

# Chapter 3: Data Link Layer

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- ❑ Datalink layer design issues
- ❑ Error detection and correction
- ❑ Simple datalink protocols
- ❑ Sliding window protocols
- ❑ Example datalink protocols

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## Data Link Layer Design Issues

- ❑ Services provided to the Network Layer
- ❑ Framing
- ❑ Error Control
- ❑ Flow Control

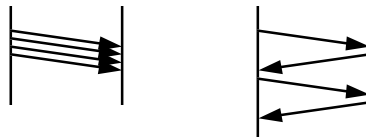
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## Datalink Layer Services

- ❑ Unacknowledged connectionless service
  - ❑ No acks, no connection
  - ❑ Error recovery up to higher layers
  - ❑ For low error-rate links or voice traffic
- ❑ Acknowledged connectionless service
  - ❑ Acks improve reliability
  - ❑ For unreliable channels. E.g.: Wireless Systems



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## Datalink Services (Cont)

- ❑ Acknowledged connection-oriented service
  - ❑ Equivalent of reliable bit-stream
  - ❑ Connection establishment
  - ❑ Packets Delivered In-Order
  - ❑ Connection Release
  - ❑ Inter-Router Traffic

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## Framing

- ❑ Framing = How to break a bit-stream into frames
- ❑ Need for framing: Error Detection/Control work on chunks and not on bit streams of data
- ❑ Framing methods:
  - ❑ Timing : risky. No network guarantees.
  - ❑ Character count: may be garbled by errors
  - ❑ Character stuffing: Delimit frame with special characters
  - ❑ Bit stuffing: delimit frame with bit pattern
  - ❑ Physical layer coding violations

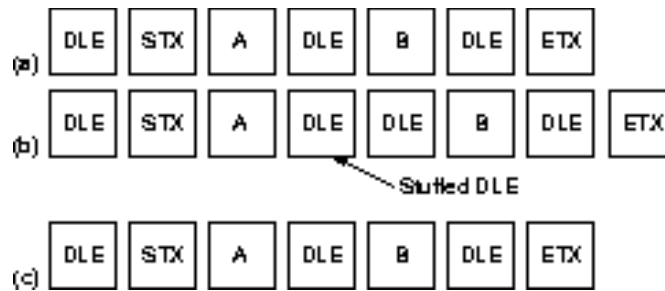
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## Character Stuffing

- Delimit with DLE STX or DLE ETX character flags
- Insert 'DLE' before accidental 'DLE' in data
- Remove stuffed character at destination



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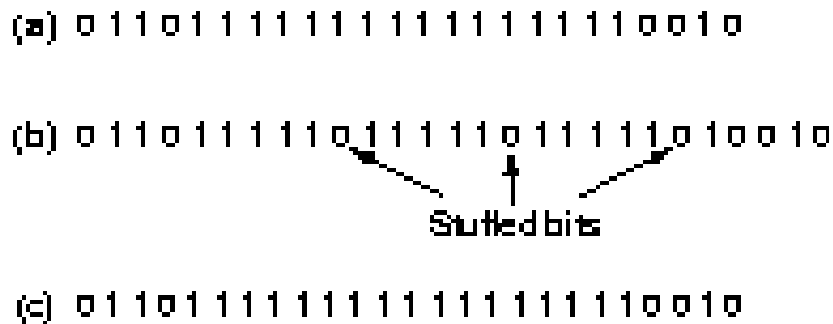
Fig 3-4

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## Bit Stuffing

- Delimit with special bit pattern (bit flags)
- Stuff bits if pattern appears in data
- Remove stuffed bits at destination



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Fig 3-5

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## Physical Coding Violations

- ❑ On networks having coding redundancy on physical medium

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## Error Control

- ❑ Error Control = Deliver frames without error, in the proper order to network layer
- ❑ Error control Mechanisms:
  - ❑ Ack/Nak: Provide sender some feedback about other end
  - ❑ Time-out: for the case when entire packet or ack is lost
  - ❑ Sequence numbers: to distinguish retransmissions from originals

## Flow Control

- ❑ Flow Control = Sender does not flood the receiver, but maximizes throughput
- ❑ Sender throttled until receiver grants permission

