King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 341 – Data and Computer Communications

Term 082

Dr. Ashraf S. Hasan Mahmoud

Rm 22-148-3

Ext. 1724

Email: ashraf@kfupm.edu.sa

Lecture Contents

1. Flow Control
   a. Stop-and-Wait flow control
   b. Sliding-Window flow control
2. Error Control
   a. Stop-and-Wait ARQ
   b. Go-Back-N ARQ
   c. Selective-Reject ARQ
3. High-Level Data Link (HDLC)
4. Other Data Link Control Protocols

What is Data Link Control

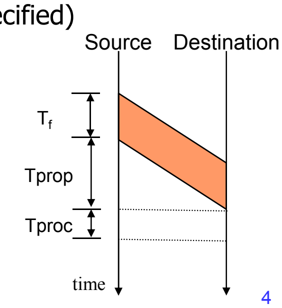
- The logic or procedures used to convert the raw stream of bits provided by the physical layer into a "*reliable*" connection
- Requirements and Objectives:
  - Frame synchronization
  - Flow control
  - Error control
  - Addressing
  - Multiplexing data and control on connection
  - Link management

Flow Control

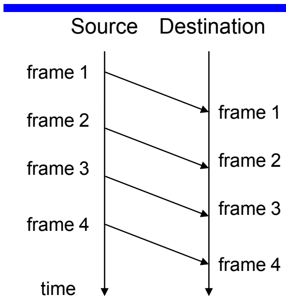
- A scheme to ensure that transmitter does not overwhelm receiver with data
- Transmission of one frame:
  - T_f: time to transmit frame
  - Tprop: time for signal to propagate
  - Tproc: time for destination to process received frame – small delay (usually ignored if not specified)
- Tproc may be ignored if not specified

$$T_f = \frac{\text{Frame Size (bits)}}{\text{Transmission Speed (bits/sec)}}$$

$$T_{prop} = \frac{\text{Distance (meters)}}{\text{Propagation Speed (meters/sec)}}$$

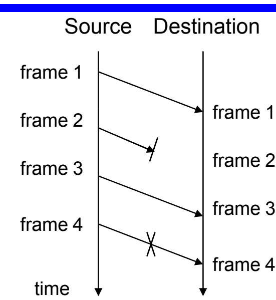


Flow Control (2)



Error-free transmission

Models of Frame Transmission



Transmission with losses (frame 2) and error (frame 4)

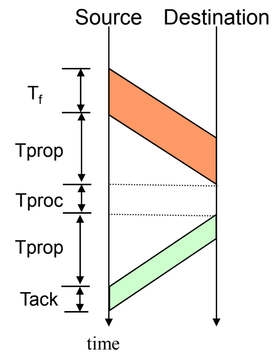
- The destination has a limited buffer space. How will the source know that destination is ready to receive the next frame?
- In case of errors or lost frame, the source need to retransmit frames – i.e. a copy of transmitted frames must be kept. How will the source know when to discard copies of old frames?
- Etc.

Stop-and-Wait Protocol

- Protocol:
  - Source transmits a frame
  - After the destination receives frame, it sends ACK
  - Source, upon the receipt of ACK, can now send the next frame
- Destination can stop source by withholding the ACK
- Simple
- Animation for Stop-and-Wait
- NOTE: ONLY one frame can be in transit at any time

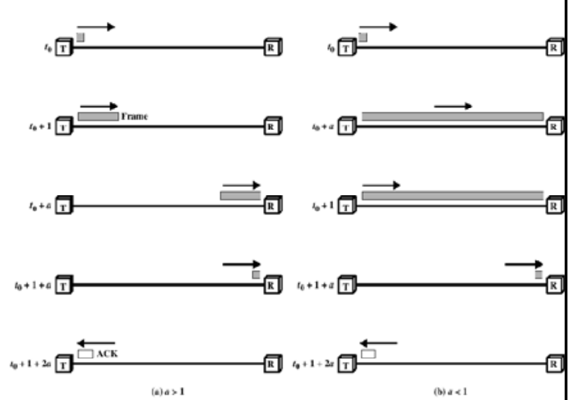
Stop-and-Wait Protocol: Efficiency

- After every frame, source must wait till acknowledgment ➔ Hence link propagation time is significant
- Total time to for one frame:
  T_total = Tf + 2Tprop + Tproc + Tack
  if we ignore Tproc and Tack (usually very small)
  T_total = Tf + 2Tprop
- Link utilization, U is equal to
  U = Tf/ (T_total), or
  = 1 / (1+2(Tprop/Tf)) = 1 / (1 + 2 a)
  where a = Tprop/Tf = length of link in bits
- If a < 1 (i.e. Tf > Tprop – when 1st transmitted bit reaches destination, source will still be transmitting ➔ U is close 100%
- If a > 1 (i.e. Tf < Tprop – frame transmission is completed before 1st bit reaches destination ➔U is low
- See figure 7.2



