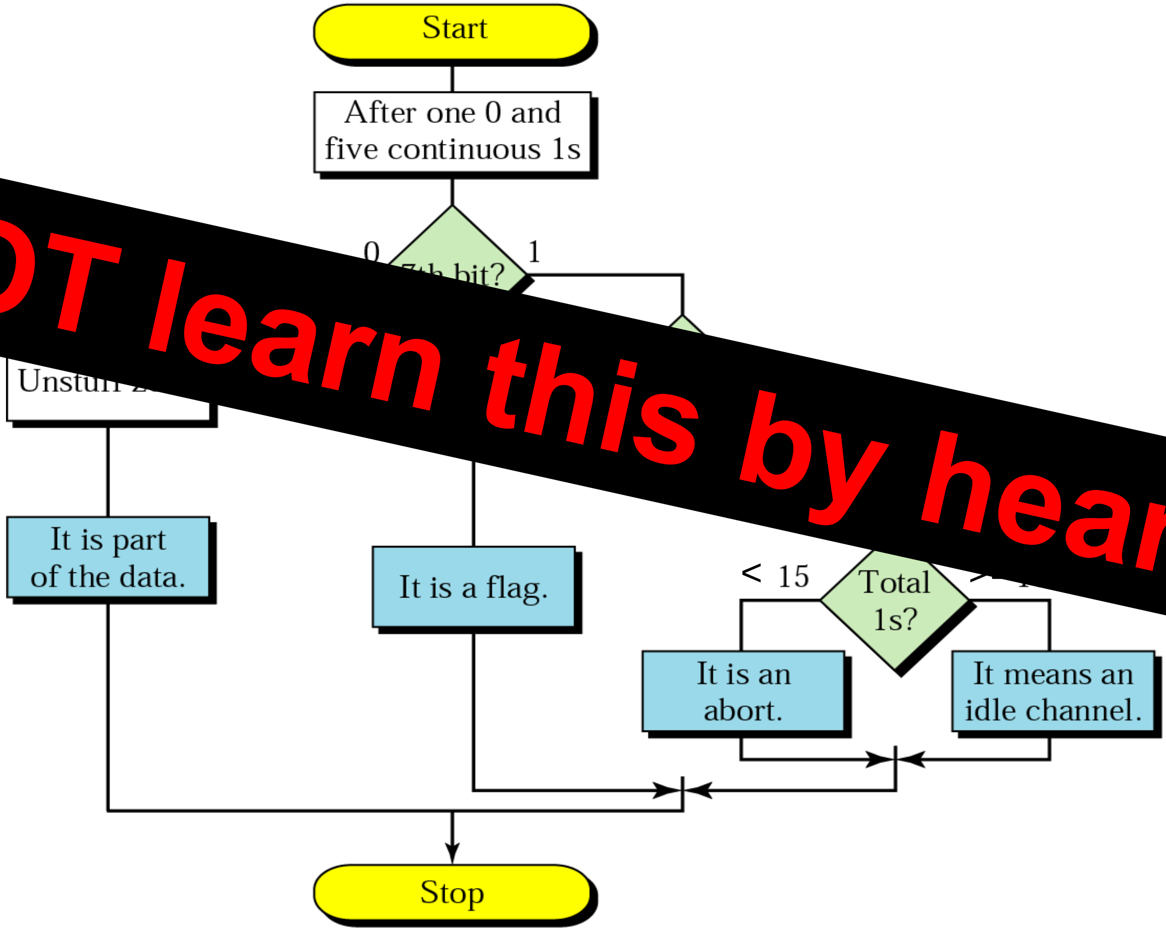
* Figure is courtesy of B. Forouzan

# Bit stuffing in HDLC



* Figure is courtesy of B. Forouzan

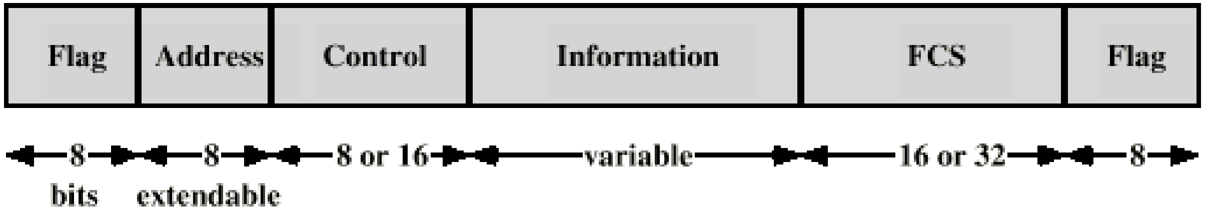
# Bit stuffing in HDLC



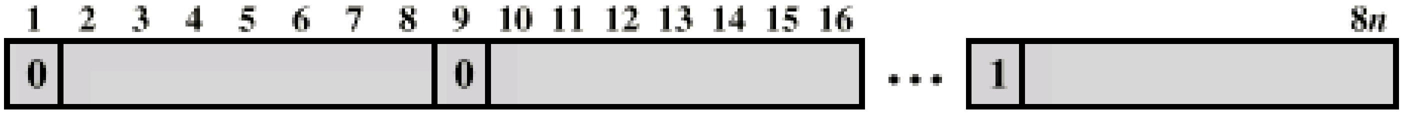
Do NOT learn this by heart!!!!!

* Figure is courtesy of B. Forouzan

# Address Field

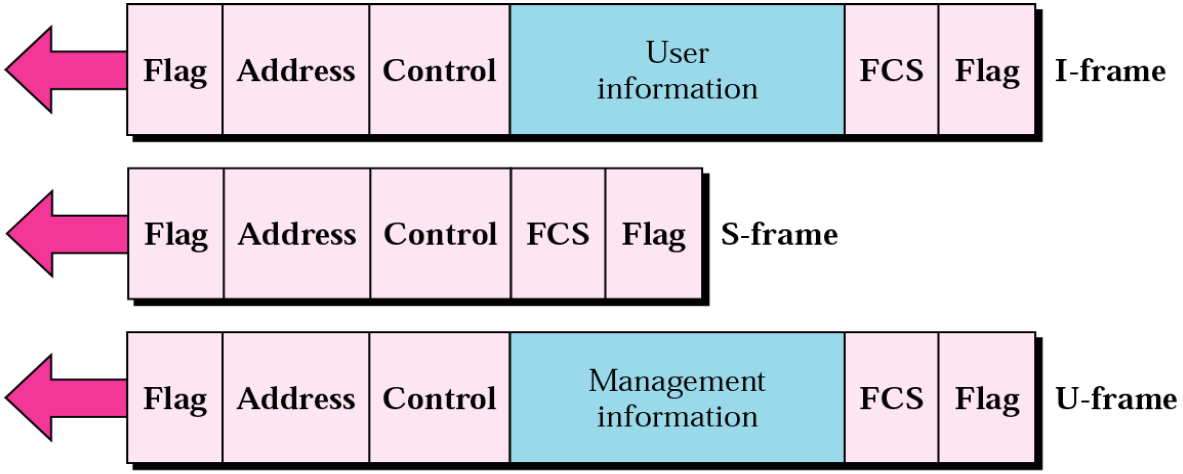


- Usually 8 bits long
- May be extended to multiples of 7 bits
  - LSB of each octet indicates that it is the last octet (1) or not (0)
- All ones (11111111) is broadcast



