

Chapter 3

The Data Link Layer

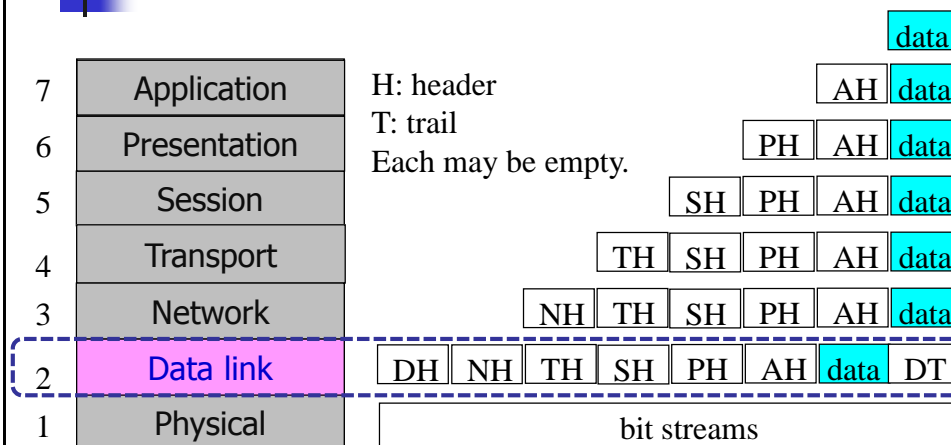
陳瑞奇(Rikki)

亞洲大學資訊工程學系

Adapted from Computer Networks,
Andrew S. Tanenbaum, Vrije University, Netherlands
& Computer Networking: A Top Down Approach,
Jim Kurose, Keith Ross


Computer Networks, Fifth Edition by Andrew Tanenbaum and David Wetherall, © Pearson Education-Prentice Hall, 2011

The Data Link Layer



OSI Reference Model

2



Data Link Layer Design Issues

- Network layer services

3

Network

2

Data link

1

Physical


DH

data

DT

bit streams

3



Packets and Frames

Relationship between packets and frames.

3

Network

2

Data link

1

Physical

Sending machine

Packet

Receiving machine

Packet

Header

Payload field

Trailer

Header

Payload field

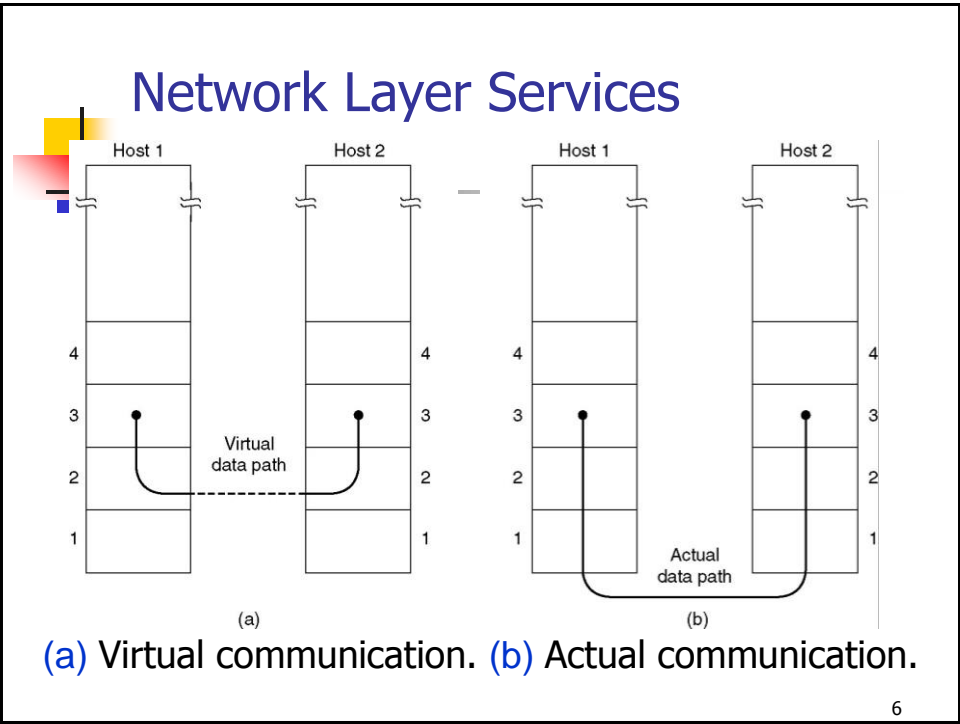
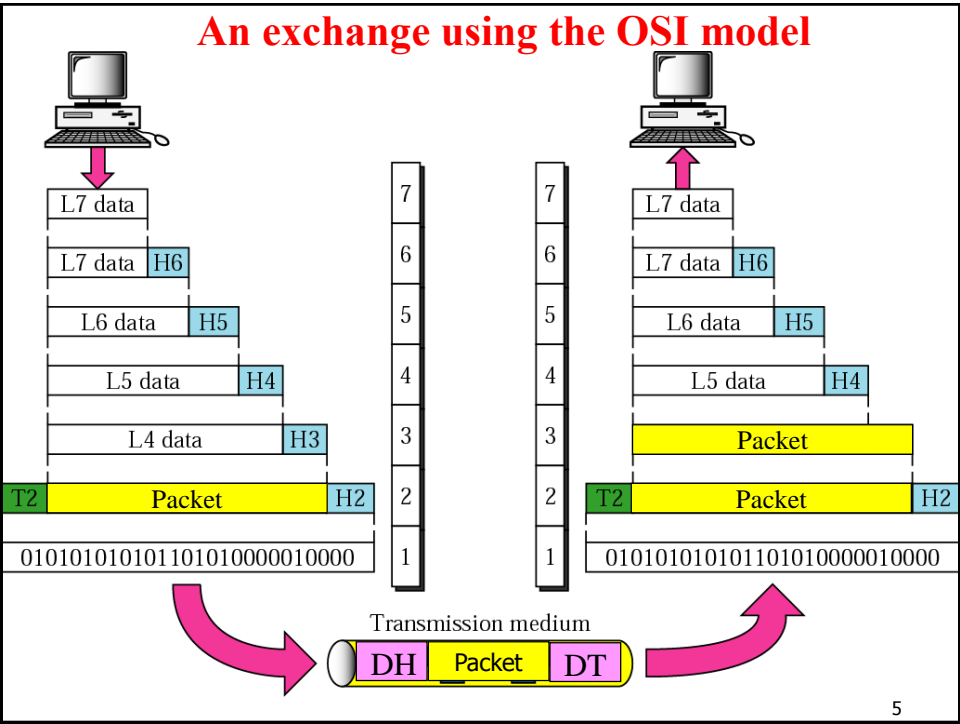
Trailer

DH

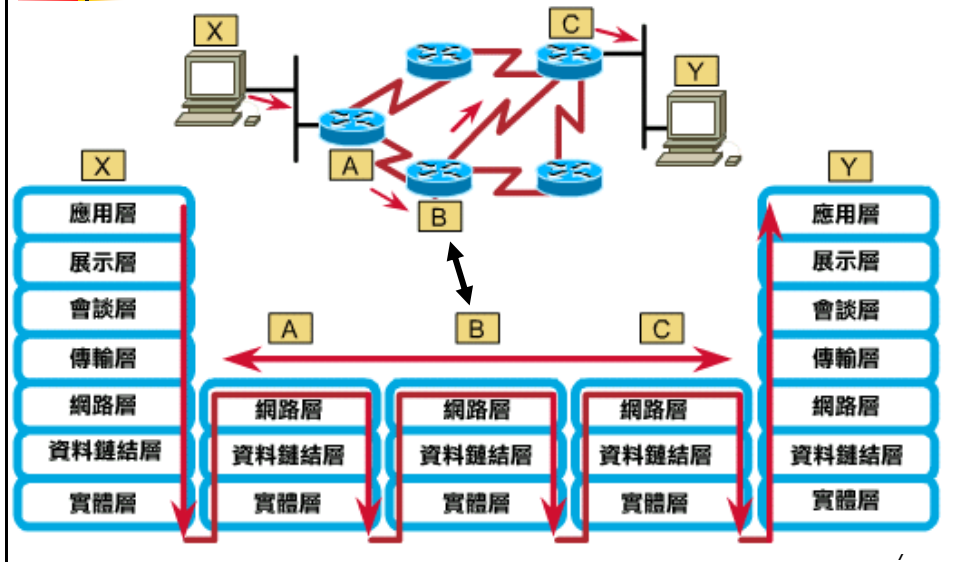
data

DT

4



Services Provided to Network Layer



Possible Services Offered

1. Unacknowledged connectionless service: Ethernet



2. Acknowledged connectionless service: WLAN, WiFi



3. Acknowledged connection-oriented service: ATM, Frame Relay

Framing methods

DH

data

DT

Flag

bit streams

- Too risky to count on **timing** to mark the start and end of each frame
- Other methods:
 - Byte Count** (rarely used anymore)
 - Flag bytes with byte stuffing** (PPP)
 - Flag bits with bit stuffing**
 - Physical layer coding violations**

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Framing (1): Byte Count

A byte stream. (a) Without errors. (b) With one error.

DH

data

DT

Byte count

One byte

5 1 2 3 4

5 6 7 8 9

8 0 1 2 3 4 5 6

8 7 8 9 0 1 2 3

Frame 1
5 bytes

Frame 2
5 bytes

Frame 3
8 bytes

Frame 4
8 bytes

(a)

Error

5 1 2 3 4

7 6 7 8 9 8 0

1

2 3

4 5 6 8

7 8 9 0 1 2 3

Frame 1

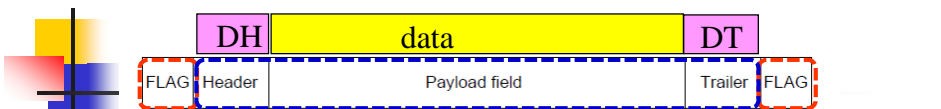
Frame 2
(Wrong)

Now a byte count

(b)

10

Framing (2): Flag bytes with byte stuffing



(a)

Original bytes

A	FLAG	B	
A	ESC	B	
A	ESC	FLAG	B
A	ESC	ESC	B

After stuffing

A	ESC	FLAG	B		
A	ESC	ESC	B		
A	ESC	ESC	ESC	FLAG	B
A	ESC	ESC	ESC	ESC	B

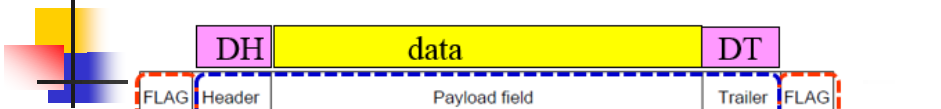
(b)

a) A frame delimited by flag bytes.

b) Four examples of byte sequences before and after byte stuffing

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Framing (3): Flag bits with bit stuffing



(a)

Flag

01111110

0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

(b)

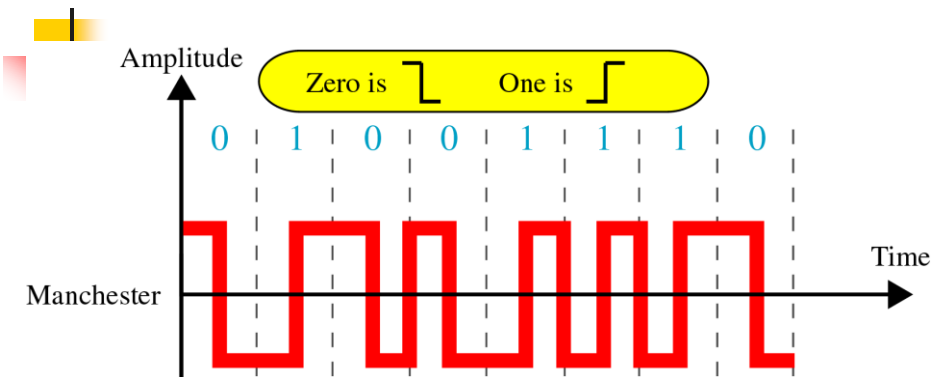
0 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 0 0 1 0

Stuffed bits

Bit stuffing. (a) The original data. (b) The data as they appear on the line.

