

King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 341 – Data and Computer
Communications

Term 032

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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

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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

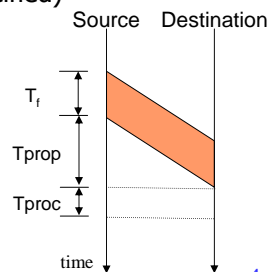
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Flow Control

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

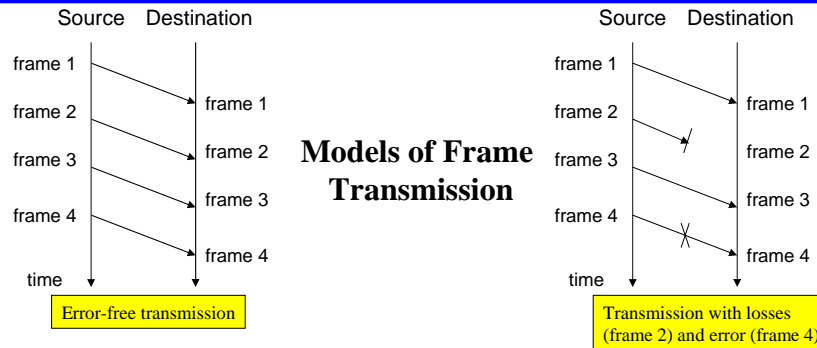


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Flow Control (2)



- 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.

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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

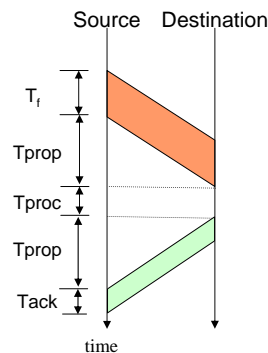
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Stop-and-Wait Protocol: Efficiency

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



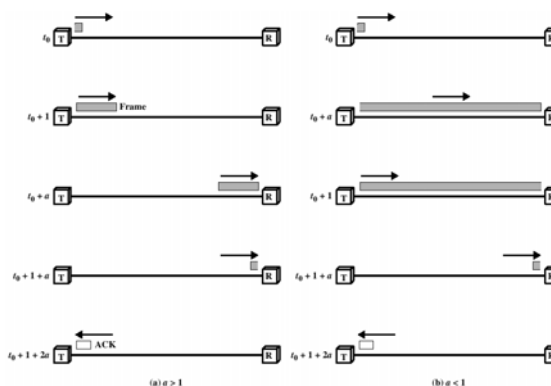
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Stop-and-Wait Protocol: Efficiency (2)

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



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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: $0, 1, 2, \dots, 2^k-1, 0, 1, \dots$ (modulo 2^k)
 - ACKs (RRs) are numbered: $0, 1, 2, \dots, 2^k-1, 0, 1, \dots$ (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 $0 \leq J < 2^k$, sent by B means B has received frames up to frame $J-1$ and is ready to receive frame J
 - B can also send RNR J : B has 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

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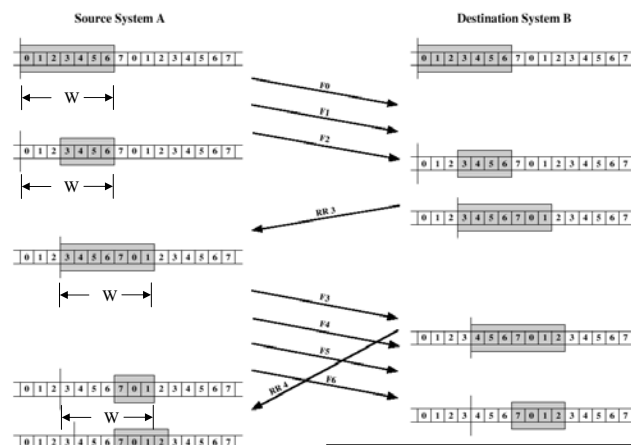
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Sliding Window Protocol (2)

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

Observations:

- A may tx $W = 7$ frames (F_0, F_1, \dots, F_6)
- After $F_0, F_1, \& F_2$ are tx-ed, window is shrunk (i.e. can not transmit except F_3, F_4, \dots, F_6)
- When B sends RR3, A knows $F_0, F_1 \& F_2$ have been received and B is ready to receive F_3
- Window is advanced to cover 7 frames (starting with F_3 up to F_9)
- A sends $F_3, F_4, F_5, \& F_6$
- B responds with RR4 when F_3 is received – A advances the window by one position to include F_4



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W = distance between first unacknowledged frame and last frame that can be sent