* Figure is courtesy of W. Stallings

# HDLC Frame Types



Flag | Address | Control | User information | FCS | Flag — I-frame

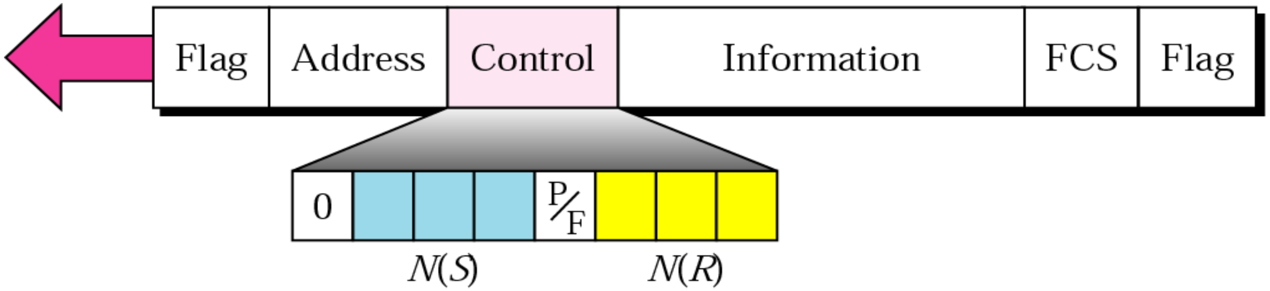
Flag | Address | Control | FCS | Flag — S-frame

Flag | Address | Control | Management information | FCS | Flag — U-frame

- I-Frame: Information Transfer Format
  - Control= 0 ? ? ? ? ? ? ?
- S-Frame: Supervisory Format
  - Control= 1 0 ? ? ? ? ? ?
- U-Frame: Unnumbered Format
  - Control= 1 1 ? ? ? ? ? ?

* Figure is courtesy of B. Forouzan

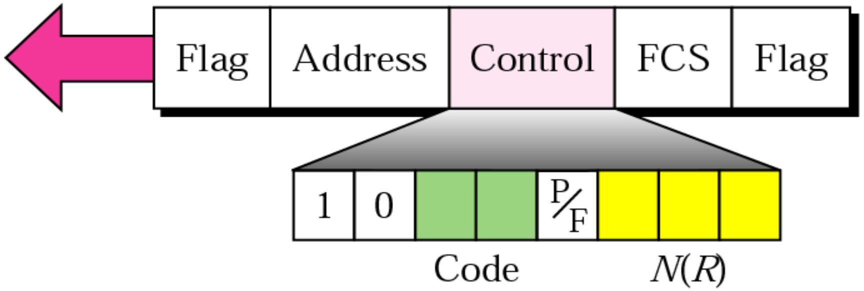
# I-Frame



- N(S)
  - Sequence Number of Sender
- N(R)
  - Sequence Number of Receiver
- P/F
  - Poll/Final bit
  - Set by Primary station as request for information
  - Set by Secondary station to signal response or to signal final frame of a transmission

* Figure is courtesy of B. Forouzan

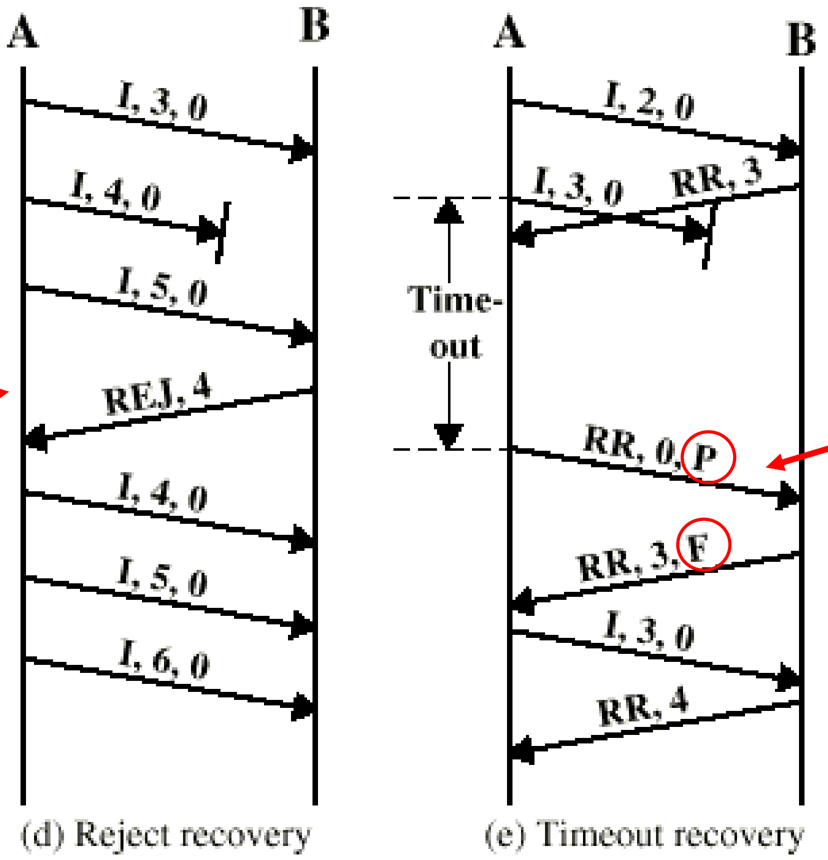
# S-Frame Control Field



- Code 00 = Receive Ready (RR)
  - Acknowledge frames & waiting for more
- Code 10 = Receive Not Ready (RNR)
  - Acknowledge frames & busy right now
- Code 01 = Reject (REJ)
  - Go-Back-N NAK
- Code 11 = Selective Reject (SREJ)
  - Selective Repeat NAK

* Figure is courtesy of B. Forouzan

# Example



(d) Reject recovery

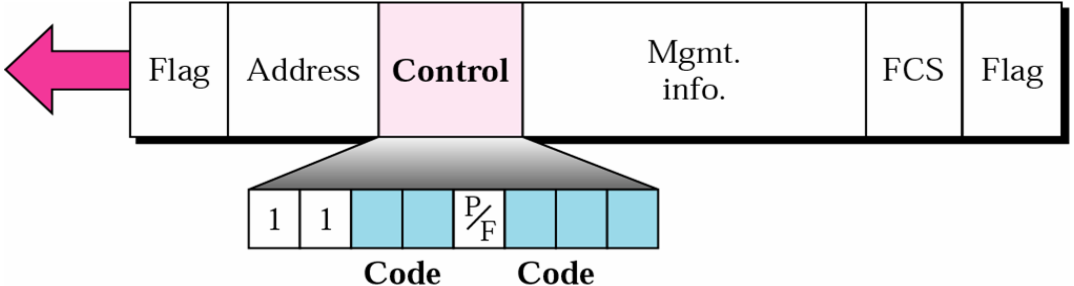
(e) Timeout recovery

Received 5 but didn't receive 4

Hello?? Anybody home??