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## Error Detection and Correction

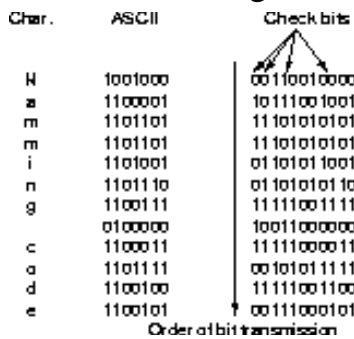
- ❑ Transmission errors: common on local loops, wireless links
- ❑ Single bit-errors vs Burst Errors
- ❑  $n$ -bit codeword =  $m$  message bits +  $r$  check bits
- ❑ Hamming Distance = number of bit positions in which two code words differ
- ❑ Distance  $D$  code = minimum hamming distance between any two code words written in the code
- ❑ To detect  $d$  errors, distance  $d+1$  code required
- ❑ To correct  $d$  errors, distance  $2d+1$  code required

## Error-Correcting Codes

- ❑ Enough redundant information in a frame to detect and correct the error
- ❑ Lower limit on number of check bits to correct 1 error:  $(m+r+1) \leq 2^r$
- ❑ Hamming's method: (corrects 1-bit errors)
  - ❑ Bit positions in powers of 2 (1,2,4 ...)  
= check bits
  - ❑ Other bit positions data
  - ❑ Every bit included in several parity computations (See text)

## Burst Error Correction

- ❑ Arrange code words as matrix
- ❑ Transmit one column at a time
- ❑ Uses  $kr$  check bits to immunize blocks of  $km$  data bits to single burst error of length  $k$  or less



## Error-Detecting Codes

- ❑ Enough redundant information in a frame to detect error
- ❑ Request retransmission from source to correct the error
- ❑ Parity checks
- ❑ Cyclic Redundancy Code (CRC) checks

## Check Digit Method

- ❑ Make number divisible by 9

**Example:** 823 is to be sent

1. Left-shift: 8230
2. Divide by 9, find remainder: 4
3. Subtract remainder from 9:  $9-4=5$
4. Add the result of step 3 to step 1: 8235
5. Check that the result is divisible by 9.

Detects all single-digit errors: 7235, 8335, 8255, 8237

Detects several multiple-digit errors: 8765, 7346

Does not detect some errors: 7335, 8775, ...

## Modulo 2 Arithmetic

$\begin{array}{r} 1111 \\ +1010 \\ \hline 0101 \end{array}$	$\begin{array}{r} 11001 \\ \times 11 \\ \hline 11001 \\ 11001 \\ \hline 101011 \end{array}$	$\begin{array}{r} \underline{1100} \\ 11 \mid 10101 \\ / 11 \downarrow \\ \text{x}11 \\ 11 \\ \hline \text{x}00 \\ 00 \\ \hline \text{x}01 \\ 00 \\ \hline \text{x}1 \\ 101 \end{array}$										
		<table style="border-collapse: collapse;"> <tr><td>010</td><td>2</td></tr> <tr><td>011</td><td>3</td></tr> <tr><td>---</td><td>--</td></tr> <tr><td>001</td><td>1 Mod 2</td></tr> <tr><td>x1</td><td>5 Binary</td></tr> </table>	010	2	011	3	---	--	001	1 Mod 2	x1	5 Binary
010	2											
011	3											
---	--											
001	1 Mod 2											
x1	5 Binary											

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## Cyclic Redundancy Check (CRC)

### ❑ Binary Check Digit Method

- ❑ Make number divisible by  $P=110101$  ( $n+1=6$  bits)

**Example:**  $M=1010001101$  is to be sent

1. Left-shift  $M$  by  $n$  bits  $2^n M = 101000110100000$
2. Divide  $2^n M$  by  $P$ , find remainder:  $R=01110$
3. Subtract remainder from  $P$
4. Add the result of step 2 to step 1 :  
 $T=101000110101110$
5. Check that the result  $T$  is divisible by  $P$ .