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Framing (4): Physical layer coding violations



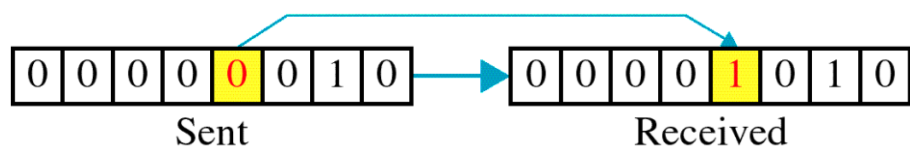
The combinations of low-low and high-high which are not used for data may be used for marking frame boundaries.

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Error Control Process (1)

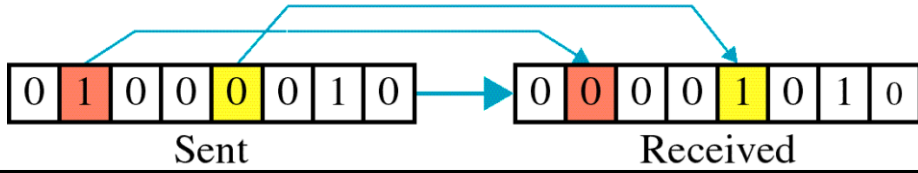
Single-bit error

0 changed to 1

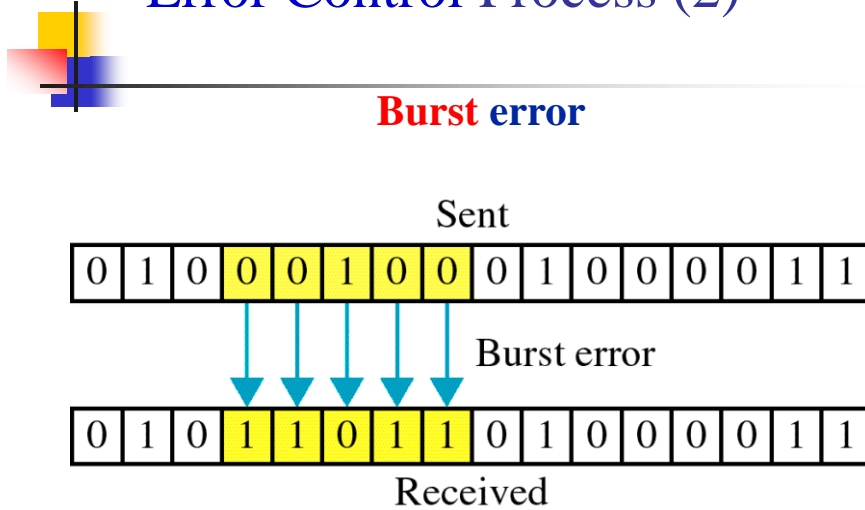


Multiple-bit error

Two errors



Error Control Process (2)

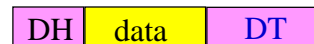
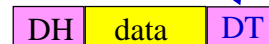


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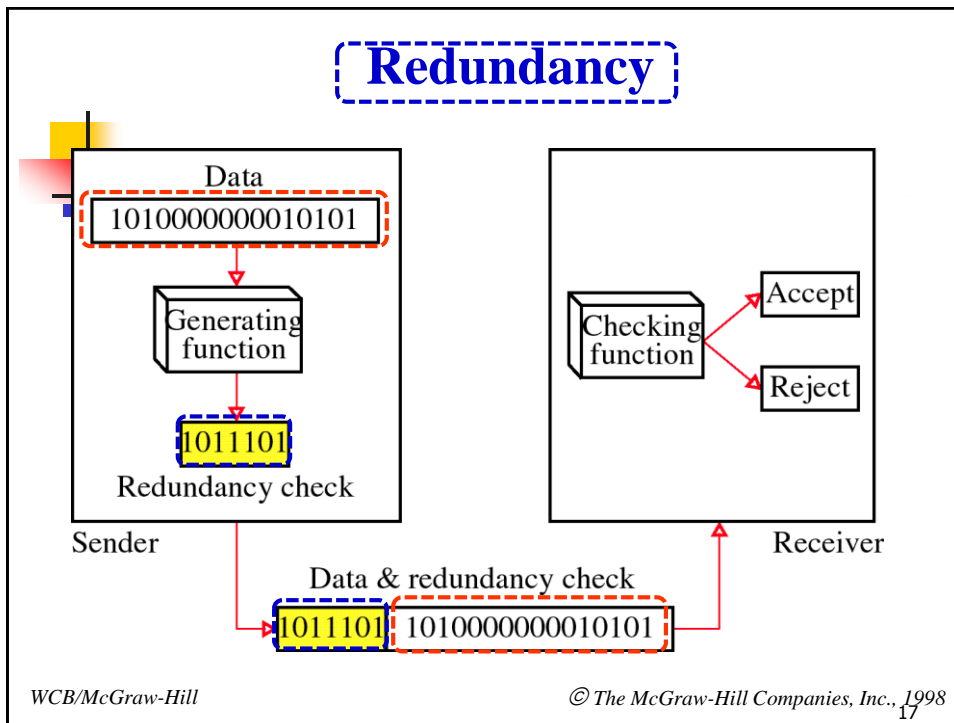
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Error Control Process (3)

- All transmission media have potential for introduction of errors
- Error control process has two components
 - **Error detection**
 - **redundancy** in data so that error can be detected
 - **Error correction**
 - once error detected, frames **corrected** or **retransmitted**



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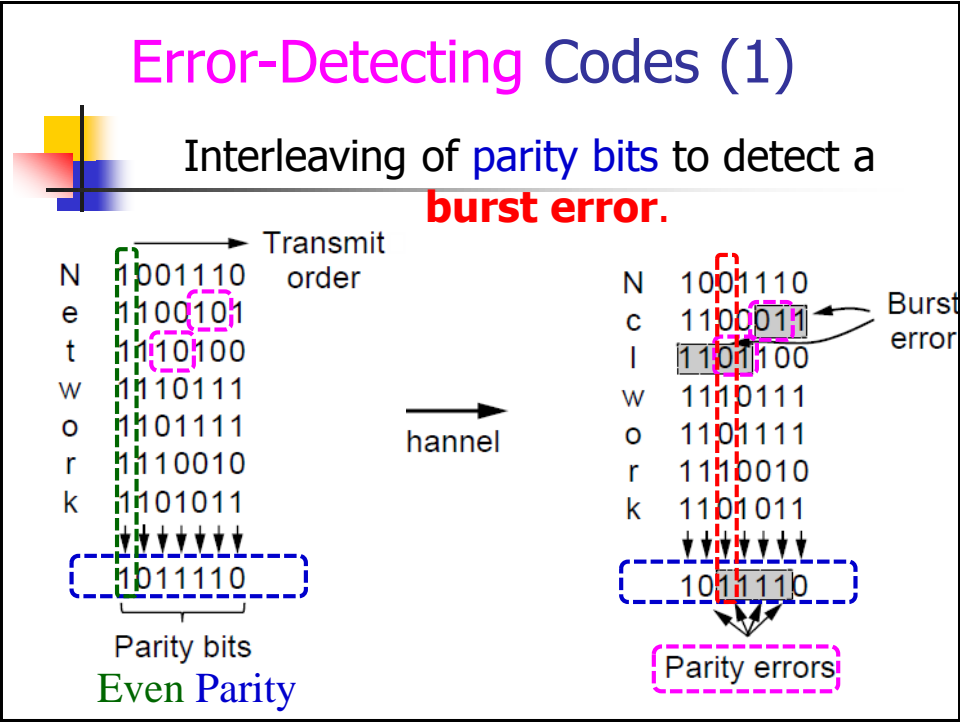
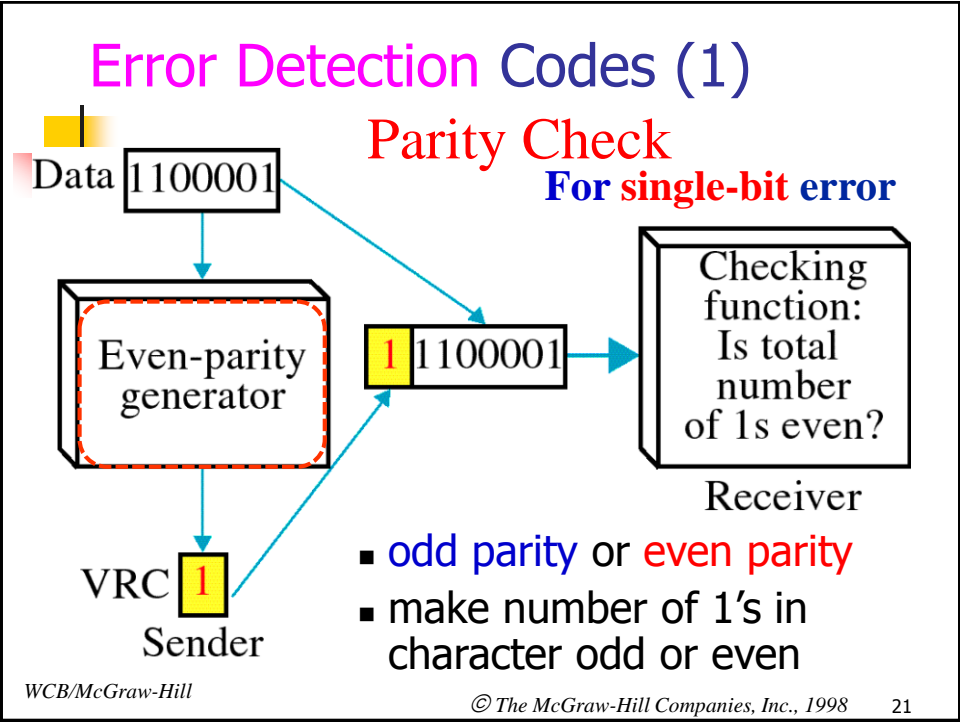