* Figure is courtesy of W. Stallings

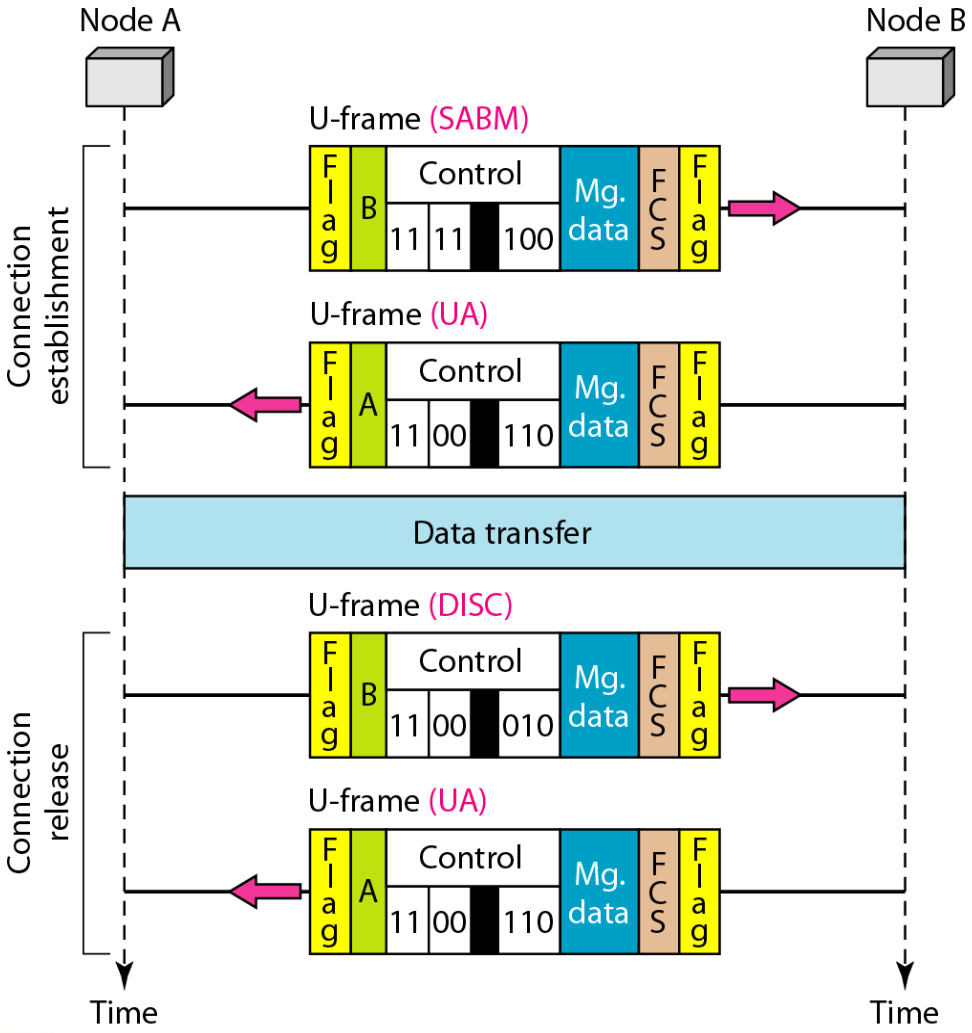
# U-Frame Control Field



| Code | Command/Response | Meaning |
|---|---|---|
| 00 001 | SNRM | Set normal response mode |
| 11 100 | SABM | Set asynchronous balanced mode |
| 00 100 | UP | Unnumbered poll |
| 00 000 | UI | Unnumbered information |
| 00 110 | UA | Unnumbered acknowledgment |
| 00 010 | DISC | Disconnect |
| 10 000 | SIM | Set initialization mode |
| 11 001 | RSET | Reset |
| 11 101 | XID | Exchange ID |
| 10 001 | FRMR | Frame reject |