Stop-and-Wait Protocol: Efficiency (2)

- Remember: a = Tprop/Tf = length of link in bits
- If a < 1 (i.e. Tf > Tprop – when 1st transmitted bit reaches destination, source will still be transmitting ➔ U is close 100%
- If a > 1 (i.e. Tf < Tprop – frame transmission is completed before 1st bit reaches destination ➔U is low
- Stop-and-Wait is efficient for links where a << 1 (long frames compared to propagation time)



Sliding Window Protocol

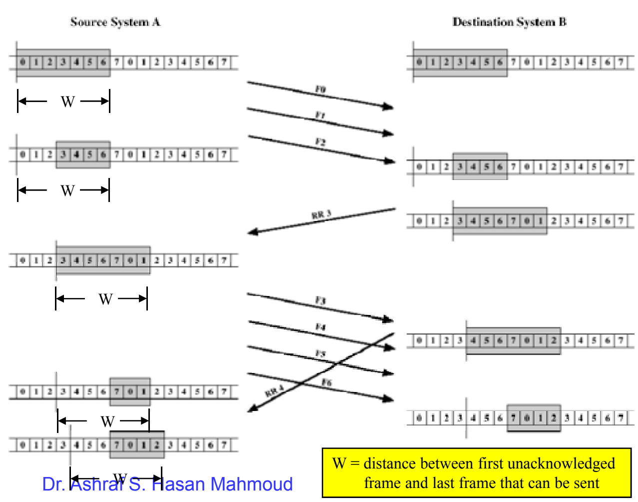
- Stop-and-Wait can be very inefficient when a > 1
- Protocol:
  - Assumes full duplex line
  - Source A and Destination B have buffers each of size W frames
  - For k-bit sequence numbers:
    - Frames are numbered: 0, 1, 2, …, 2^k-1, 0, 1, … (modulo 2^k)
    - ACKs (RRs) are numbered: 0, 1, 2, …, 2^k-1, 0, 1, … (modulo 2^k)
  - A is allowed to transmit up to W frames without waiting for an ACK
  - B can receive up to W consecutive frames
  - ACK J (or RR J), where 0<=J<= 2^k-1, sent by B means B is have received frames up to frame J-1 and is ready to receive frame J
  - B can also send RNR J: B have received all frames up to J-1 and is not ready to receive any more
- Window size, W can be less or equal to 2^k-1

Sliding Window Protocol (2)

- Example of Sliding-Window-Protocol: k = 3 bits, W = 7

Observations:

- A may tx W = 7 frames (F0, F1, …, F6)
- After F0, F1, & F2 are tx-ed, window is shrunk (i.e. can not transmit except F3, F4, …, F6)
- When B sends RR3, A knows F0, F1 & F2 have been received and B is ready to receive F3
- Window is advanced to cover 7 frames (starting with F3 up to F1)
- A sends F3, F4, F5, & F6
- B responds with RR4 when F3 is received – A advances the window by one position to include F2



Sliding Window Protocol - Piggybacking

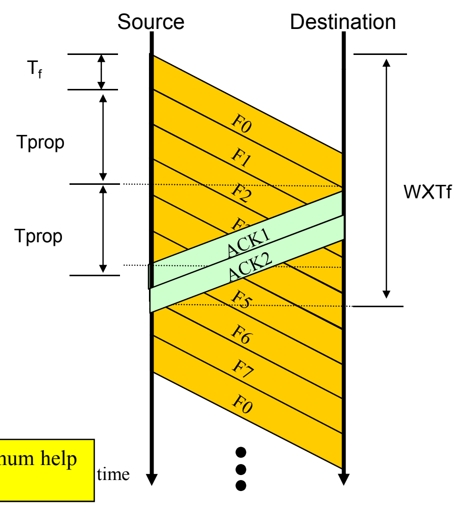
- When using sliding window protocol in full duplex connections:
  - Node A maintains its own transmit window
  - Node B maintains its own transmit window
  - A frame contains: data field + ACK field
  - There is a sequence number for the data field, and a sequence number for the ACK field