Sliding Window Protocol - Piggybacking

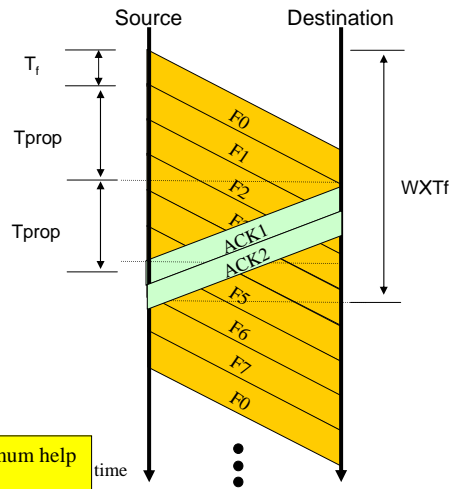
- When using sliding window protocol in full duplex connections:
 - Node A maintains its own transmit window
 - Node B maintains its own transmit window
 - A frame contains: data field + ACK field
 - There is a sequence number for the data field, and a sequence number for the ACK field

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 F_0 is received is the maximum help the destination can do to increase utilization

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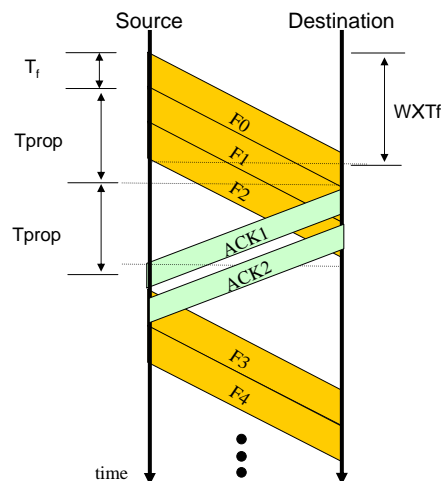
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Sliding Window Protocol - Efficiency - Case 2

- 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

$$\text{Utilization} = \frac{W \times T_f}{T_f + 2 \times T_{prop}}$$

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



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Sliding Window Protocol - Efficiency

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

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

where $a = T_{prop}/T_f$ or length of link in bits

- Sliding window protocol can achieve 100% utilization if $W \geq (2a + 1)$

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Sliding Window Protocol

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

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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

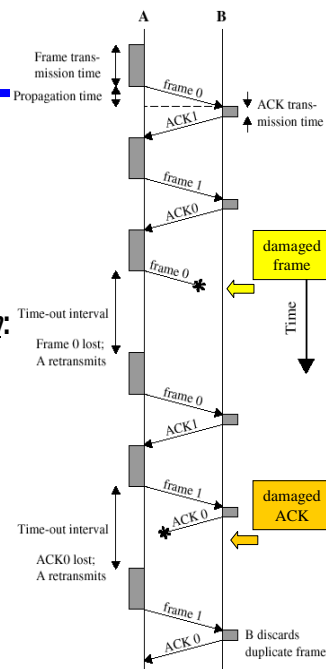
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Stop-and-Wait ARQ

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



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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 ($i+1, i+2, \dots$), B responds with REJ $i \rightarrow$ 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) \rightarrow 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
 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

Check for status of B before resending the frame

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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

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Window Size for Selective-Reject ARQ – Why?

- Window size: should be 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

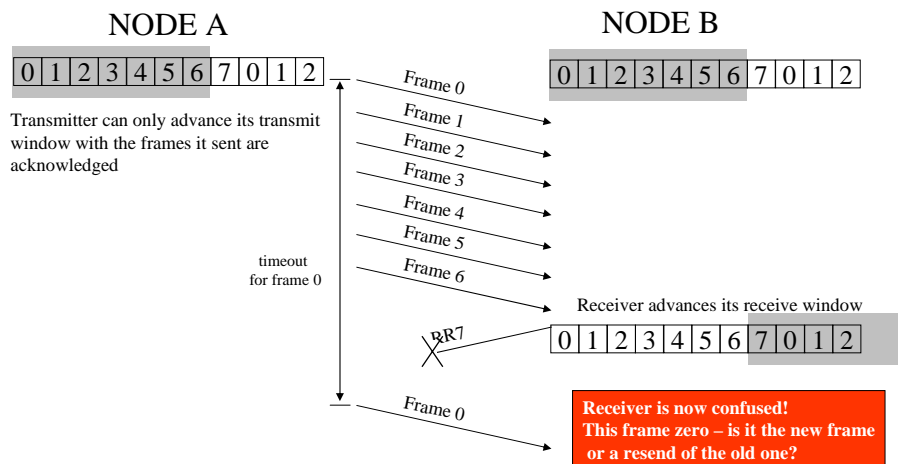
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Window Size for Selective-Reject ARQ – Why? (2)