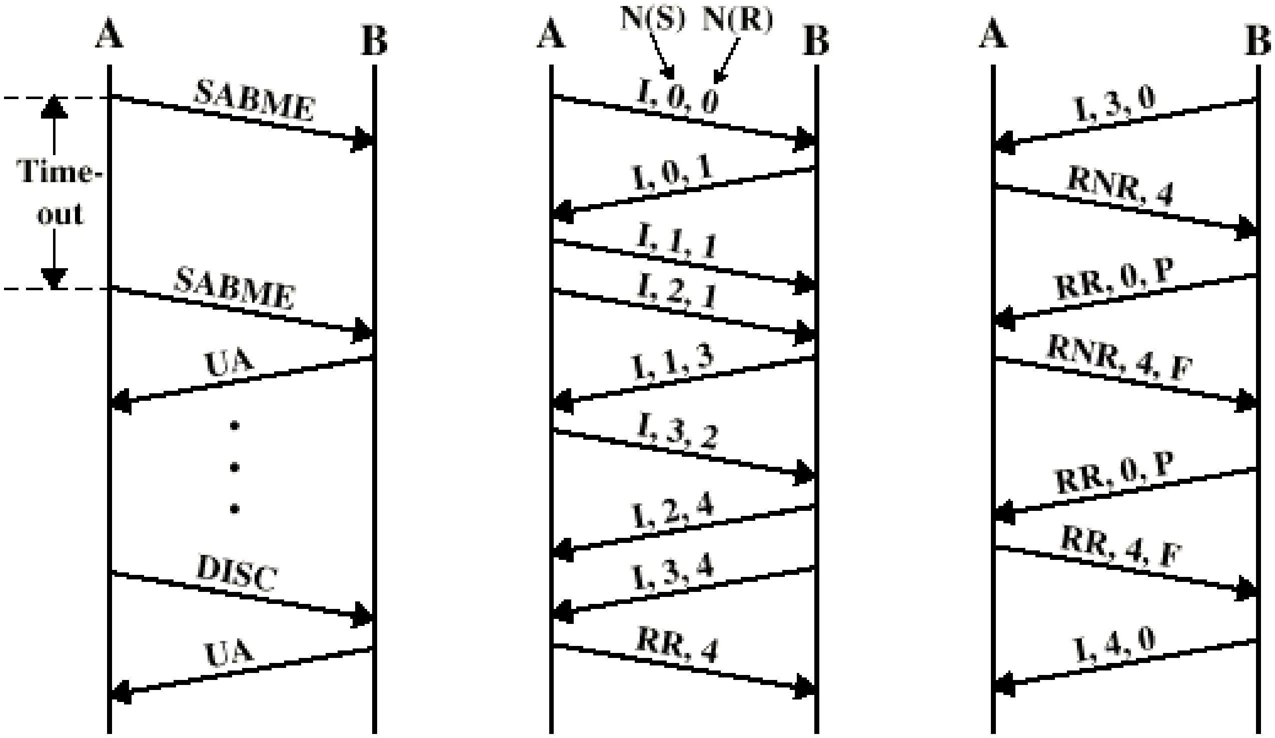
* Figure is courtesy of B. Forouzan

# Connection & Disconnection



* Figure is courtesy of B. Forouzan

# Examples of Operation

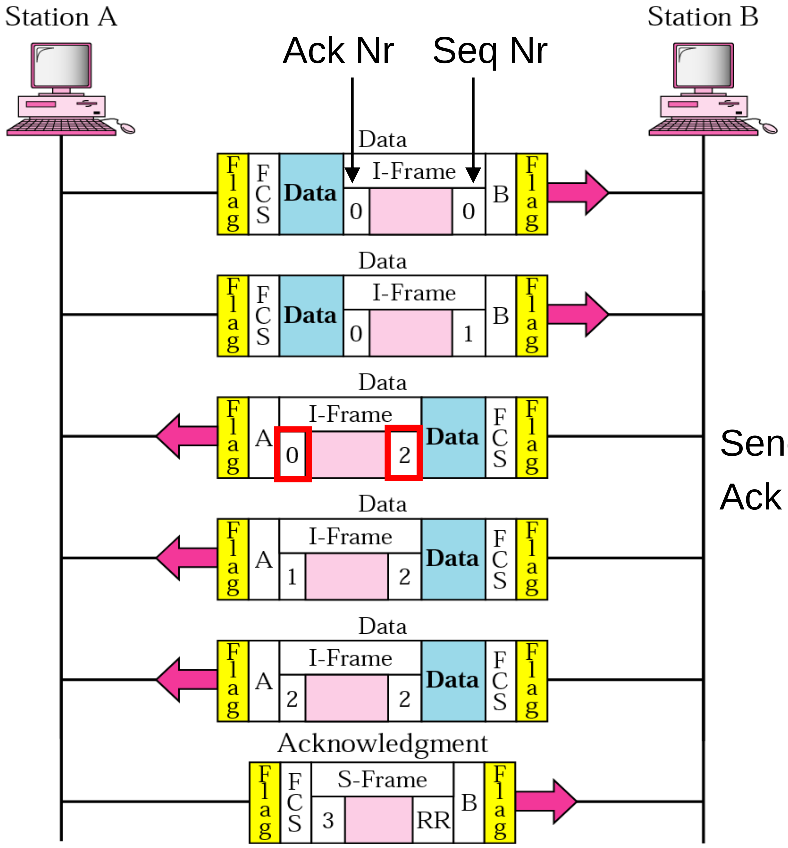


(a) Link setup and disconnect (b) Two-way data exchange (c) Busy condition

| | | | |
|---|---|---|---|
| SABME | Set asynchronous balanced mode | RR | Receive Ready |
| I | Information | RNR | Receive Not Ready |
| UA | Unnumbered acknowledgment | REJ | Reject |
| DISC | Disconnect | SREJ | Selective Reject |

* Figure is courtesy of W. Stallings

# Piggybacking without Error

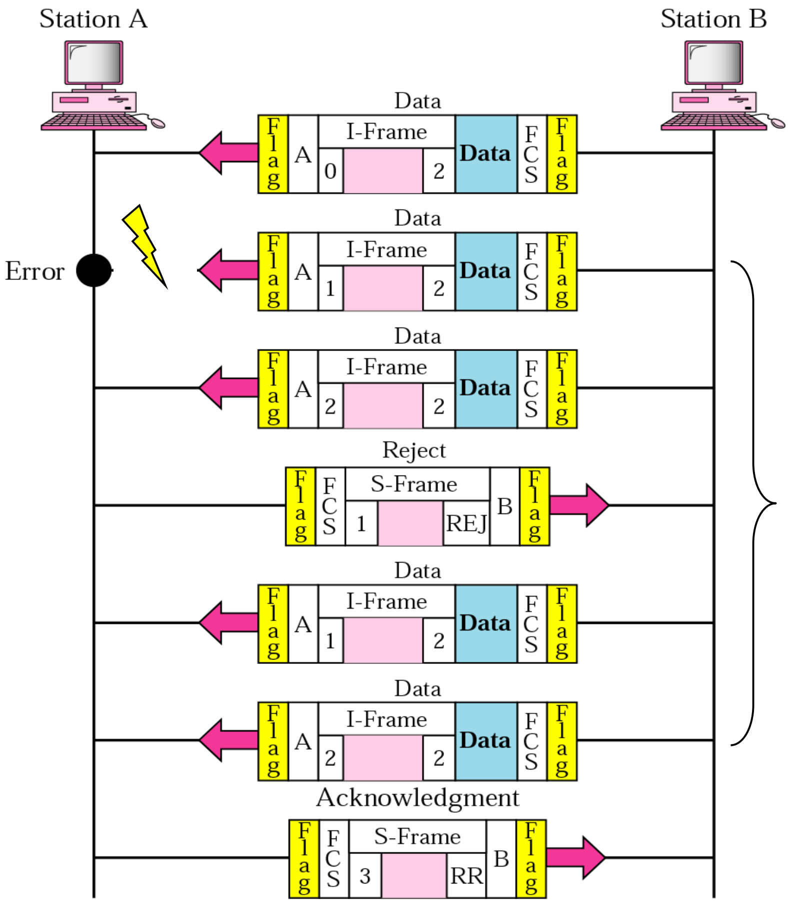


Send Frame 0 &

Ack Frame 0+1

* Figure is courtesy of B. Forouzan

# Piggybacking with Error



Go-Back-N

* Figure is courtesy of B. Forouzan

# Summary: HDLC

- Three station types
  - Primary station
  - Secondary station
  - Combined station
- Operation modes
  - Normal response mode
  - Asynchronous response mode
- Three frame types
  - I-Frame: Information Transfer Format
  - S-Frame: Supervisory Format – Flow Control
  - U-Frame: Unnumbered Format – Connection setup/term./etc

- Bit-Stuffing - to avoid confusion of data and flag

# HDLC – Why?

- ‘should give you a feeling for a protocol

- It includes most of the basic mechanisms
  - Framing
  - Addressing
  - Bit-stuffing
  - Flow/Error control

- Once you can run through HDLC in your head, you understand the basics of link layer protocols