Sliding Window Protocol - Efficiency

- Again we can distinguish two cases:
- Case 1: $W \geq 2a + 1$
- Case 2: $W < 2a + 1$

Sliding Window Protocol - Efficiency - Case 1

- Assume k=3, W = 7
  (ignoring Tack)
- Source can continuously keep transmitting!!
  - Because the ACK can arrive to source before the window is completed
- Utilization = 100%

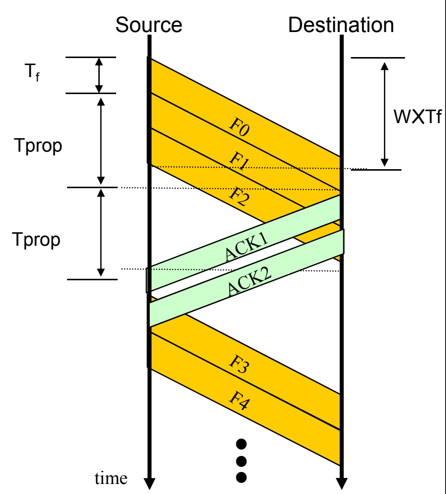


Sending ACK0 as soon as F0 is received is the maximum help the destination can do to increase utilization

Sliding Window Protocol - Efficiency - Case 2

- Assume k = 3, W = 3 (ignoring Tack)
- Source can NOT continuously keep transmitting!!
  - Because the ACK can NOT arrive to source before the window is completed
- Utilization = $\frac{W \times Tf}{Tf + 2 \times Tprop}$

$$= \frac{W}{1 + 2a}$$



Sliding Window Protocol - Efficiency

- Refer to Appendix A
- When window size is W (for error free), link utilization, U, is given by

$$U = \begin{cases} 1 & W \geq (2a+1) \\ \dfrac{W}{2a+1} & W < (2a+1) \end{cases}$$

where a = Tprop/Tf or length of link in bits

- Sliding window protocol can achieve 100% utilization if W >= (2a + 1)

Sliding Window Protocol

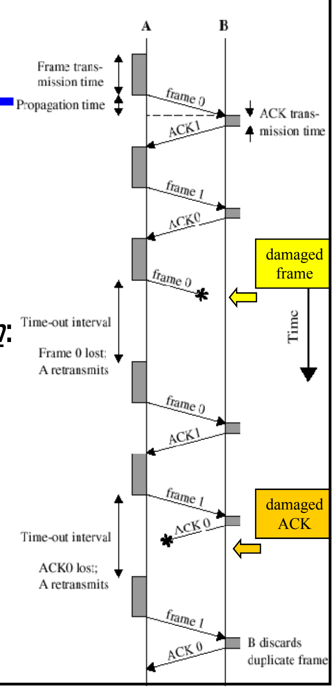
- Animation for Sliding Window protocol
- Sliding Window Protocol Simulation (http://www.cs.stir.ac.uk/~kjt/software/comms/jasper/SWP3.html)

Error Control

- Types of Errors:
  - Lost frame
  - Damaged frame
- Error control Techniques (Automatic Repeat Request - ARQ):
  - Error detection – discussed previously
  - +ve ACK
  - Retransmission after timeout
  - -ve ACK and retransmission
- ARQ Procedures: convert an unreliable data link into a reliable one.
  - Stop-and-wait
  - Go-back-N
  - Selective-reject

Stop-and-Wait ARQ

- Based on the stop-and-wait control flow procedure - Stop-and-Wait Protocol slide
- Two types of errors:
  1. Frame lost or damaged – *Solution*: timeout timer
  2. Damaged or lost ACK – The timeout timer solves this problem



Go-Back-N ARQ

- Based on the sliding-window flow control procedure - Sliding Window Protocol slide
- Three types of errors:
  1. i^{th} frame damaged:
     a. If A send subsequent frames (i+1, i+2, …), B responds with REJ i ➔ A must retransmit i^{th} frame and ***all subsequent frames***
     b. If A does not send subsequent frames and B does not respond with RR or REJ (since frame was damaged) ➔ timeout timer at A expires – send a POLL signal to B; B sends an RR i, i.e. it expect the i^{th} frame – A sends the i^{th} frame again