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## Modulo 2 Division

$Q = \underline{1101010110}$   
 $P = 110101) 1010001101\underline{00000} = 2^M$

<u>110101</u>	
111011	010110
<u>110101</u>	<u>000000</u>
011101	101100
<u>000000</u>	<u>110101</u>
111010	110010
<u>110101</u>	<u>110101</u>
011111	001110
<u>000000</u>	<u>000000</u>
111110	01110 = R
<u>110101</u>	

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## Checking At The Receiver

$\underline{1101010110}$   
 $110101) 1010001101\underline{01110}$

<u>110101</u>	
111011	010111
<u>110101</u>	<u>000000</u>
011101	101111
<u>000000</u>	<u>110101</u>
111010	110101
<u>110101</u>	<u>110101</u>
011111	00000
<u>000000</u>	
111110	
<u>110101</u>	

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## Polynomial Representation

- Number the bits 0, 1, ..., from right

$$b_n b_{n-1} b_{n-2} \dots b_3 b_2 b_1 b_0$$

$$b_n x^n + b_{n-1} x^{n-1} + b_{n-2} x^{n-2} + \dots + b_3 x^3 + b_2 x^2 + b_1 x + b_0$$

- Example:

543210

↓↓↓↓↓

$$110101 = x^5 + x^4 + x^2 + 1$$

$$\begin{array}{cccccccc} \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow & \uparrow \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 11 & 10 & 9 & 8 & & & 1 & 0 \end{array} = x^{11} + x^{10} + x^8 + x^7 + x^4 + x + 1$$

## Cyclic Redundancy Check (CRC)

### Polynomial Division Method

Make  $T(x)$  divisible by  $P(x) = x^5 + x^4 + x^2 + 1$  (Note:  $n=5$ )

**Example:**  $M=1010001101$  is to be sent

$$M(x) = x^9 + x^7 + x^3 + x^2 + 1$$

1. Multiply  $M(x)$  by  $x^n$ ,  $x^n M(x) = x^{14} + x^{12} + x^8 + x^7 + x^5 +$

....

2. Divide  $x^n M(x)$  by  $P(x)$ , find remainder:

$$R(x) = 01110 = x^3 + x^2 + x$$

## CRC (Cont)

- 3. Add the remainder  $R(x)$  to  $x^nM(x)$  :  
 $T(x) = x^{14} + x^{12} + x^8 + x^7 + x^5 + x^3 + x^2 + x$
- 4. Check that the result  $T(x)$  is divisible by  $P(x)$ .
- Transmit the bit pattern corresponding to  $T(x)$ :  
101000110101110

## Popular CRC Polynomials

- 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: Ethernet, FDDI, ...  
 $x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11}$   
 $+ x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$

Even number of terms in the polynomial

⇒ Polynomial is divisible by  $1+x$

⇒ Will detect all odd number of bit errors

## Errors Detected by CRC

- ❑ All single bit errors
- ❑ Any burst error of length  $n$  bits or less,  
 $n$ =degree of the polynomial
- ❑ Most larger burst errors  
 $P(\text{undetected burst errors}|\text{error has occurred}) = 2^{-n}$
- ❑ Any odd number of errors if  $P(x)$  has  $1+x$  as a factor, i.e., has even number of terms
- ❑ Any double bit errors as long as  $P(x)$  has a factor with 3 terms,  
e.g.,  $(1+x^4+x^9)(\dots)$

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## Elementary Data Link Protocols

- ❑ Unrestricted Simplex Protocol
  - ❑ Framing only
  - ❑ No error or flow control
- ❑ Simplex Stop-and-Wait
  - ❑ Send one packet
  - ❑ Wait for Ack before proceeding

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## Elementary Datalinks (Cont)

- ❑ Simplex Protocol for a Noisy Channel
  - ❑ Automatic Repeat request (ARQ) protocols
  - ❑ Positive Ack
  - ❑ 1-bit sequence number in frames (not in acks)
  - ❑ Timeout to detect lost frames/acks
  - ❑ Retransmission
  - ❑ Can fail under early timeout conditions
- ❑ Full Duplex Communication
  - ❑ Piggybacking of acks