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



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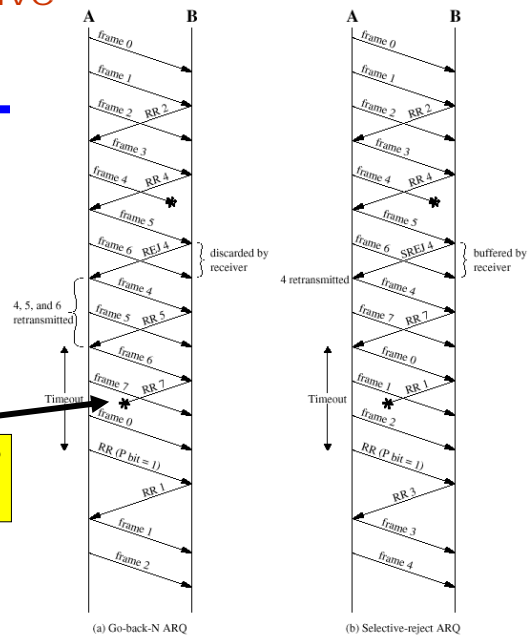
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Go-Back-N/Selective- Reject ARQ Examples

- 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?



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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:

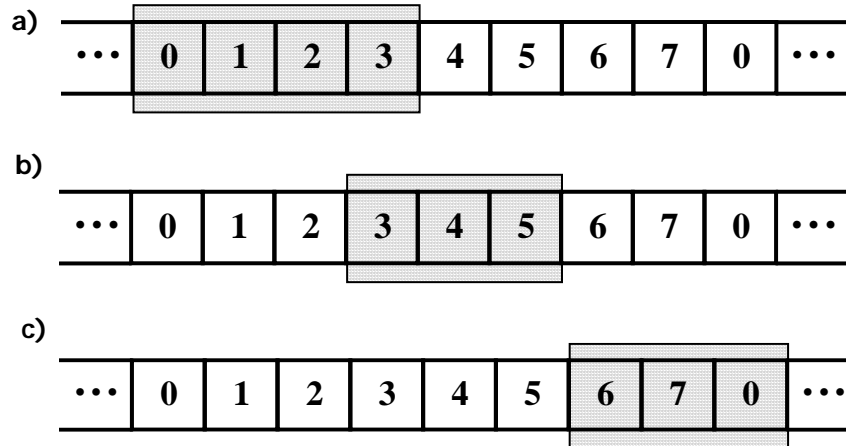
- Before A sends any frames
- After A sends frame 0, 1, 2 and B acknowledges 0, 1 and the ACKs are received by A
- After A sends frames 3, 4, and 5 and B acknowledges 4 and the ACK is received by A

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Example: Problem 7-9 - Solution



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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

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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](#)

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HDLC - Applications

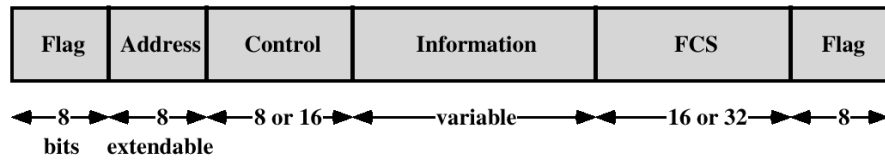
- NRM:
 - Point-multi-point (multi-drop line): one computer (primary) polls multiple terminals (secondary stations)
 - Point-to-point: computer and a peripheral
- ABM: most widely used (no polling involved)
 - Full duplex point-to-point
- ARM: rarely used

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HDLC – Frame Structure – Flag Field



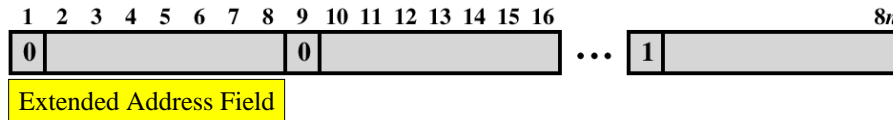
- Flag Field: unique pattern 01111110
 - Used for synchronization
 - To prevent this pattern from occurring in data → *bit stuffing*
 - Tx-er inserts a 0 after each 5 1s
 - Rx-er, after detecting flag, monitors incoming bits – when a pattern of 5 1s appears; the 6th/7th bit are checked:
 - If 0, it is 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

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HDLC – Frame Structure - Address Field



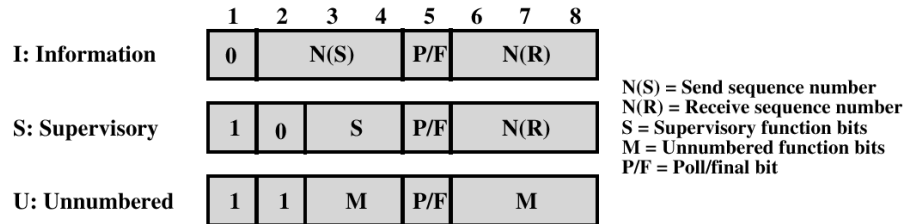
- Address field identifies the secondary station that transmitted or is to receive frame
- Not used (but included for uniformity) for point-to-point links
- Extendable – by prior arrangement
- Address = 11111111 (single octet) used for broadcasting; i.e. received by all secondary stations