Error Detection Codes

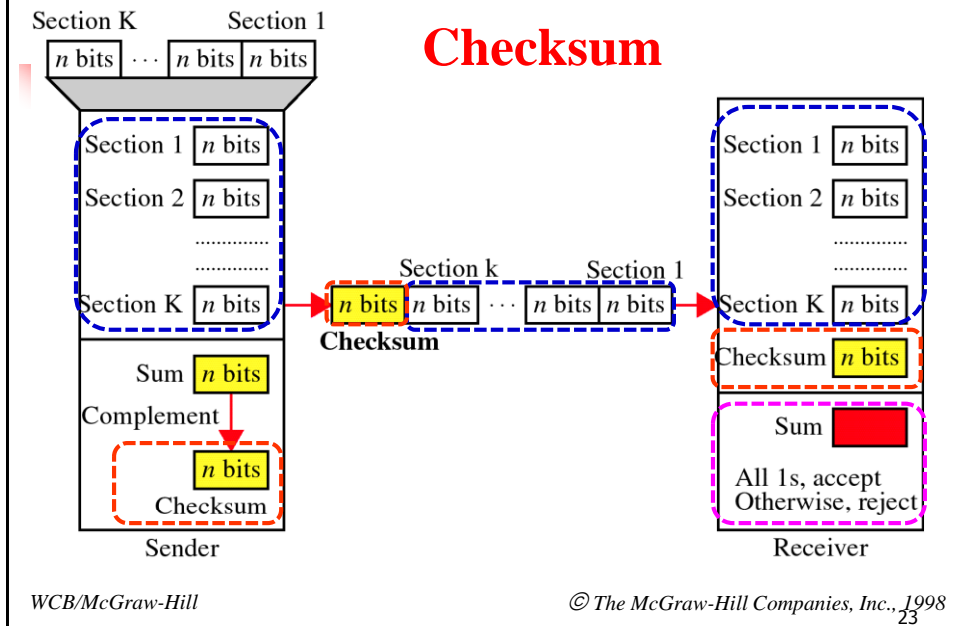
Linear,
systematic
block
codes

1. Parity.
2. Checksums.
3. Cyclic Redundancy Checks (CRCs).
4. Hamming codes.
5. Binary convolutional codes.
6. Reed-Solomon codes.
7. Low-Density Parity Check codes.

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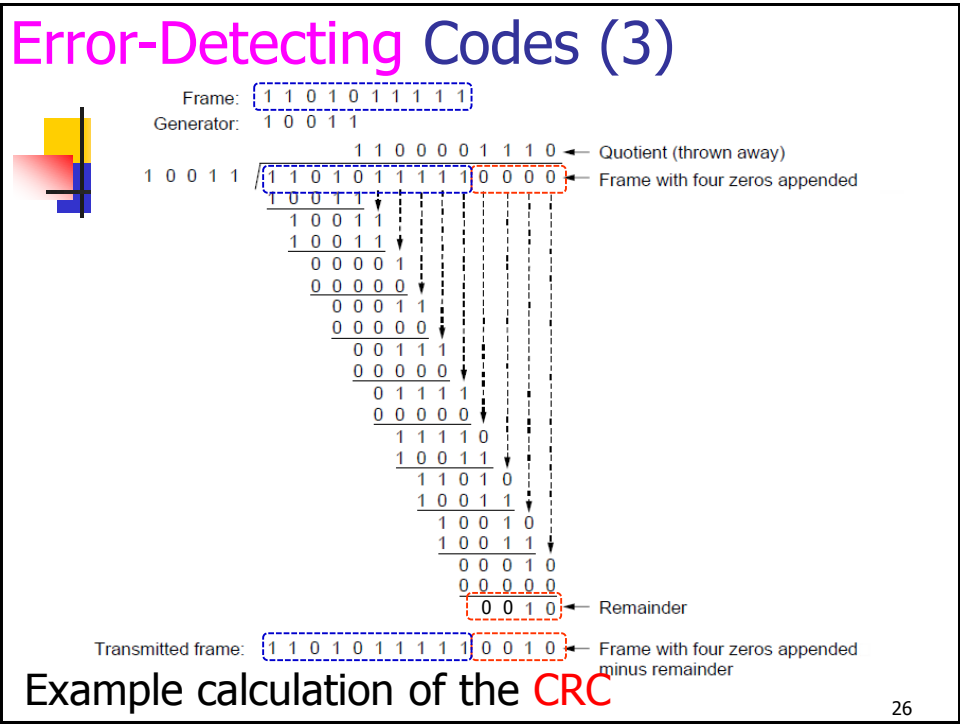
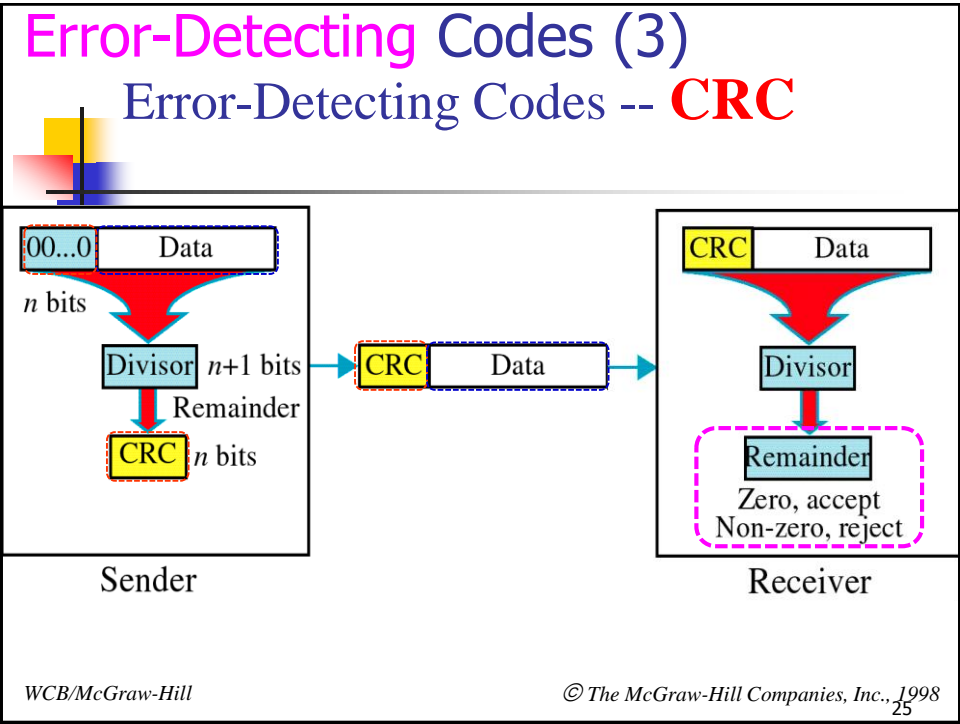
Error-Detecting Codes (2)



Error Detection Codes (3)

- **Cyclic Redundancy Check (CRC)**
 - treat **frame** as one **long binary number**
 - attach **remainder** to frame
 - 16-bit (32-bit) **CRC**





Error-Detecting Codes (3)

CRC (Cyclic Redundancy Check)

CRC Code = Polynomial Code

$$110001 = x^5 + x^4 + x^0$$

Original Message (dividend): $M(x)$

Generator (divisor): $G(x)$

Degree of $G(x)$: r

Quotient: $Q(x)$

Remainder (CRC): $R(x)$

Transmitted Message: $T(x)$

Modulo 2 division
(add/sub = XOR)

$$\begin{array}{r} Q(x) \\ G(x) \overline{) x^r M(x)} \\ \hline R(x) \end{array}$$

$$T(x) = x^r M(x) - R(x) = M(x) \& R(x)$$

$$T(x)/G(x) = 0$$



If $T'(x)/G(x) = 0$ then Correct, otherwise Error

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Error-Detecting Codes (3): CRC

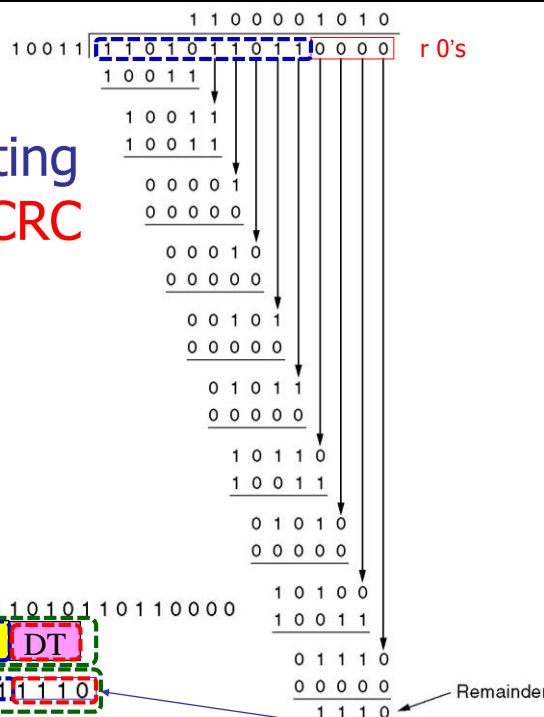
Calculation of the
polynomial code
checksum.