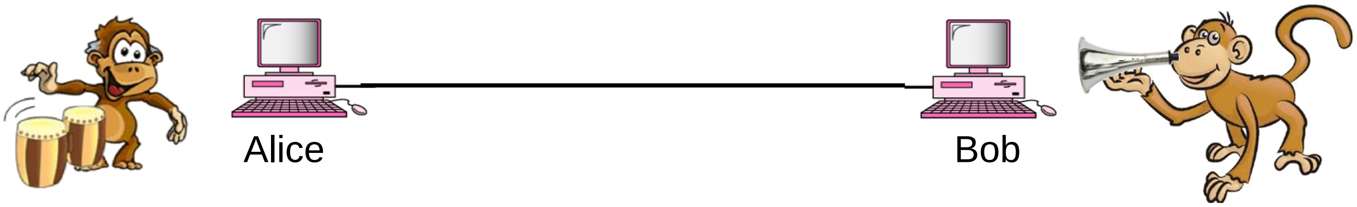
# Binary Example

01111110011111000111101101010110101111110

0111111001111010110001101110110101111110

01111110011111000110000101011110101111110

0111111001111010110001101110110101111110



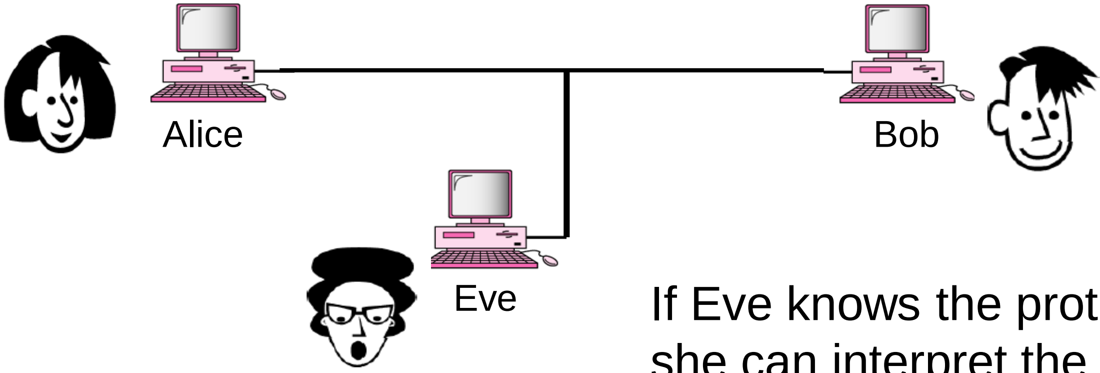
# Binary Example

01111110011111000111101101010110101111110

0111111001111010110001101110110101111110

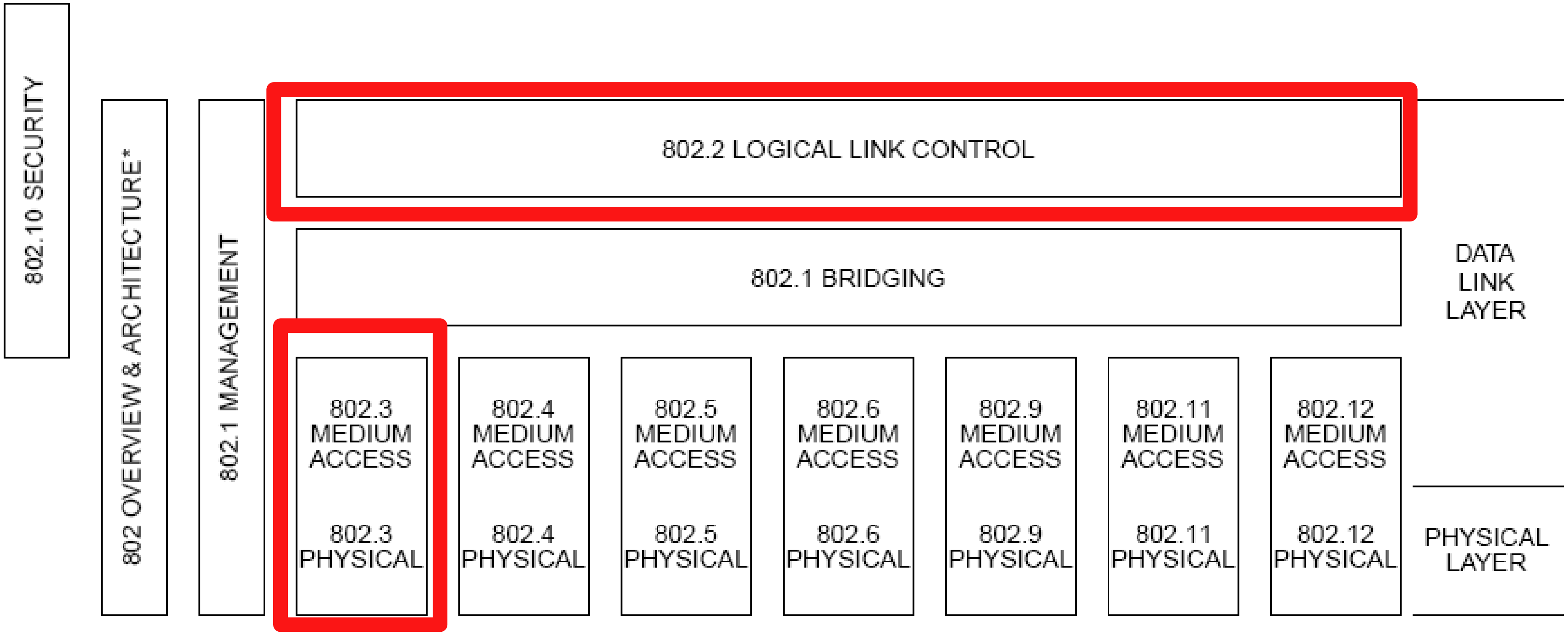
01111110011111000110000101011110101111110

0111111001111010110001101110110101111110



If Eve knows the protocol,
she can interpret the interformation

# IEEE 802



802.10 SECURITY

802 OVERVIEW & ARCHITECTURE*

802.1 MANAGEMENT

802.2 LOGICAL LINK CONTROL

802.1 BRIDGING

DATA LINK LAYER

802.3 MEDIUM ACCESS | 802.4 MEDIUM ACCESS | 802.5 MEDIUM ACCESS | 802.6 MEDIUM ACCESS | 802.9 MEDIUM ACCESS | 802.11 MEDIUM ACCESS | 802.12 MEDIUM ACCESS