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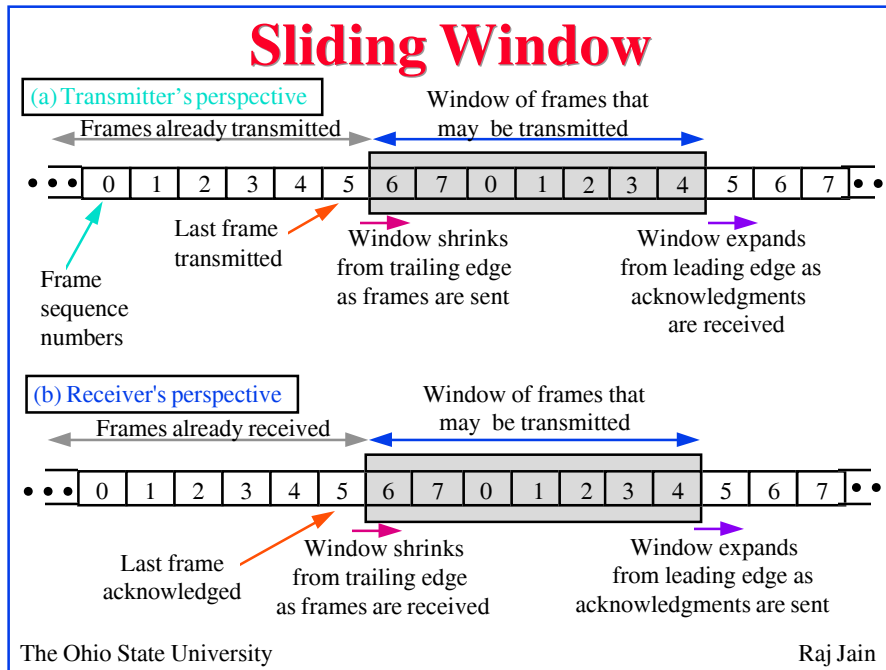
## Sliding Window Protocols

- ❑ Window = Set of sequence numbers to send/receive
- ❑ Sender window
  - ❑ Sender window increases when ack received
  - ❑ Packets in sender window must be buffered at source
  - ❑ Sender window may grow in some protocols

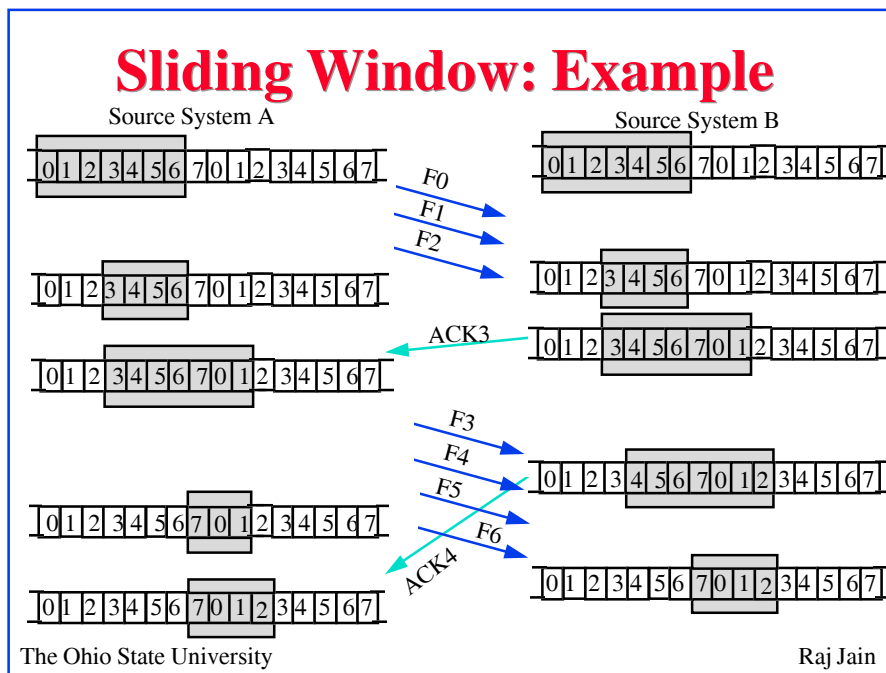
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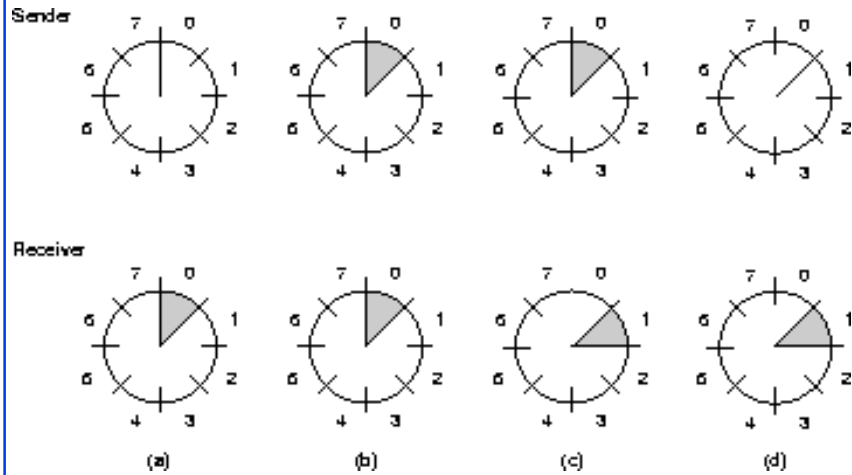