     Check for status of B before resending the frame
  2. Damaged RR (B receives i^{th} frame and sends RR i+1 which is lost or damaged):
     a. Since ACKs are cumulative – A may receive a subsequent RR j (j >i+1) before A times out
     b. If A times out, it sends a POLL signal to B – if B fails to respond (i.e. down) or its response is damaged subsequent POLLs are sent; procedure repeated certain number of time before link reset
  3. Damaged REJ – same as 1.b

Selective-Reject ARQ

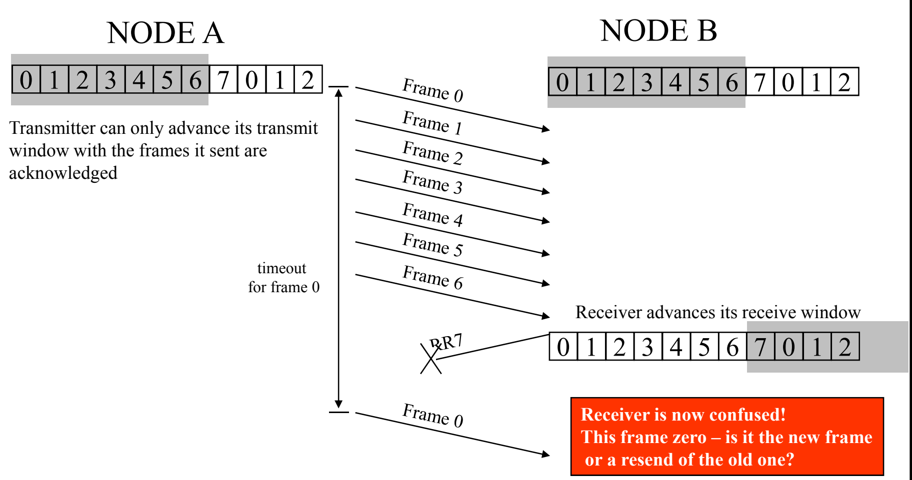
- In contrast to Go-Back-N, the only frames retransmitted are those that receive –ve ACK (called SREJ) or those that time out
- More efficient:
  - Rx-er must have large enough buffer to save *post*-SREJ frames
  - Buffer manipulation – re-insertion of out-of-order frames

Window Size for Selective-Reject ARQ – Why?

- Window size: should less or equal to half range of sequence numbers
  - For n-bit sequence numbers, Window size is $\leq 2^{n-1}$ (remember sequence numbers range from 0,1, …, 2^n-1)
- Why? See next example

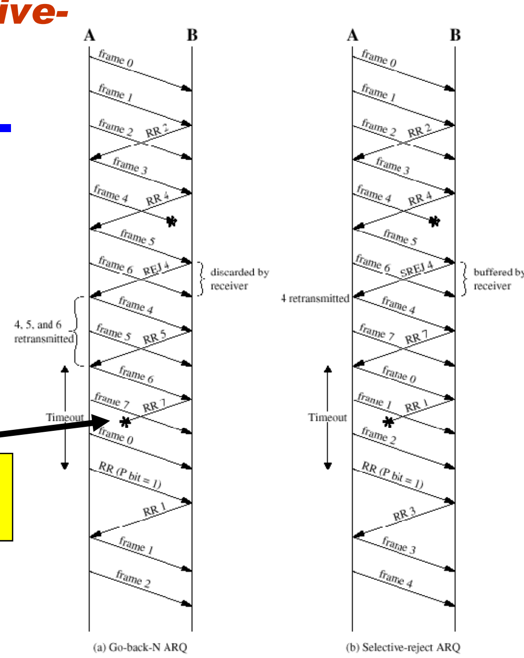
Window Size for Selective-Reject ARQ – Why? (2)

- Example: Consider 3-bit sequence number and window size of 7



Go-Back-N/Selective-Reject ARQ Examples

- With Go-back-N frames 4,5 and 6 are retransmitted
- With Selective-Reject only frame 4 is retransmitted



Did this lost RR7 affect flow?
How did the link recover?