Frame : 1101011011

Generator: 10011

Message after 4 zero bits are appended: 11010110110000

Transmitted frame:



Standard Polynomials

CRC-12

$$x^{12} + x^{11} + x^3 + x + 1$$

CRC-16

$$x^{16} + x^{15} + x^2 + 1$$

(used in HDLC)

CRC-ITU

$$x^{16} + x^{12} + x^5 + 1$$

CRC-32

$$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

(used in Ethernet)

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Hardware CRC

Source: <http://www.erg.abdn.ac.uk/users/gorry/course/dl-pages/crc.html>

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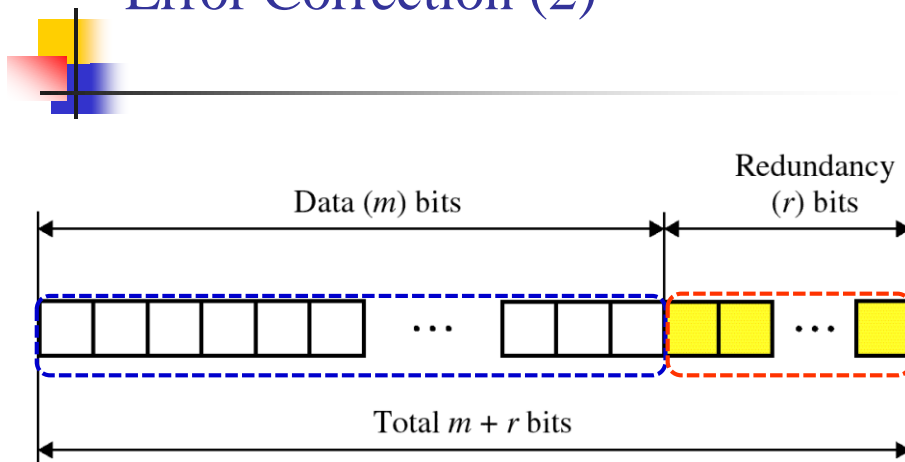
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Error Correction (1)

- Two types of errors
 - **Lost frame** - never arrives
 - **Damaged frame** - error in bits
- Automatic Repeat reQuest (ARQ)
 - Error detection
 - **Positive acknowledgment (ACK)** if received
 - **Retransmission** after **time-out** if not **ACK**
 - **Negative ACK (NACK)** and **retransmission** if error
- Error-Correcting Codes

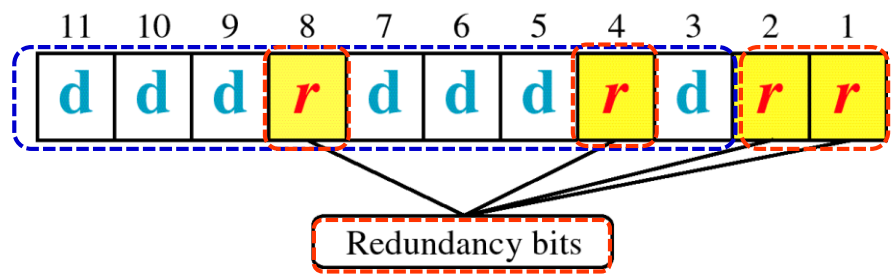
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Error Correction (2)



Error Correction (3)

Hamming Code

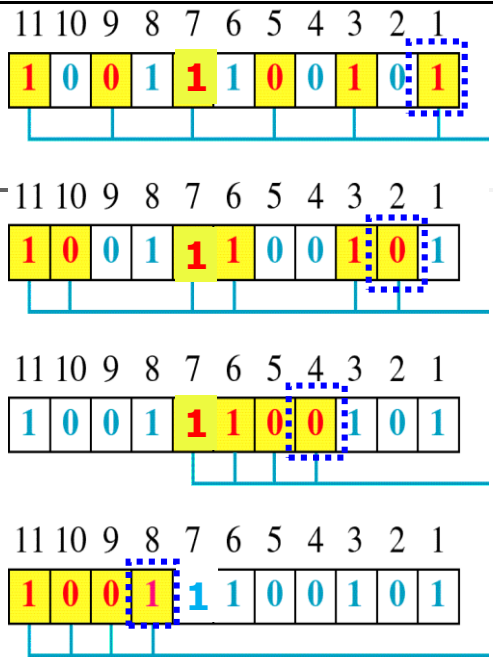


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Hamming Code (4)

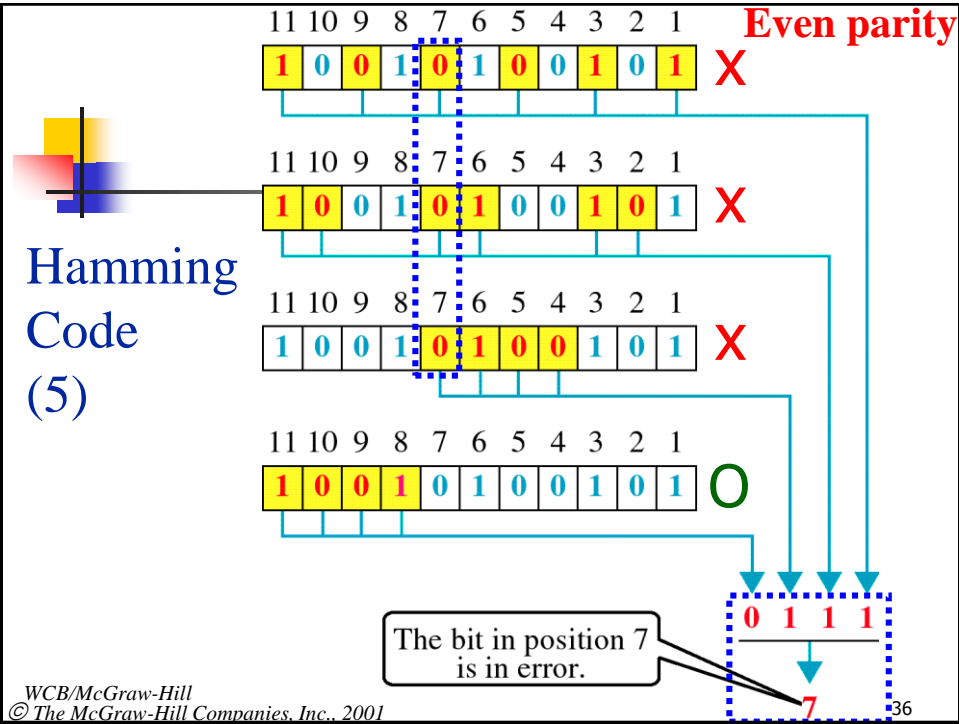


Generation of Hamming Code (Even Parity Check)

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Error-Correcting Codes

Use of a **Hamming code** to correct 1-bit errors.

Char.	ASCII	Check bits
H	1001000	00110010000
a	1100001	10111001001
m	1101101	11101010101
m	1101101	11101010101
i	1101001	01101011001
n	1101110	01101010110
g	1100111	01111001111
	0100000	10011000000
c	1100011	11111000011
o	1101111	10101011111
d	1100100	11111001100
e	1100101	00111000101

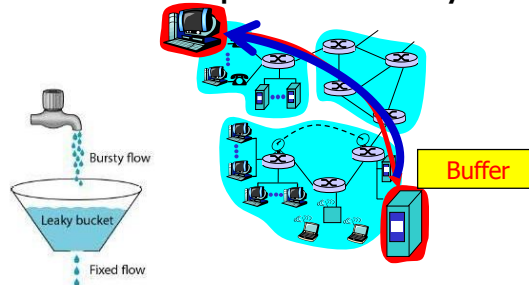
Order of bit transmission

Bit 1,2,4,8
與上頁
左右顛倒
(也是可以)

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Flow Control

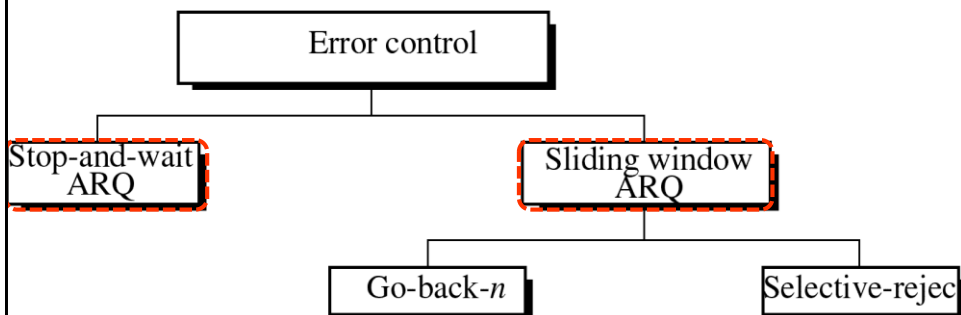
- Necessary when **data** is being **sent faster** than it can be processed by **receiver**

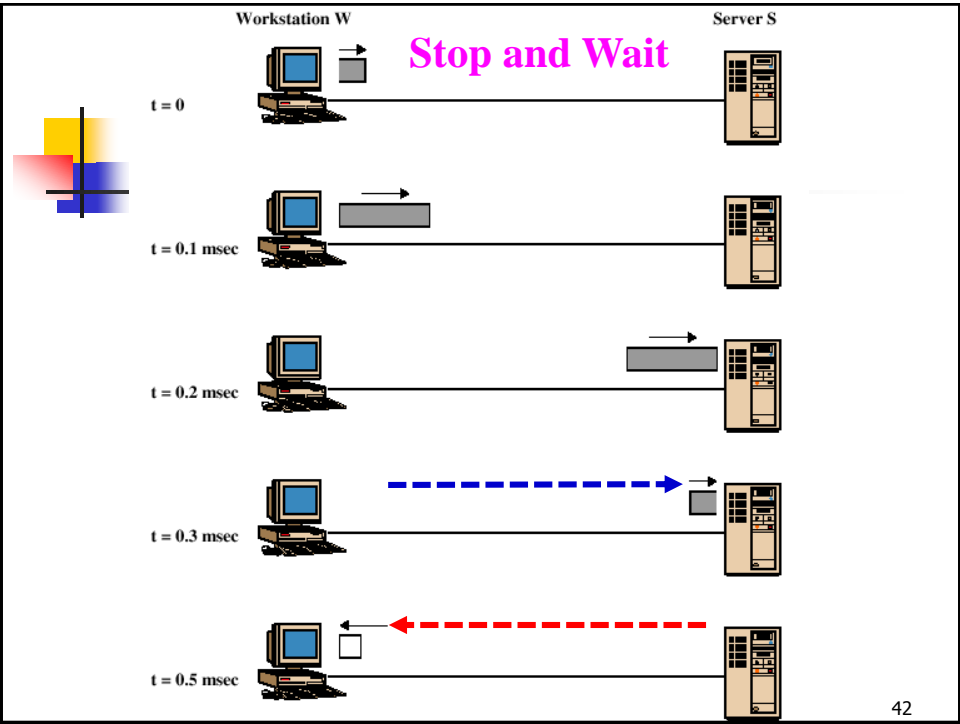


- Usually **a buffer** is filled, and transfer is stopped until buffer is emptied