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## Sliding Window: Example



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## Sliding Window (Cont)

- Receiver window
  - Packets outside window discarded
  - Window advances when sequence number = low edge of window received
  - Receiver window always constant
- Sender transmits  $W$  frames before blocking (pipelining)

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## One-Bit Sliding Window

- ❑ Stop and Wait + error control
- ❑ Piggybacked acks
- ❑ Acks sent instantly
- ❑ Packets may be resent to accommodate immediate piggybacking
- ❑ Acks contain sequence number
- ❑ Peculiar case: when both sides start simultaneously

## One-Bit: Example

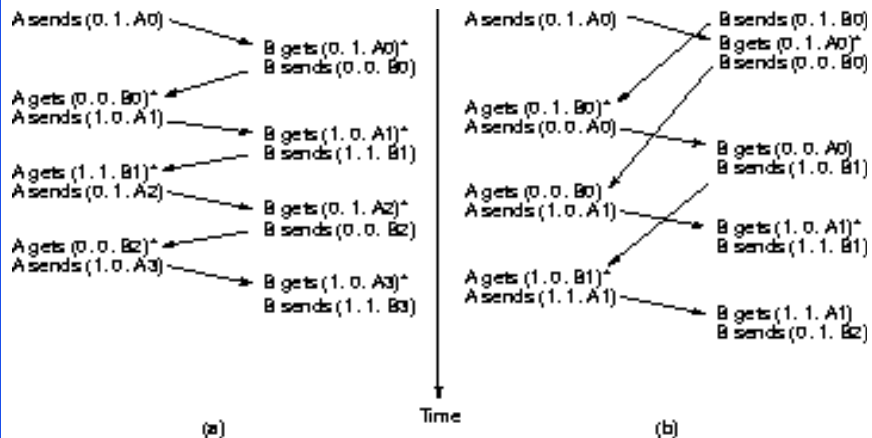
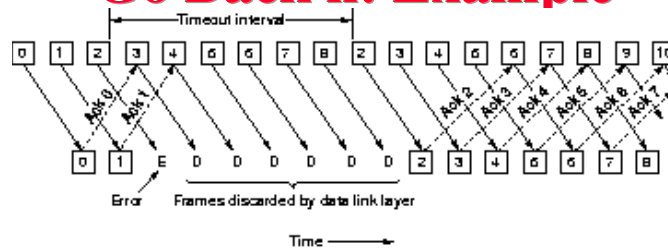