Example: Problem 7-9

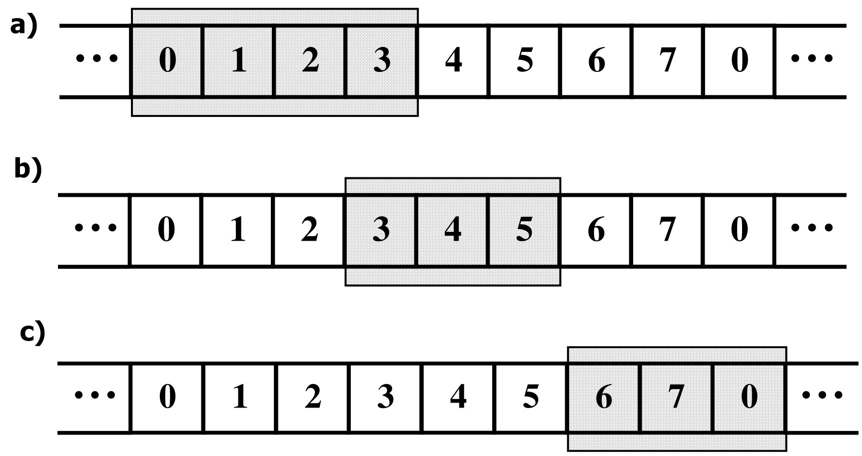
7-9: Two neighboring nodes A and B use a sliding-window protocol with a 3-bit sequence numbers. As the ARQ mechanism, go-back-N is used with a window size of 4. Assuming A is transmitting and B is receiving, show the window positions for the following succession of events:

a) **Before A sends any frames**

b) **After A sends frame 0, 1, 2 and B acknowledges 0, 1 and the ACKs are received by A**

c) **After A sends frames 3, 4, and 5 and B acknowledges 4 and the ACK is received by A**

Example: Problem 7-9 - Solution



High-Level Data Link Control Protocol (HDLC)

- One of the most important data link control protocols
- Basic Characteristics:
  - Primary Station: issues *commands*
  - Secondary Station: issues *responses* – operates under the control of a primary station
  - Combined Station: issues commands and responses
- Two link configurations are defined:
  - Unbalanced: one primary plus one or more secondary
  - Balanced: two combined (functions as primary and/or secondary) stations

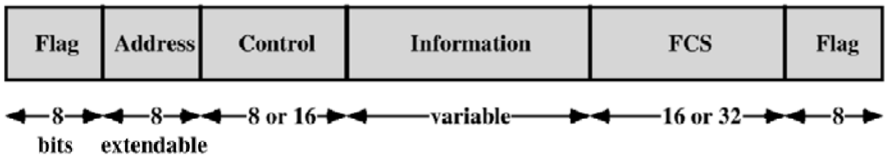
High-Level Data Link Control Protocol (HDLC) (2)

- Three transfer modes are defined:
  - Normal Response Mode (NRM) – used in unbalanced conf.; secondary may only tx data in response to a command from primary
  - Asynchronous Balanced Mode (ABM) – used in balanced conf.; either combined station may tx data without receiving permission from other station
  - Asynchronous Response Mode (ARM) – used in unbalanced conf.; Secondary may initiate data tx without explicit permission; primary still retains line control (initialization, error recovery, …)
- Animation for HDLC

HDLC - Applications

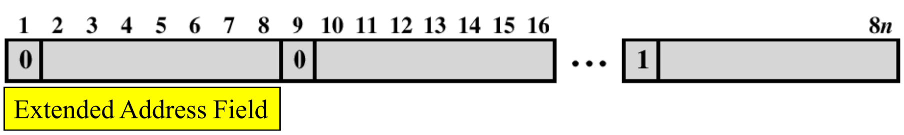
- NRM:
  - Point-multi-point (multi-drop line): one computer (primary) polls multiple terminals (secondary stations)
  - Point-to-point: computer and a peripheral
- ABM: most widely used (no polling involved)
  - Full duplex point-to-point
- ARM: rarely used

HDLC – Frame Structure – Flag Field



- Flag Field: unique pattern 01111110
  - Used for synchronization
  - To prevent this pattern form occurring in data ➔ *bit stuffing*
    - Tx-er inserts a 0 after each 5 1s
    - Rx-er, after detecting flag, monitors incoming bits – when a pattern of 5 1s appears; the $6^{th}/7^{th}$ bit are checked:
      - If 0, it is deleted
      - If 10, this is a flag
      - If 11, this is an ABORT
- Pitfalls of bit stuffing: one bit errors can split one frame into two or merge two frames into one