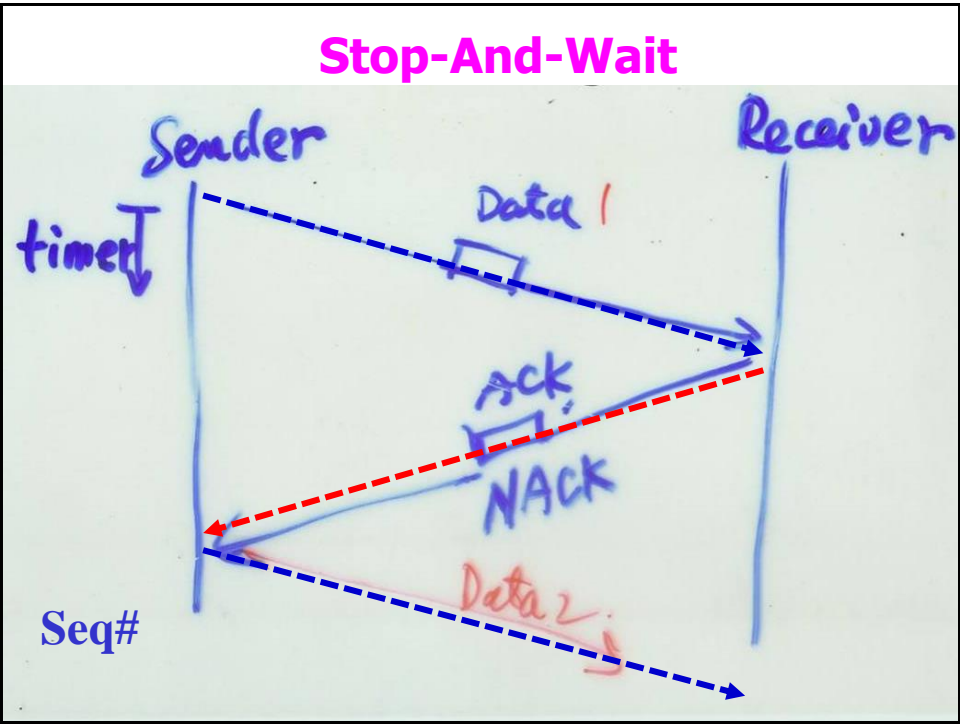
38

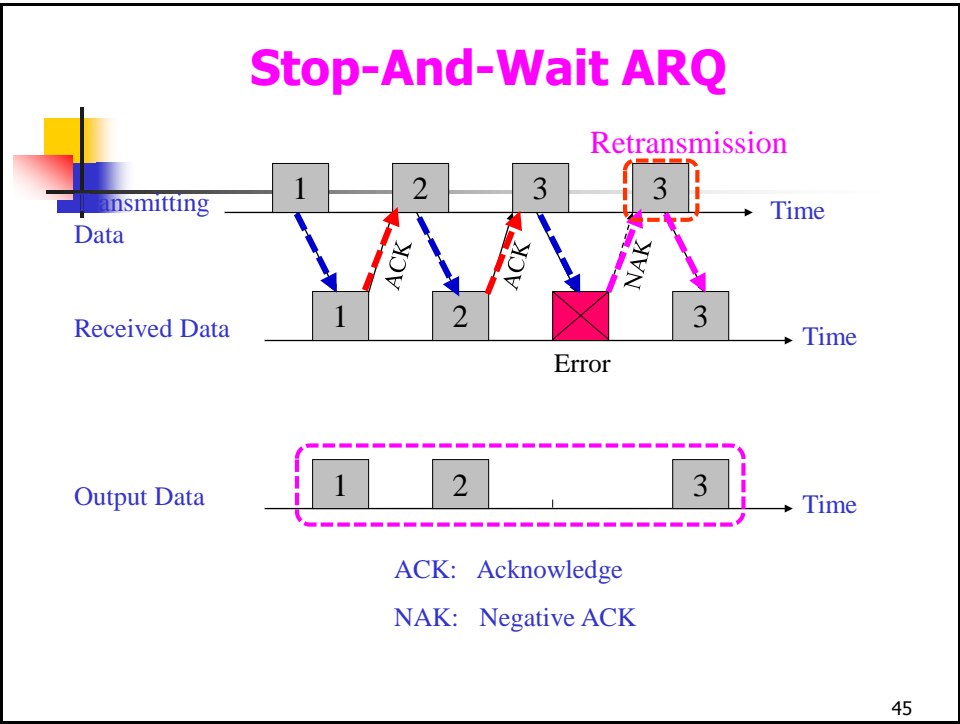
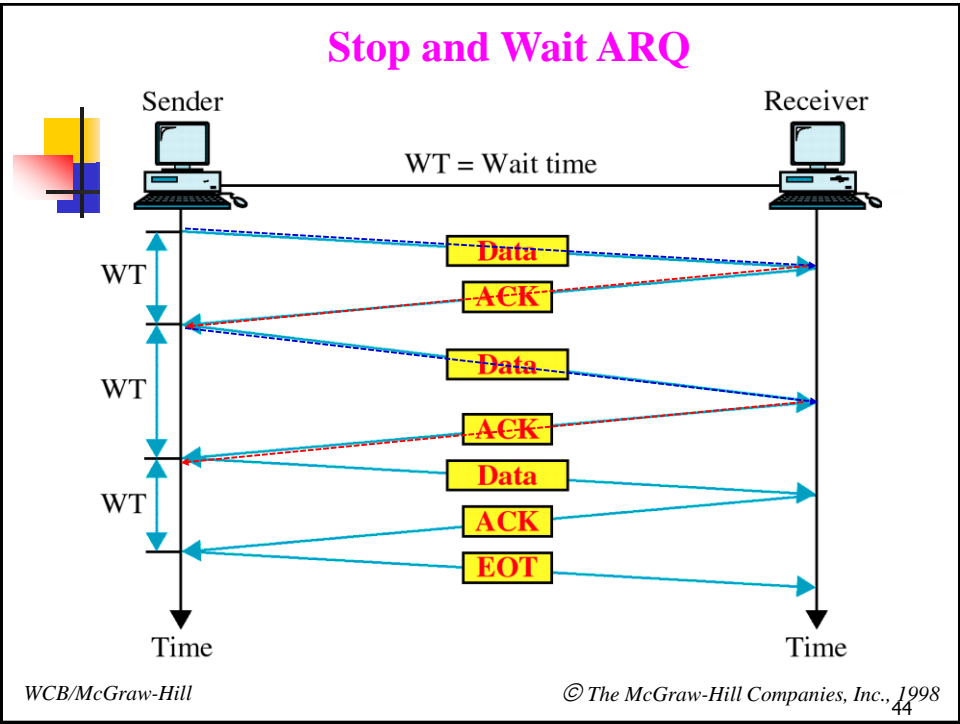
Flow Control with Error Control





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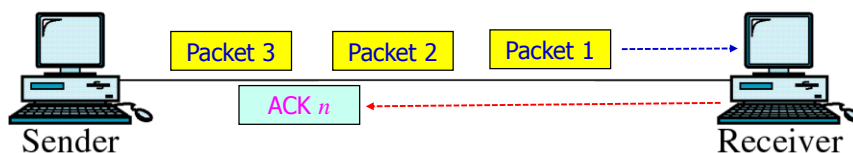
Stop-and-Wait Flow Control

- Simplest form of Frame-Oriented Control
- Source may not send new frame until receiver acknowledges previous one
- Very inefficient, especially when a single message is broken into many small frames
 - buffer size of receiver is limited
 - if error, detected sooner and less data need be retransmitted

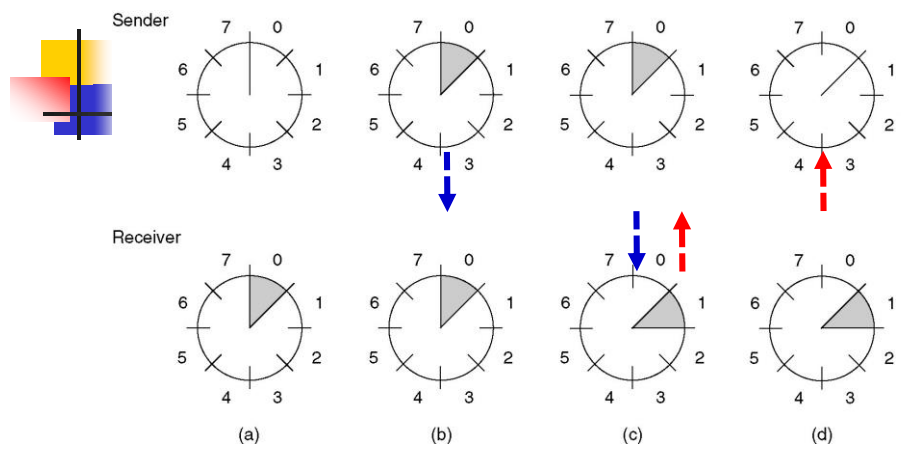
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Sliding-Window Flow Control

- Allows multiple frames to be in transit
- Receiver sends acknowledgement with sequence number of next frame
- Sender maintains list of sequence numbers it can send, receiver maintains list of sequence numbers it can receive

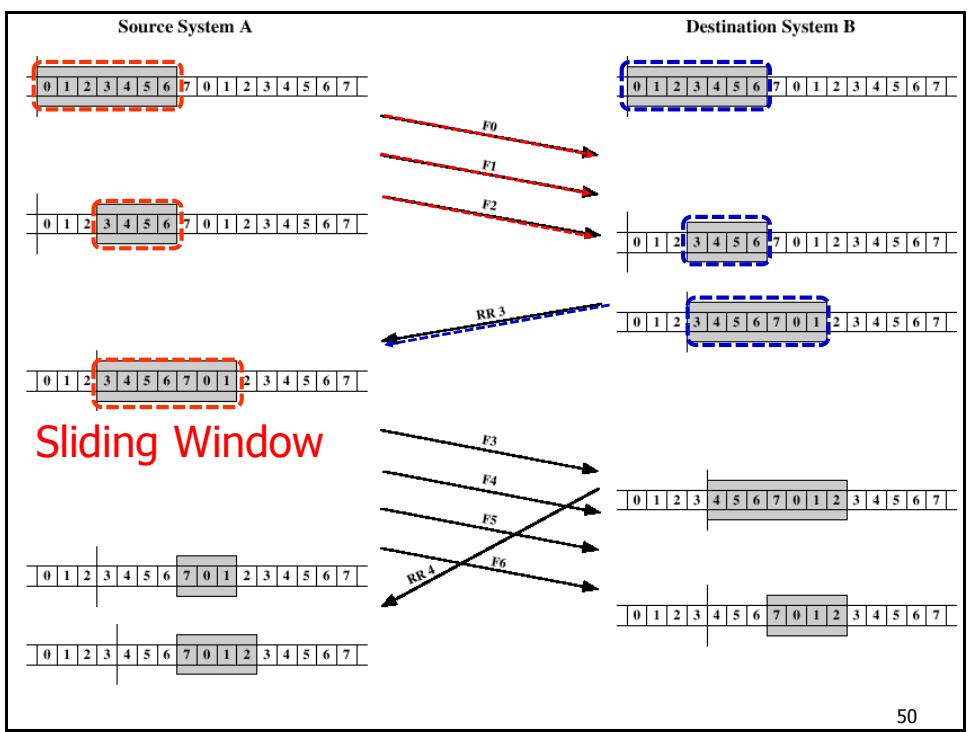


Sliding Window Protocols (2)



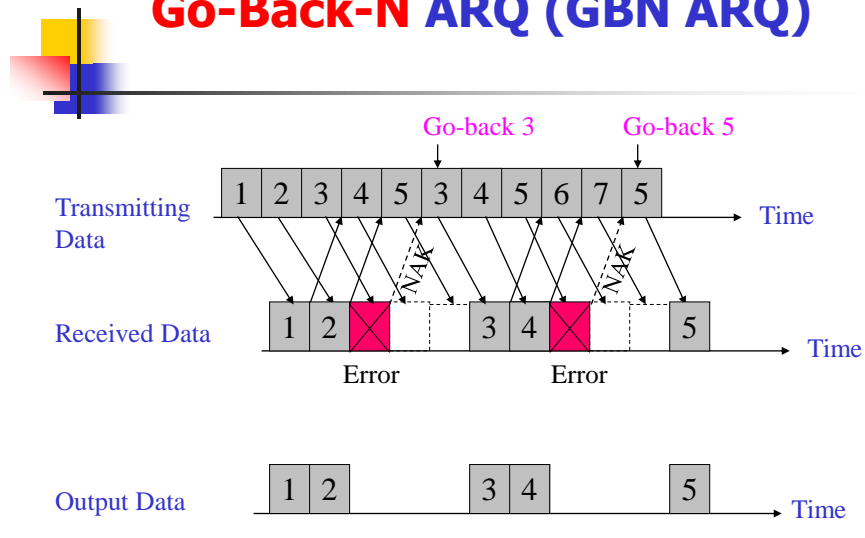
A sliding window of size 1, with a 3-bit sequence number.