Fig 3-14

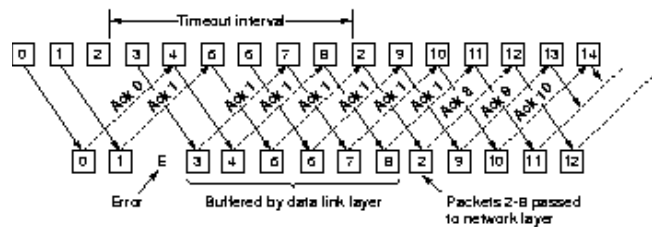
## Go Back n

- ❑ Round trip propagation + transmission time not negligible
- ❑ Stop and Wait not efficient
- ❑ Sliding Window + Retransmit all packets starting from earliest unacked packet
- ❑ Acks are cumulative
- ❑ Ack the latest packet (N) if all packets (< N) are received.
- ❑ Can waste a lot of bandwidth if error rate high

## Go Back n: Example



(a)

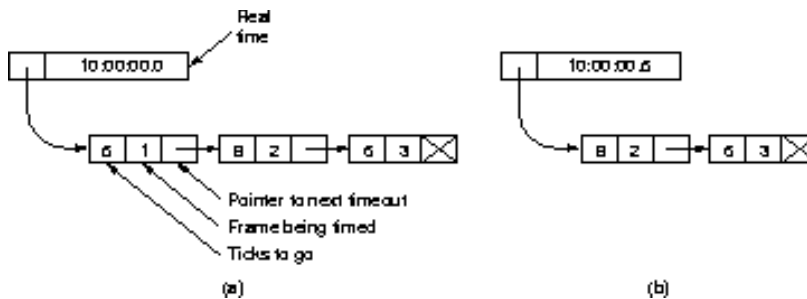


(b)

Fig 3-15

## Go Back n (Cont)

- ❑ Out-of-order buffering not mandatory at destination
- ❑ Maximum Window = Sequence Number Space - 1
- ❑ N timers or 1 timer may be used



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Fig 3-17

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## Selective Repeat

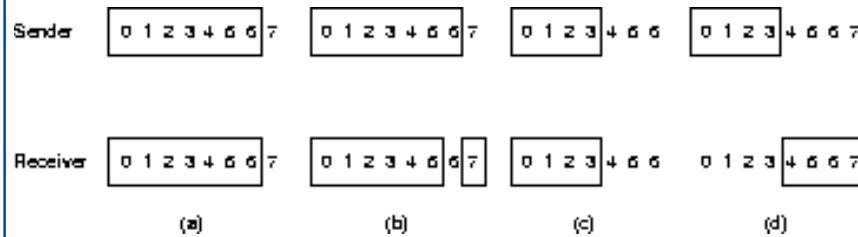
- ❑ Sliding Window + Retransmit just the bad frame when Nak received
- ❑ Out-of-order buffering required at destination
- ❑ Loses time (and hence throughput) if bursty loss of frames
- ❑ Acks not cumulative.
- ❑ Non-sequential arrival of packets
  - ⇒ ensure no overlap with old window when receiver advances window
  - ⇒ Maximum Window = (Sequence Number Space)/2

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## Selective Repeat: Example



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Fig 3-19

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## Selective Repeat (Cont)

- ❑ Enhancement to piggybacking
  - ❑ Auxiliary Ack timer
  - ❑ Set timer when packet to be acked is received
  - ❑ If no reverse data, generate Ack when timer goes off
- ❑ Send negative ack (Nak) when out-of-order frame received
  - ❑ Source retransmits Nak'ed frame
  - ❑ Naks not cumulative
  - ❑ Do not send duplicate Nak

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## Example Data link Protocols

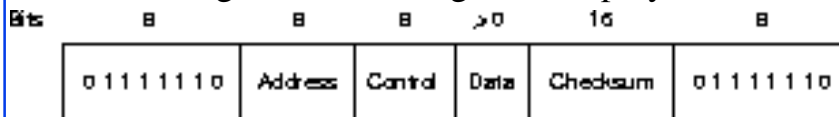
- ❑ HDLC
- ❑ SLIP
- ❑ PPP
- ❑ ATM

## HDLC Family

- ❑ Synchronous Data Link Control (SDLC): IBM
- ❑ High-Level Data Link Control (HDLC): ISO
- ❑ Link Access Procedure-Balanced (LAPB): X.25
- ❑ Link Access Procedure for the D channel (LAPD): ISDN
- ❑ Link Access Procedure for modems (LAPM): V.42
- ❑ Link Access Procedure for half-duplex links (LAPX): Teletex
- ❑ Point-to-Point Protocol (PPP): Internet
- ❑ Logical Link Control (LLC): IEEE
- ❑ Advanced Data Communications Control Procedures (ADCCP): ANSI
- ❑ V.120 and Frame relay also use HDLC