HDLC – Frame Structure - Address Field



- Address field identifies the secondary station that transmitted or is to receive frame
- Not used (but included for uniformity) for point-to-point links
- Extendable – by prior arrangement
- Address = 11111111 (single octet) used for broadcasting; i.e. received by all secondary stations

HDLC – Frame Structure - Control Field

	1	2	3	4	5	6	7	8
I: Information	0	N(S)	N(S) (cont.)	N(S) (cont.)	P/F	N(R)	N(R) (cont.)	N(R) (cont.)
S: Supervisory	1	0	S	S (cont.)	P/F	N(R)	N(R) (cont.)	N(R) (cont.)
U: Unnumbered	1	1	M	M (cont.)	P/F	M	M (cont.)	M (cont.)

N(S) = Send sequence number
N(R) = Receive sequence number
S = Supervisory function bits
M = Unnumbered function bits
P/F = Poll/final bit

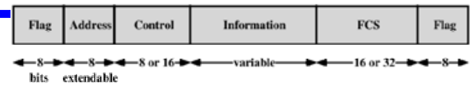
- First 2 bits of field determine the type of frame
  - Information frame (I): carry user data (upper layers) – flow and error control info is piggybacked on these frames as well
  - Supervisory frame (S): carry flow and error control info when there is no user data to tx
  - Unnumbered frame (U): provide supplementary link control
- Poll/Final (P/F) bit:
  - In command frames (P): used to solicit response from peer entity
  - In response frames (F): indicate response is the result of soliciting command

HDLC – Frame Structure - Control Field (2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Information	0	N(S)	N(S) (cont.)	N(S) (cont.)	N(S) (cont.)	N(S) (cont.)	N(S) (cont.)	N(S) (cont.)	P/F	N(R)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)
Supervisory	1	0	S	S (cont.)	0	0	0	0	P/F	N(R)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)	N(R) (cont.)

- "Set-mode" command ➔ extends control field to 16 bit for S and I frames
- Extension: 7-bit sequence numbers rather than 3-bit ones
- Unnumbered frames always use 3-bit sequence numbers

HDLC – Frame Structure – Information/FCS Fields



- Information field:
  - Present ONLY in I-frames and some U-frames
  - Contains integer number of octets
  - Length is variable – up to some system defined maximum
- FCS field:
  - Error detecting code
  - Calculated from *ALL* remaining bits in frame
  - Normally 16 bits (CRC-CCITT polynomial = $X^{16}+X^{12}+X^5+1$)
  - 32-bit optional FCS

HDLC Operation

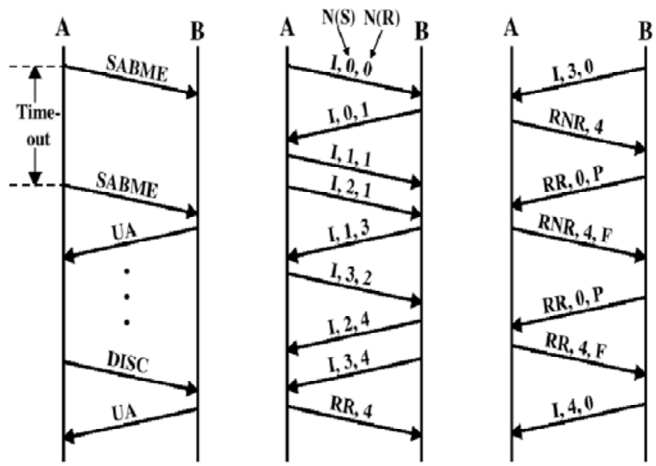
- Initialization
  - One side signals to the other the need for initialization
  - Specifies which of the three modes to use: NRM, ABM, or ARM
  - Specifies 3- or 7-bit sequence numbers
  - The other side can accept by sending unnumbered acknowledgment (UA)
  - The other side can reject by sending - A disconnected mode (DM) frame is sent
- Data Transfer
  - Exchange of I-frames: data and can perform flow/error control
  - S-frames can be used as well: RR, RNR, REJ, or SREJ
- Disconnect
  - DISC frame → UA