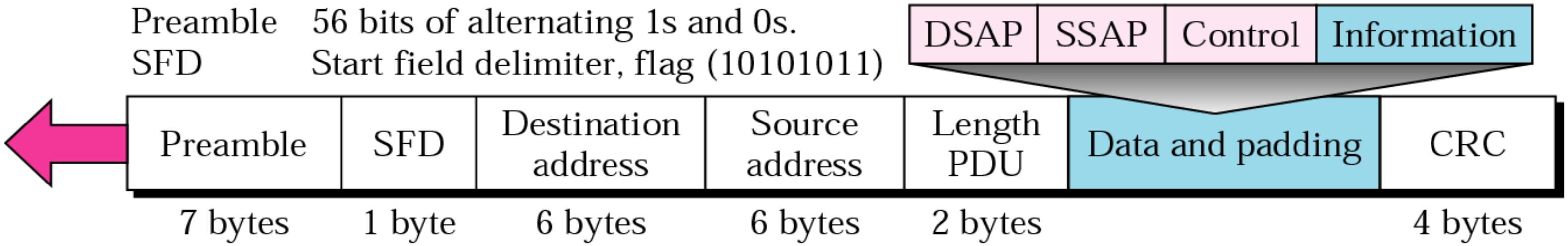
802.3 PHYSICAL | 802.4 PHYSICAL | 802.5 PHYSICAL | 802.6 PHYSICAL | 802.9 PHYSICAL | 802.11 PHYSICAL | 802.12 PHYSICAL

PHYSICAL LAYER

- 802.3: Ethernet
- 802.11: Wifi
- 802.16: WiMAX
- 802.20: Mobile Broadband Wireless Access (MBWA)
- 802.15.1: Bluetooth
- 802.15.4: ZigBee

* Figure is courtesy of ANSI/IEEE Std 802.11

# 802.3 MAC Frame



- 64-bit frame preamble (10101010) used to synchronize reception
  - 7 bit preamble (10101010) + 1 start flag (10101011)

- Maximum frame length: 1518 bytes

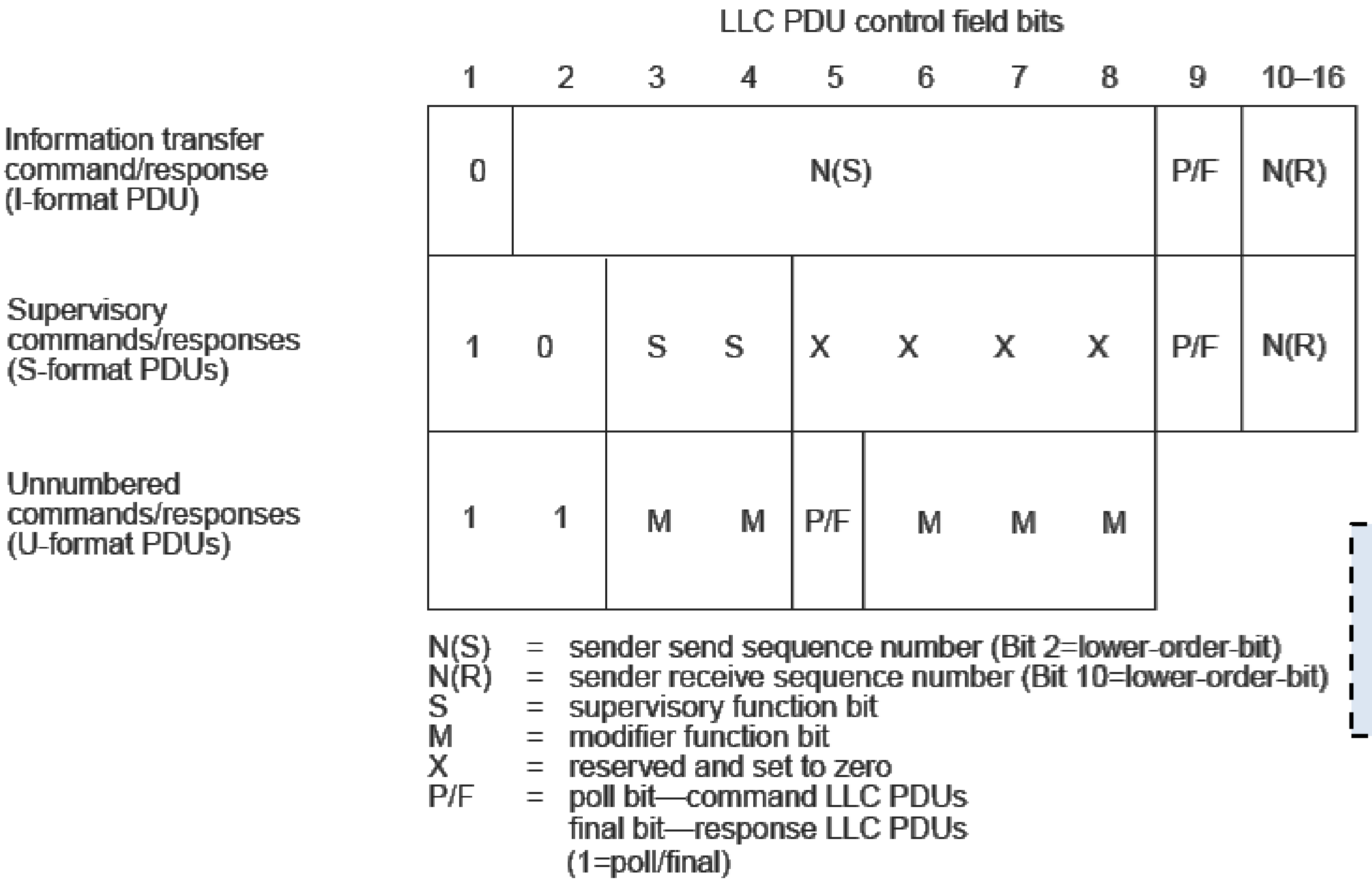
  ⇨ max 1500 bytes payload

- Minimum frame length: 64 bytes

  ⇨ min 46 bytes payload

* Figure is courtesy of B. Forouzan

# 802.2 LLC Control Fields



LLC PDU control field bits

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10–16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Information transfer command/response (I-format PDU) | 0 | N(S) | | | | | | | P/F | N(R) |
| Supervisory commands/responses (S-format PDUs) | 1 | 0 | S | S | X | X | X | X | P/F | N(R) |
| Unnumbered commands/responses (U-format PDUs) | 1 | 1 | M | M | P/F | M | M | M | | |