# HDLC

- ❑ High-level Data Link Control
- ❑ Bit-oriented, bit-stuffing for transparency
- ❑ Control field for seq numbers, acks etc
- ❑ Data field arbitrarily long (practical limits: checksum efficiency)
- ❑ CRC using CRC-CCITT generator polynomial



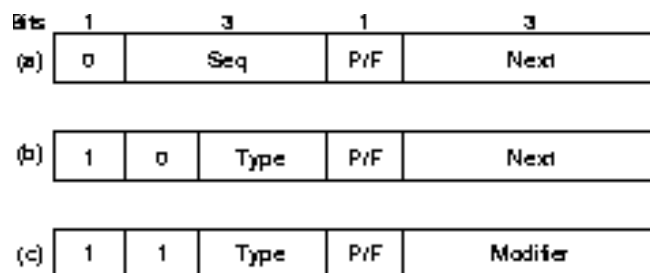
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## HDLC Frame Types

- ❑ Information, Supervisory, Unnumbered frames
- ❑ Sliding window with 3-bit sequence number, piggybacked acks
- ❑ Connection Management through supervisory frames



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Fig 3-25

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## HDLC Frames

- ❑ Information Frames: User data
  - ❑ Piggybacked Acks: Next frame expected
  - ❑ Poll/Final = Command/Response
- ❑ Supervisory Frames: Flow and error control
  - ❑ Go back N and Selective Reject
  - ❑ Final  $\Rightarrow$  No more data to send
- ❑ Unnumbered Frames: Control
  - ❑ Mode setting commands and responses
  - ❑ Information transfer commands and responses
  - ❑ Recovery commands and responses
  - ❑ Miscellaneous commands and responses

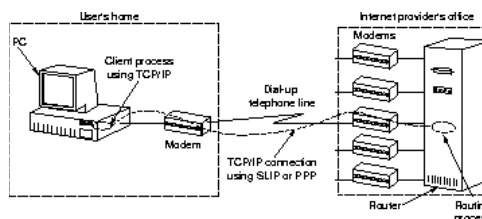
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## Data Link Layer in the Internet

- ❑ Point-to-Point link scenarios
- ❑ Router-router leased line (PPP)
- ❑ dial-up host-router connection (SLIP, future PPP)
- ❑ SLIP: Not an approved Internet Standard
  - $\Rightarrow$  incompatibilities
- ❑ PPP: Official Internet Standard.



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## SLIP: Serial Line IP

- ❑ For dial-up lines. Reference: RFC 1055 and 1144.
- ❑ Raw IP packets + Character flags + Character stuffing
- ❑ Later versions: header compression

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## SLIP Problems

- ❑ No error detection or correction
- ❑ Supports only IP
  - ❑ Each side must know other's IP address in advance
    - ⇒ dynamic IP address assignment not possible
    - ⇒ Issue because of shortage of IP addresses
- ❑ No authentication ⇒ you do not know whom you are dialing up to

# PPP

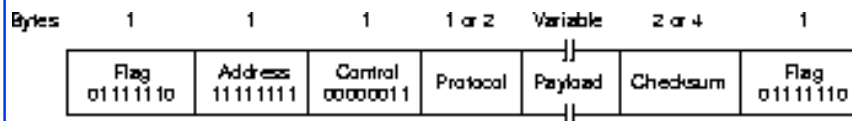
- ❑ Point to Point Protocols
- ❑ Reference: RFCs 1661, 1662 1663
- ❑ Frame method to unambiguously delineate frames and for error control
- ❑ Link Control Protocol(LCP): link management
- ❑ Network Control Protocol (NCP): Supports multiple network layers

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# PPP Frames



- ❑ Resembles HDLC, but character-oriented
- ❑ (The HDLC flag 01111110 is considered as a character and stuffed)
- ❑ PPP can run over dial-up lines, SONET lines, or bit-oriented HDLC (inter-router) lines