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HDLC – Frame Structure - Control Field



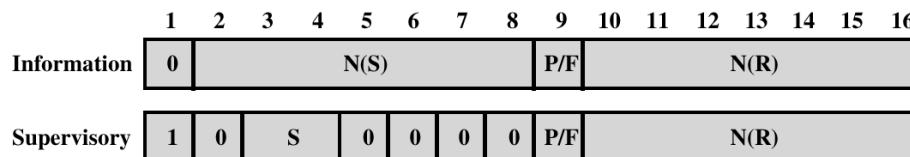
- First 2 bits of field determine the type of frame
 - Information frame (I): carry user data (upper layers) – flow and error control info is piggybacked on these frames as well
 - Supervisory frame (S): carry flow and error control info when there is no user data to tx
 - Unnumbered frame (U): provide 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

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HDLC – Frame Structure - Control Field (2)



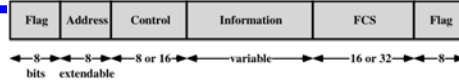
- "Set-mode" command → extends control field to 16 bit for S and I frames
- Extension: 7-bit sequence numbers rather than 3-bit ones
- Unnumbered frames always use 3-bit sequence numbers

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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

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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

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HDLC - Operation

a) Link Setup & Disconnect:

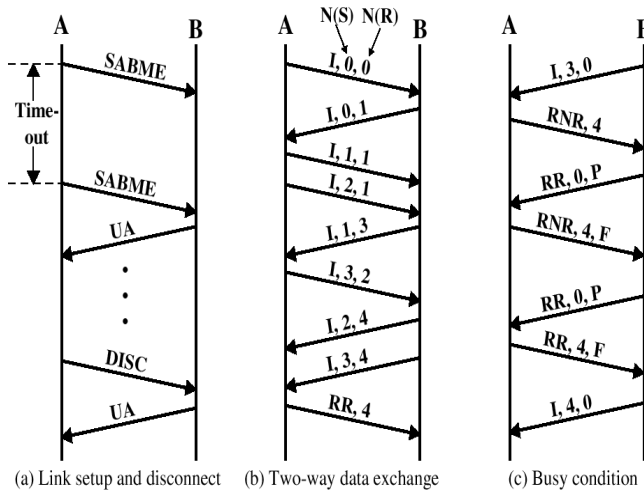
- SABM command – starts timer
- B responds with UA (or DM if not interested)
- A receives UA and initializes its variables
- To disconnect: issue DISC command

b) Two-Way Data Exchange:

- Full-duplex exchange of I-frames

c) Busy Condition:

- Note the use of the P and F bits



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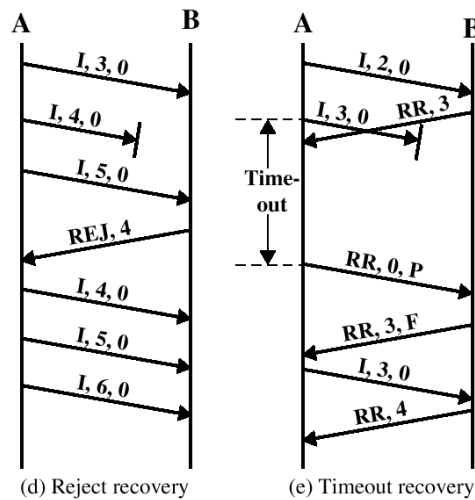
HDLC - Operation (2)

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



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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)

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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!)

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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

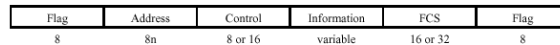
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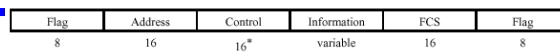
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Other Data Link Control Protocols (4)

- Frame Formats



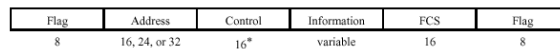
(a) HDLC, LAPB



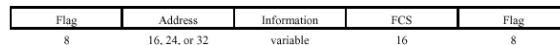
(b) LAPD



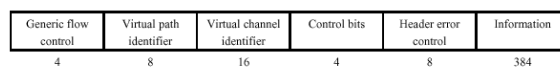
(c) LLC/MAC



(d) LAPF (control)



(e) LAPF (core)



(f) ATM

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Textbook Problems of INTEREST

- **Textbook:**