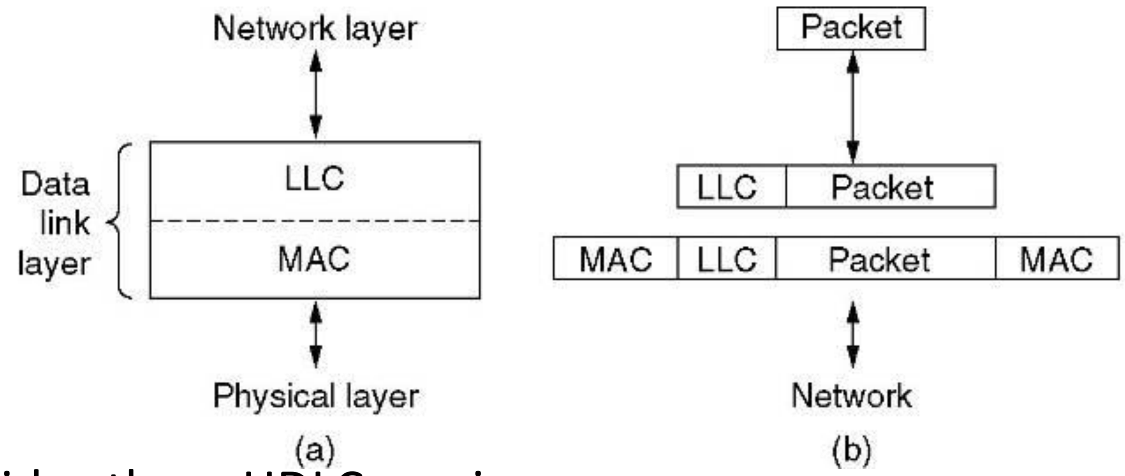
| | | |
|---|---|---|
| N(S) | = | sender send sequence number (Bit 2=lower-order-bit) |
| N(R) | = | sender receive sequence number (Bit 10=lower-order-bit) |
| S | = | supervisory function bit |
| M | = | modifier function bit |
| X | = | reserved and set to zero |
| P/F | = | poll bit—command LLC PDUs<br>final bit—response LLC PDUs<br>(1=poll/final) |

**Figure 9—LLC PDU control field formats**

$m = 7$
$2^m = 128$
max w-size= 64 frames

ANSI/IEEE Std 802.2, 1998 Edition

# IEEE 802.2: Logical Link Control (LLC)



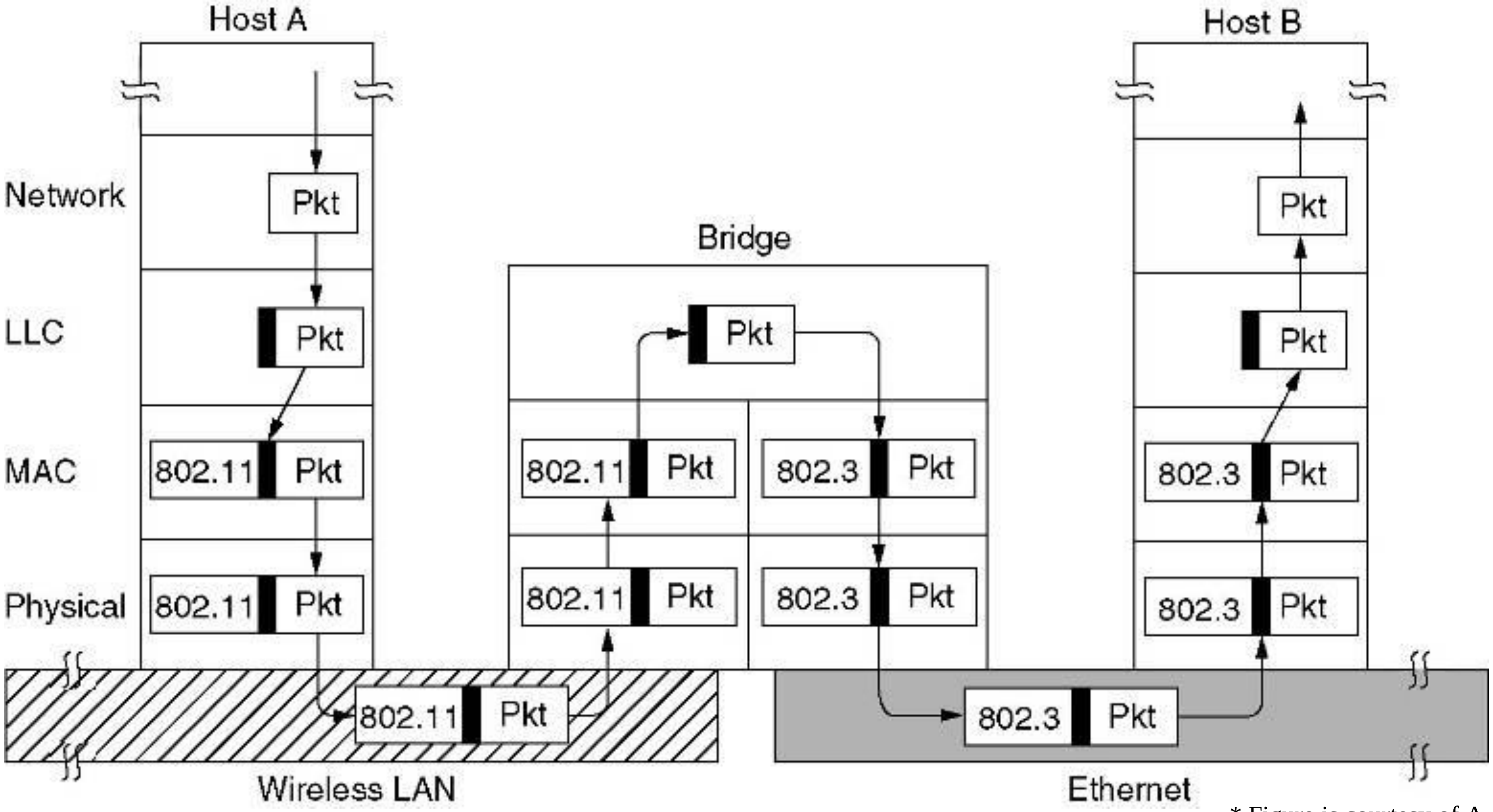
- LLC provides three HDLC services:
  - 1. Unacknowledged connectionless service, recall HDLC has unnumbered frames;
  - 2. Reliable connection-oriented service in the form of  HDLC ABM mode;
  - 3. Acknowledged connectionless service, need to add two unnumbered frames to HDLC frame set.