HDLC – Operation

a) Link Setup & Disconnect:
- SABM command – starts timer
- B responds with UA (or DM if not interested)
- A receives UA and initializes its variables
- To disconnect: issue DISC command

b) Two-Way Data Exchange:
- Full-duplex exchange of I-frames

c) Busy Condition:
- Note the use of the P and F bits

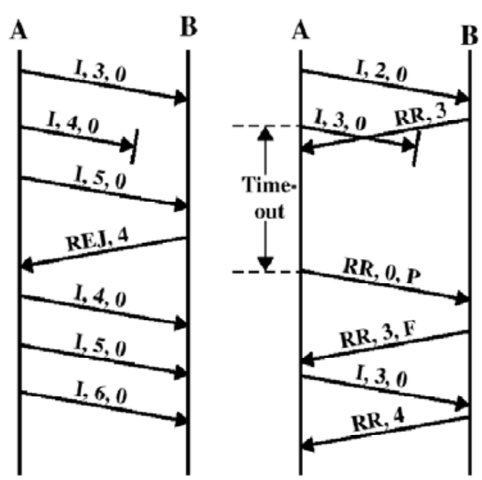


(a) Link setup and disconnect (b) Two-way data exchange (c) Busy condition

HDLC – Operation (2)

a) Reject Recovery:
- I-frame 4 was lost
- B receives I-frame 5 (out of order) – responds with REJ 4
- A resend I-frame 4 and all subsequent frames (Go-back-N)

b) Timeout Recovery:
- A sends I-frame 3 – but it is lost
- Timer expires before acknowledgement arrives
- A polls Node B
- B responds indicating it is still waiting for frame 3 – B set the F bit because this a response to A's solicitation



(d) Reject recovery (e) Timeout recovery

Other Data Link Control Protocols

- Link Access Procedure – Balanced (LAPB):
  - Part of X.25 packet-switching interface standard
  - Subset of HDLC – only ABM is provided
  - Designed for point-to-point
  - Frame format is same as HDLC
- Link Access Procedure – D-Channel (LAPD):
  - Part of ISDN – functions on the D-channel
  - 7-bit sequence numbers only
  - FCS field is always 16-bit
  - 16-bit address fields (two sub-addresses)

Other Data Link Control Protocols (2)

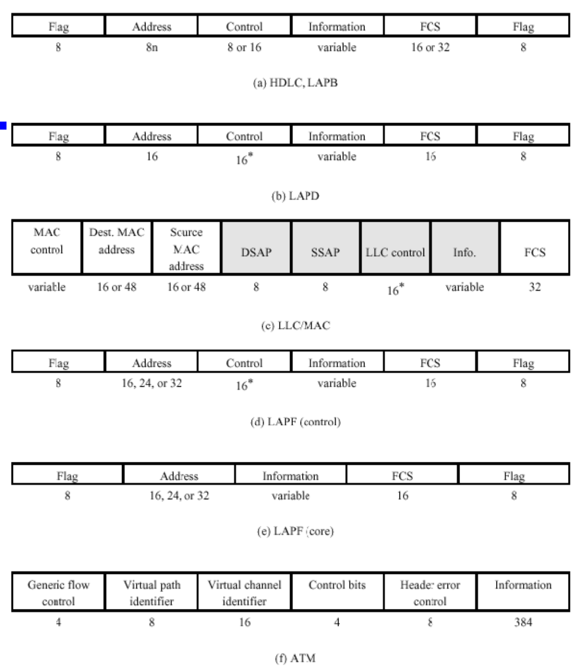
- Logical Link Control (LLC):
  - Part of IEEE802 family for LANs
  - Different frame format than HDLC
- Link Access Control Protocol for Frame-Mode Bearer Service (LAPF):
  - Designed for Frame Relay Protocol
  - Provides only ABM mode
  - Only 7-bit sequence numbers
  - Only 16-bit CRC field
  - Address field is 16, 24, or 32 bits long – containing a 10-bit, 16-bit, or 23-bit data link connection identifier (DLCI)
  - No control field – I.e. CANNOT do flow or error control (remember that frame relay was designed for fast and reliable connections!)

Other Data Link Control Protocols (3)

- Asynchronous Transfer Mode (ATM):
  - Like frame relay designed for fast and reliable links
  - NOT based on HDLC
  - New frame format – called CELL (53 bytes: 48 Bytes for payload or user data and 5 Bytes for overhead)
  - Cell has minimal overhead
  - NO error control for payload

Other Data Link Control Protocols (4)

- Frame Formats



Textbook Problems of INTEREST

- **Textbook:**