- (a) Initially.
- (b) After the first frame has been sent.
- (c) After the first frame has been received.
- (d) After the first acknowledgement has been received.

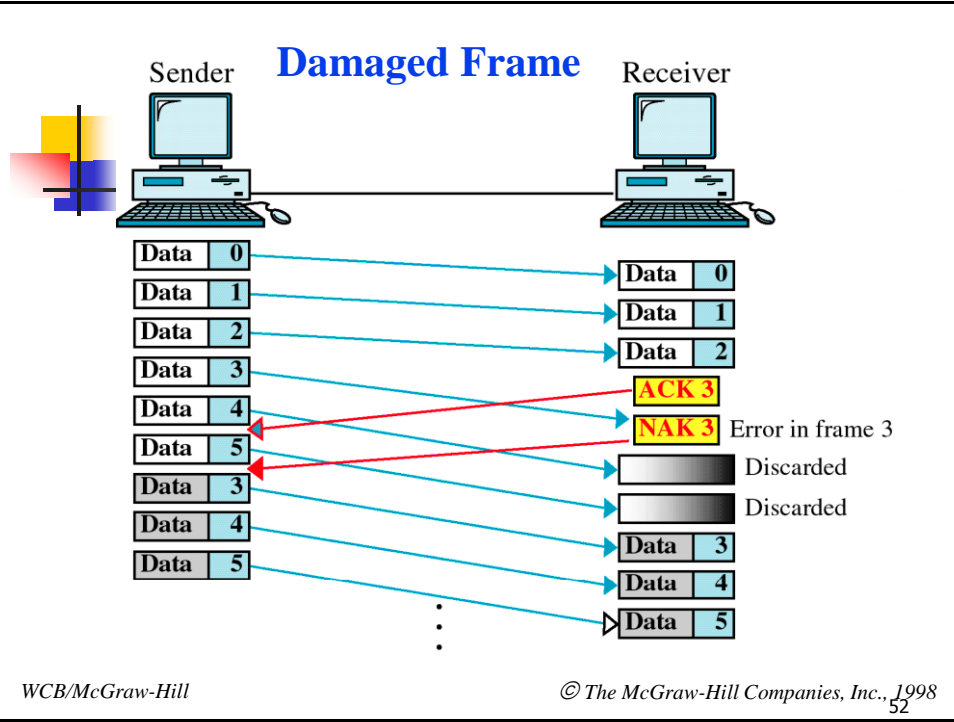


Sliding-Window Flow Control (1)

Go-Back-N ARQ (GBN ARQ)

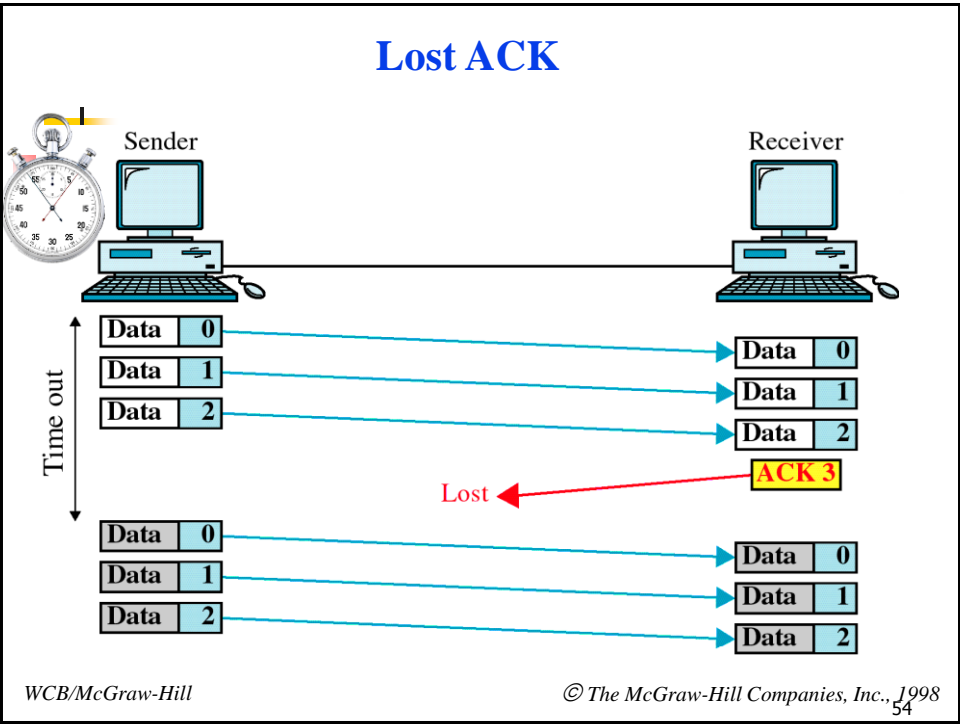
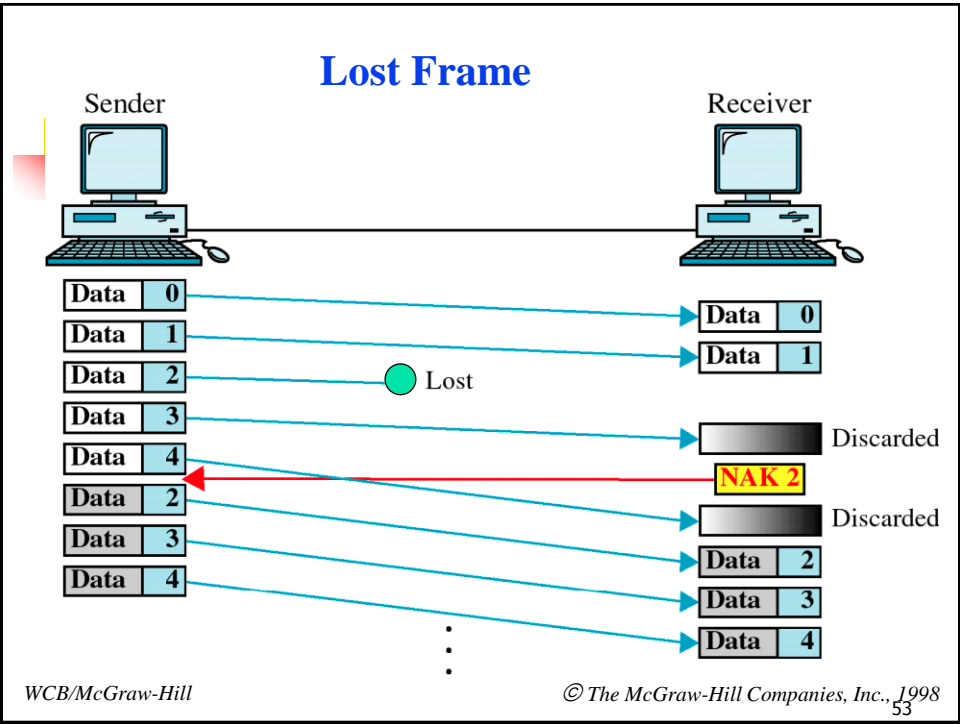