- LLC can provide reliable packet transfer service

* Figure is courtesy of A. Tanenbaum

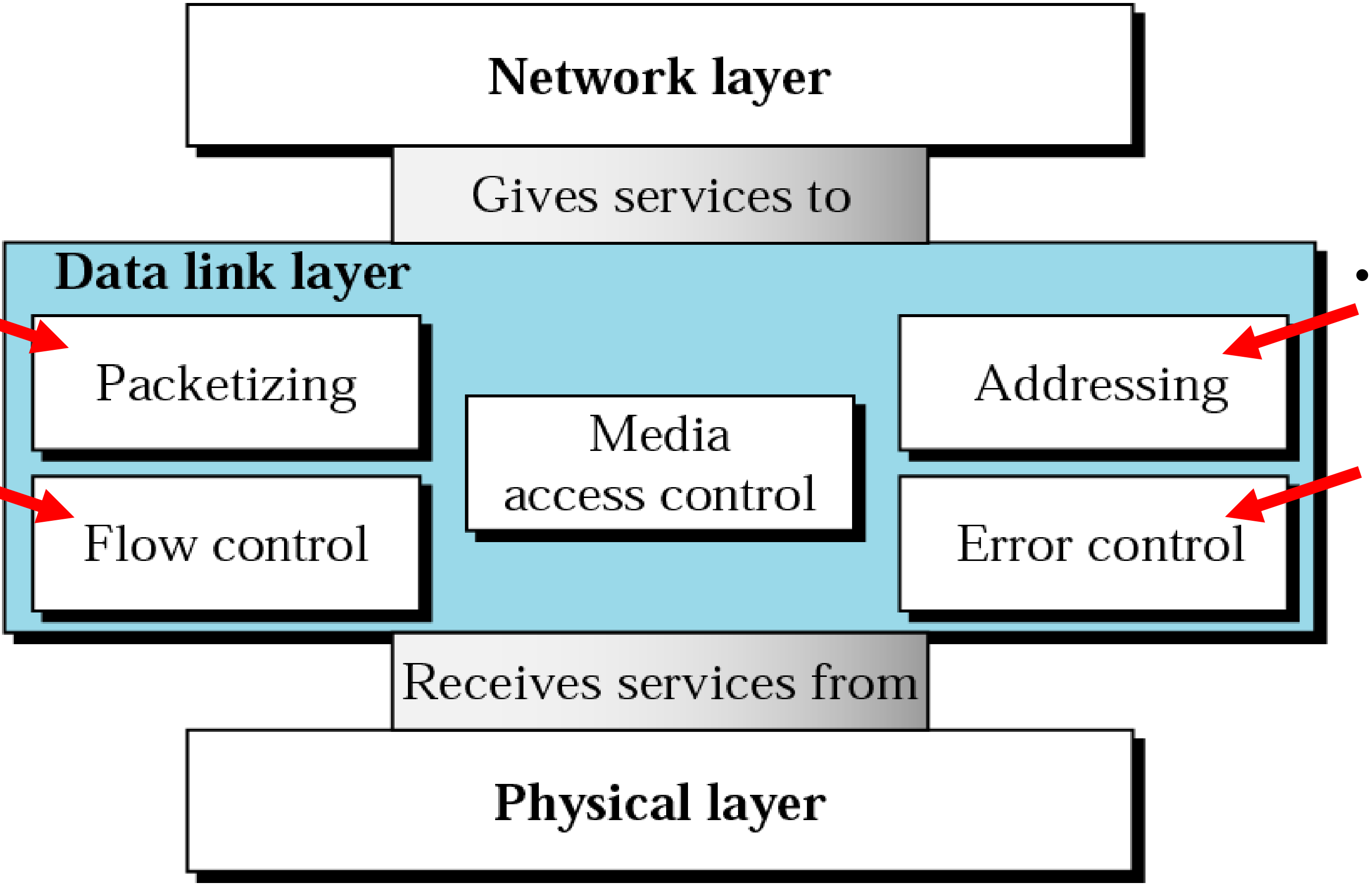
# Bridges from 802.x to 802.y

Operation of a LAN bridge from 802.11 to 802.3.



* Figure is courtesy of A. Tanenbaum

# Link Layer



- Flag Bytes
- Frame Format

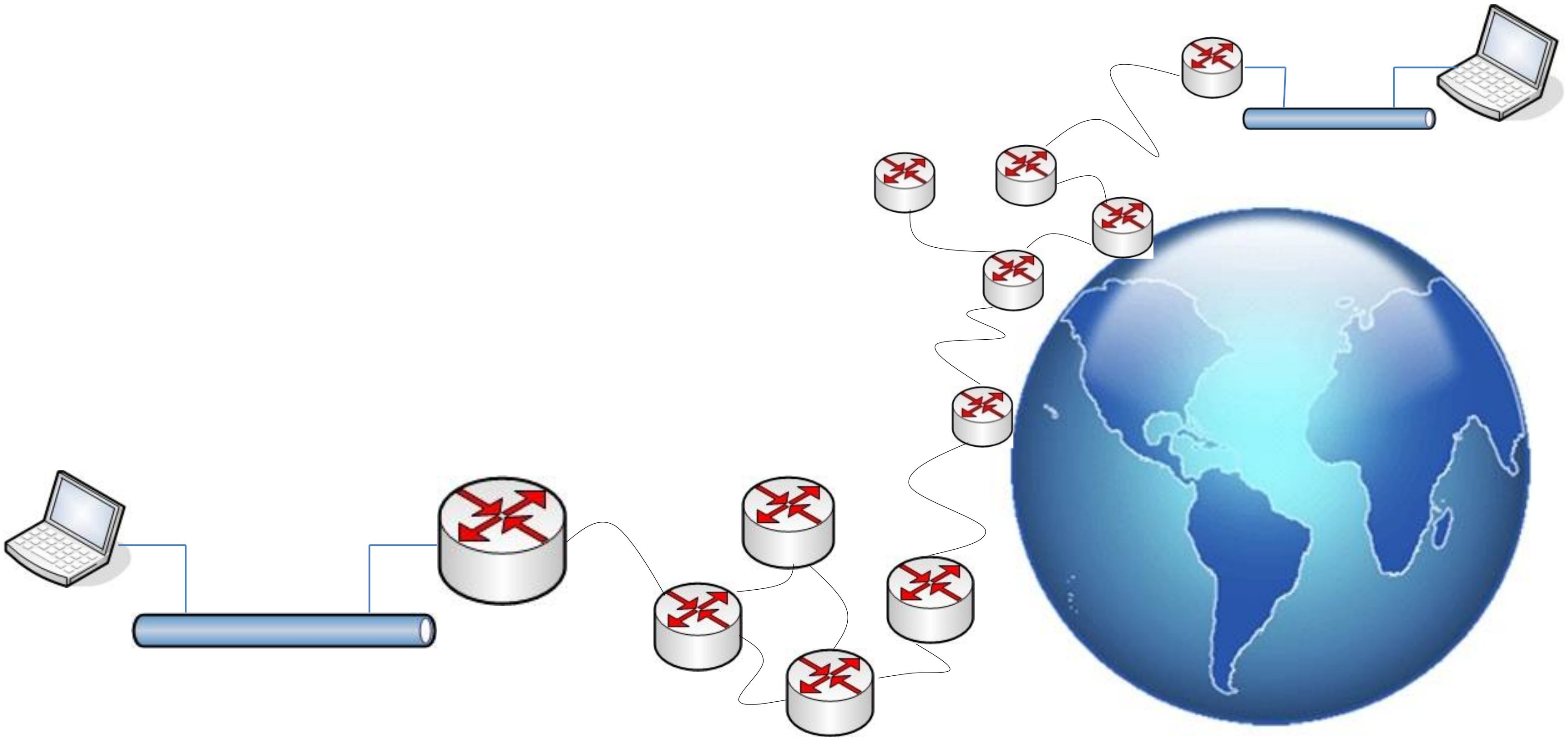
- Options for Stop&Wait, Selective Repeat, etc

- Destination Address

- CRC

* Figure is courtesy of B. Forouzan

# Every Connection involves the Link Layer



That's all folks
Telecomms II