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## PPP Procedures

- Connection setup:
  - Home PC Modem calls Internet Provider's router: sets up physical link
  - PC sends series of LCP packets as PPP payload
    - + Select PPP (data link) parameters
    - + Authenticate
  - PC sends series of NCP packets as PPP payload
    - + Select network parameters
    - + E.g., Get dynamic IP address

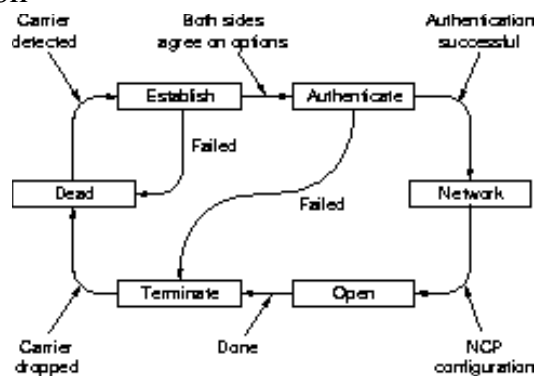
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## PPP Procedures (Cont)

- Connection Teardown:
  - NCP first followed by LCP and physical connection



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## ATM Cell Transmission

- ❑ Lines assumed reliable
- ❑ Lightweight data links:  
minimum error checking, no flow control
- ❑ Data link functionality  
= Transmission convergence (TC) sublayer

## HEC

- ❑ Header Error Control
- ❑ Corrects 1-bit errors
- ❑ No checksum for payload
- ❑ ATM designed for fiber: highly reliable, 99.64%  
errors are 1-bit errors
- ❑ Reliable data link  
⇒ EX-OR a sequence of cells and  
reconstruct up to 1 lost/garbled cell at destination

## **ATM on Synchronous medium**

- ❑ Transmit cells according to predefined timing pattern
- ❑ Generate idle cell if no data cell available
- ❑ Operation and Management (OAM) cells: Used by ATM switches to exchange control information
- ❑ Mappings from ATM to other systems (T1, T3, FDDI exist)

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## **ATM Cell Reception**

- ❑ Problem: Finding Cell boundaries in the some bit streams
- ❑ No flags like HDLC
- ❑ Trick: receiver layer looks for HEC
- ❑ E.g., Use 40 bit shift register

## ATM Reception (Cont)

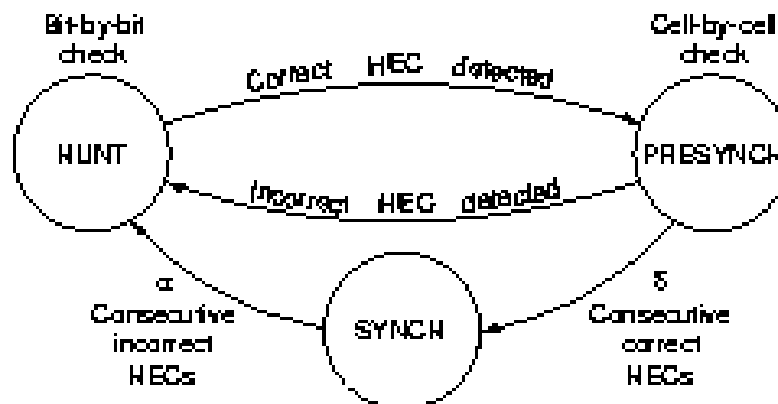
- HEC = last 8 bits computed over first 32 bits
- Accuracy limited since HEC small
- Improve accuracy with finite state machine
- HUNT, PRESYNCH and SYNCH states
- Verify guess about HEC
- Check 424 bits ahead to see if HEC test passes again
- Repeat check  $\delta$  times
- If not synchronized, discard cell and resynchronize

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## Cell Delineation



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## Summary

- ❑ Function: Convert raw bit stream to frame stream
- ❑ Framing methods
- ❑ Error and Flow Control: Sliding Window
- ❑ HDLC, SLIP, PPP, ATM Data Link

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## Homework

- ❑ Read sections complete chapter 3 except 3.5
- ❑ Exercises: 2, 9, 19, 25