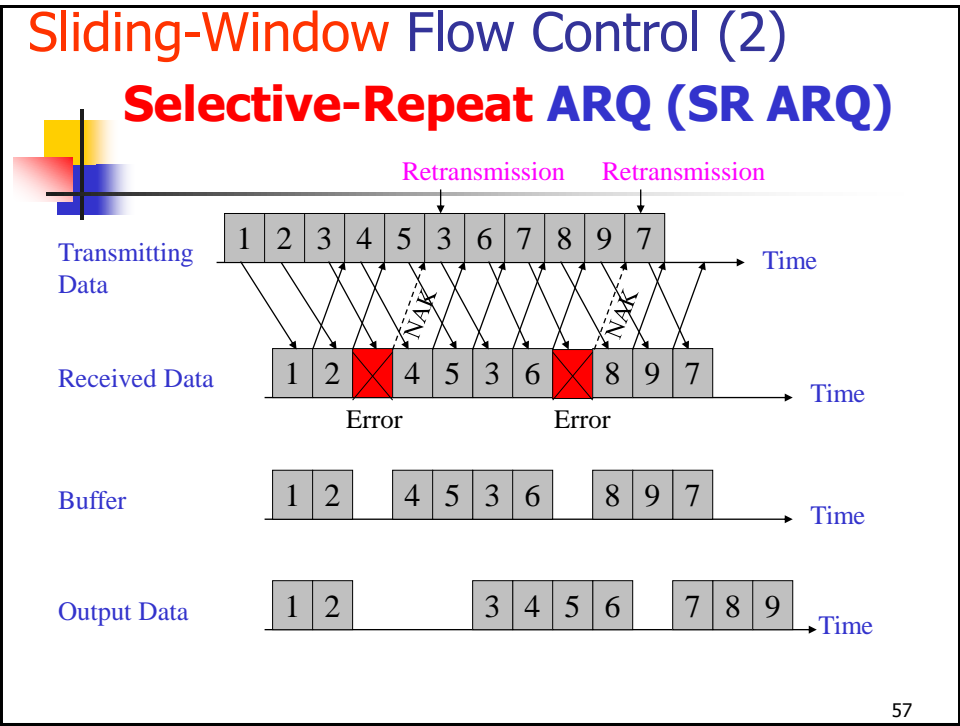
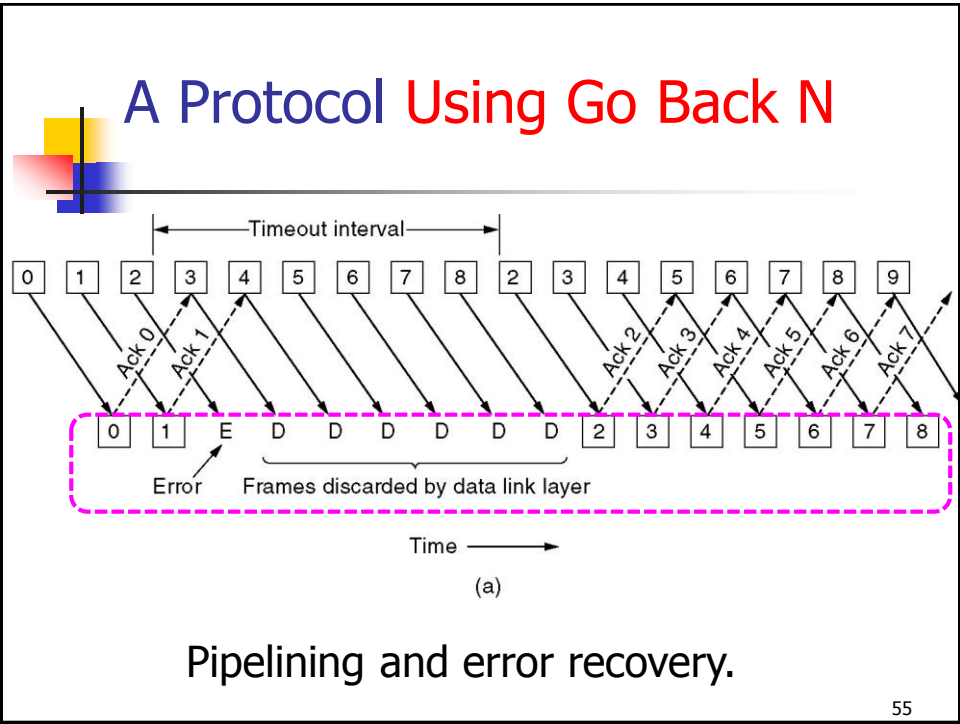
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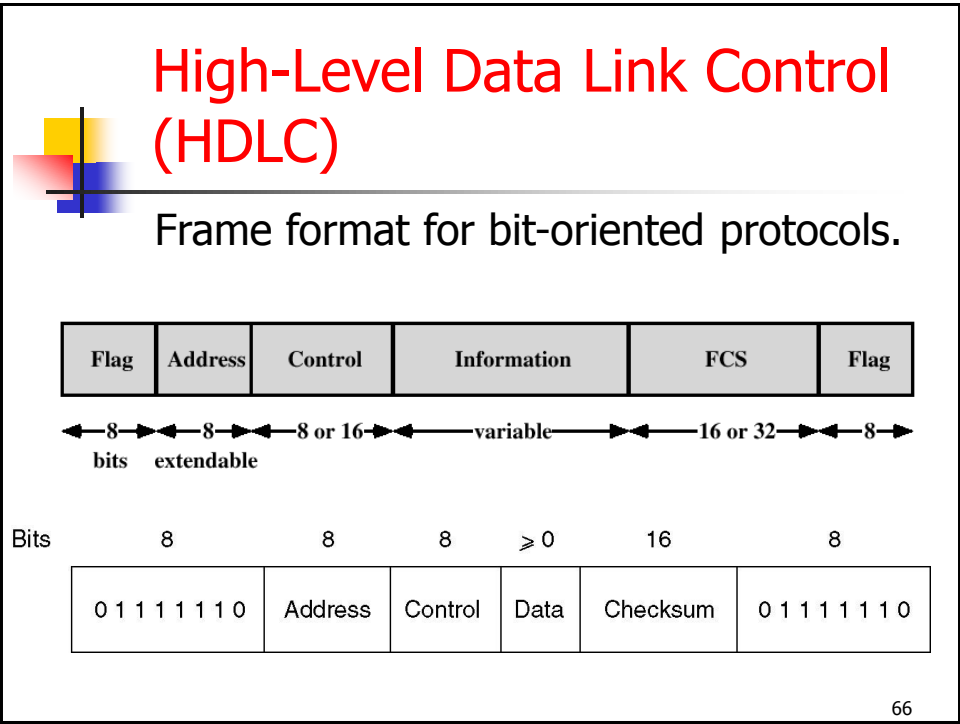
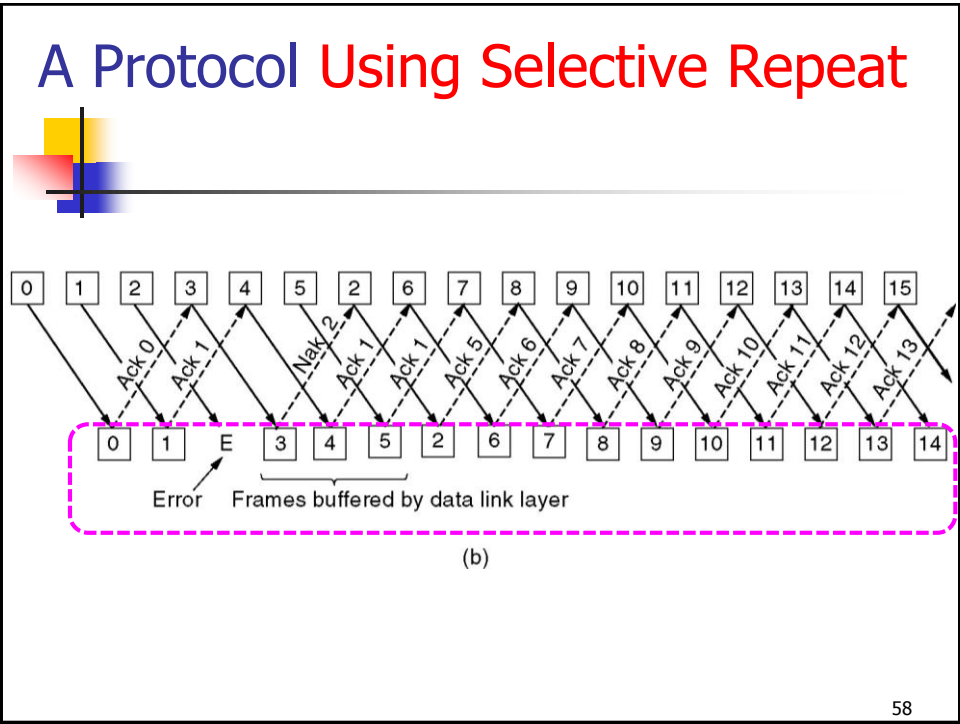


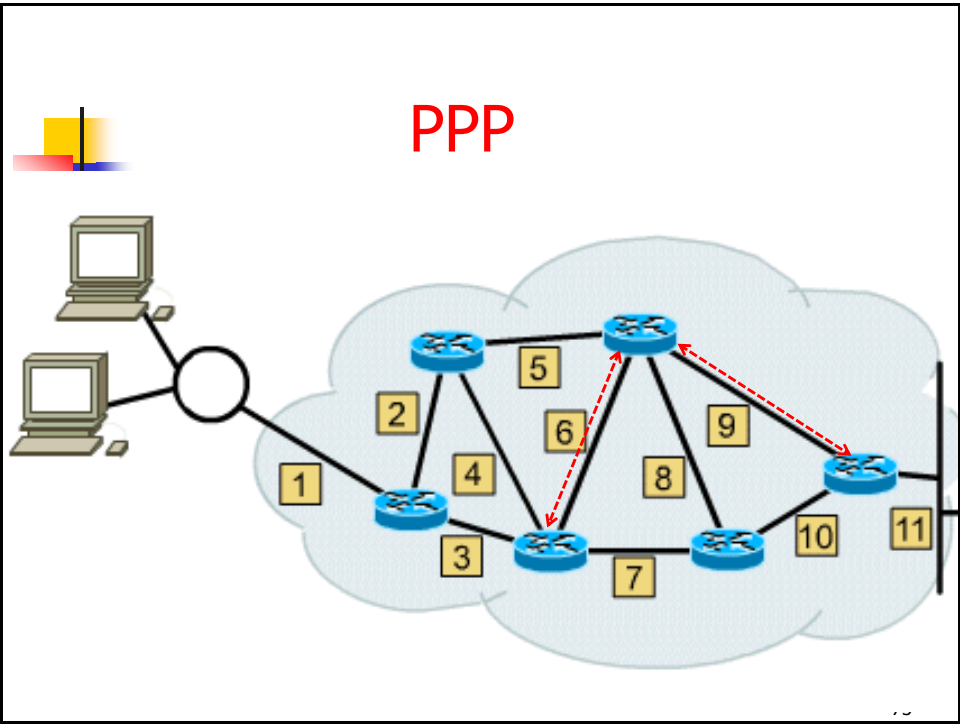
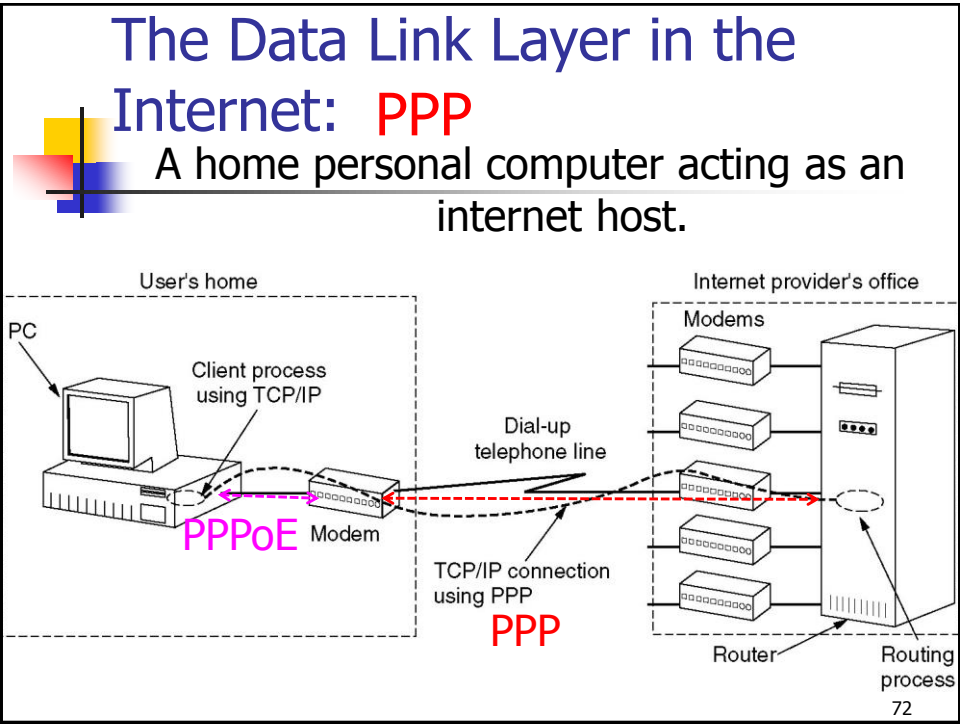
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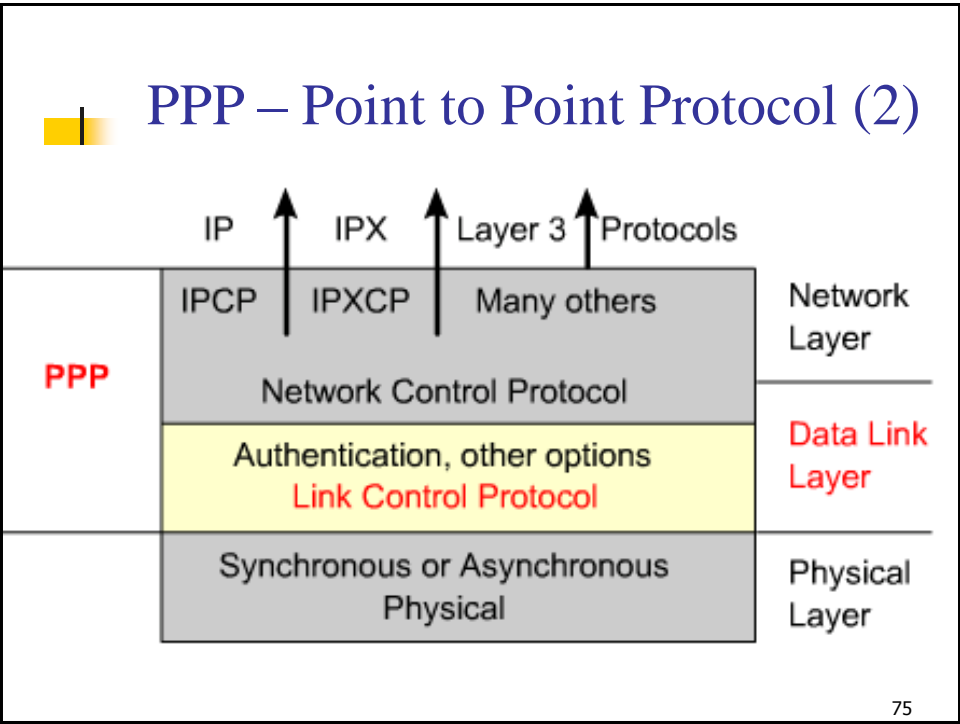
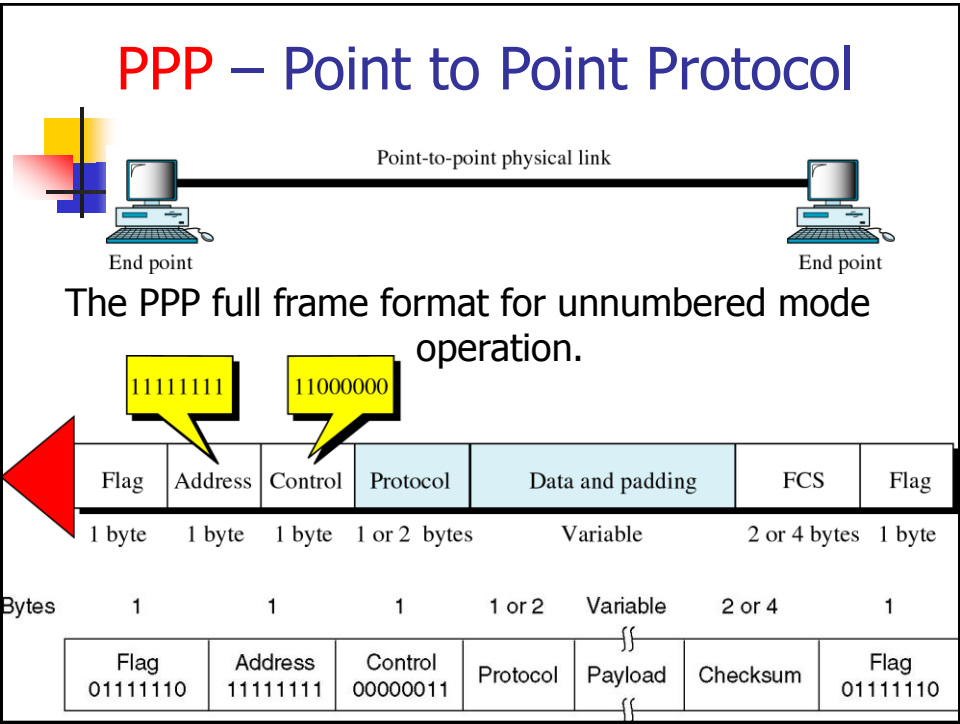
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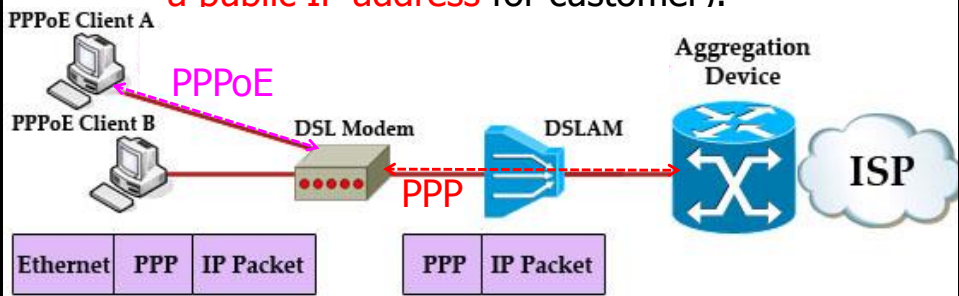






PPP over Ethernet (PPPoE)

- Internet Service Provider (ISP) still like PPP because of authentication (PPP supports CHAP), accounting (checking customer's bill), link management (ISP can use PPP to assign a public IP address for customer).

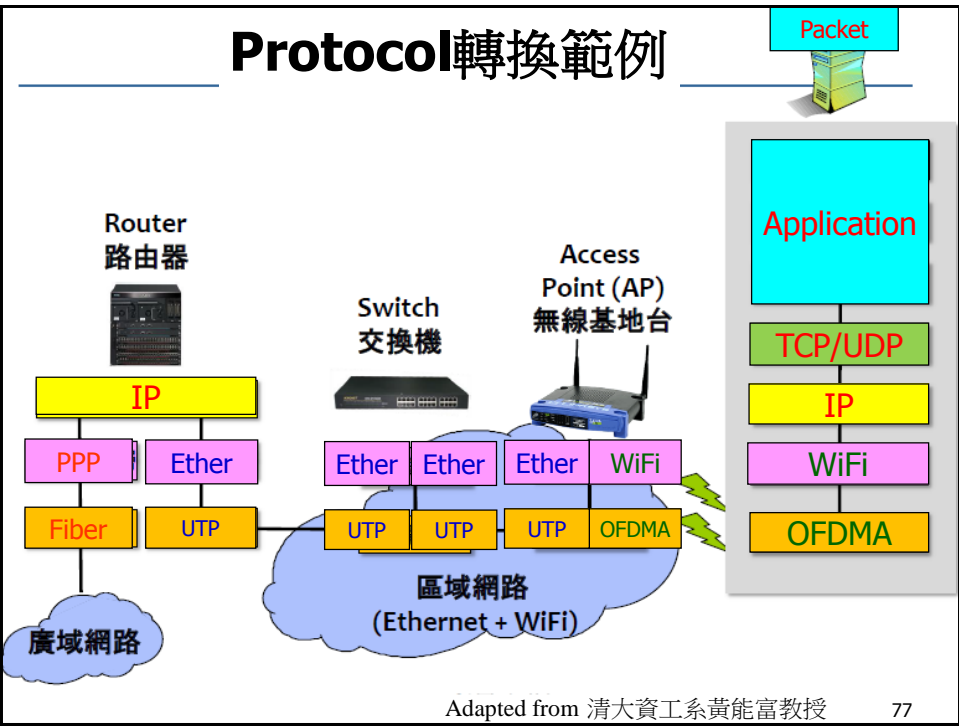


DSLAM: Digital Subscriber Line Access Multiplexer

Source: <http://www.digitaltut.com/ppp-over-ethernet-pppoe-tutorial>

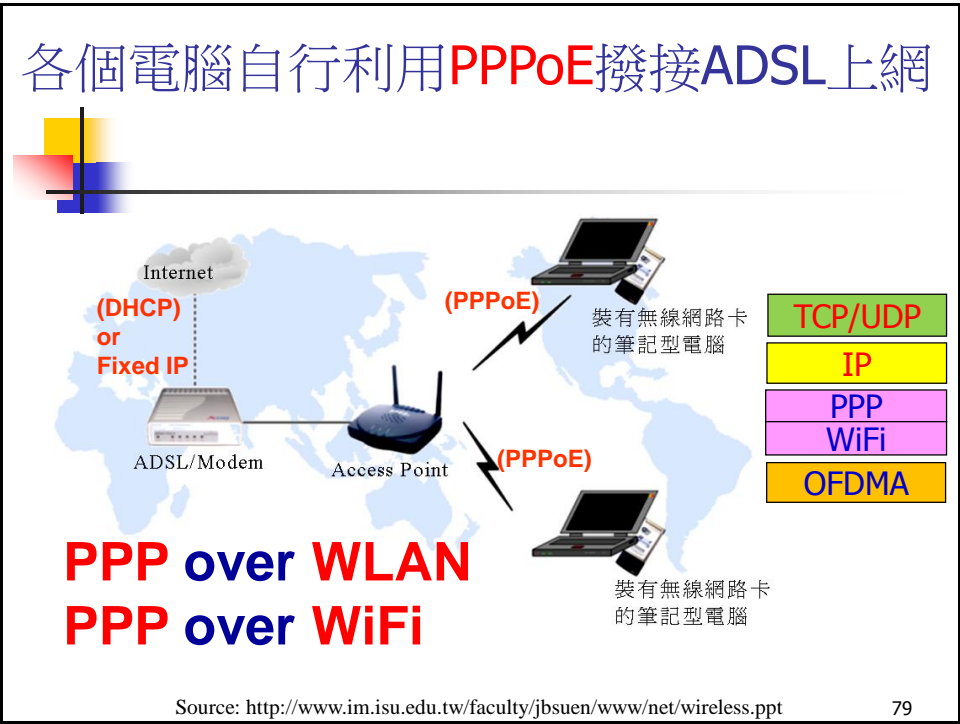
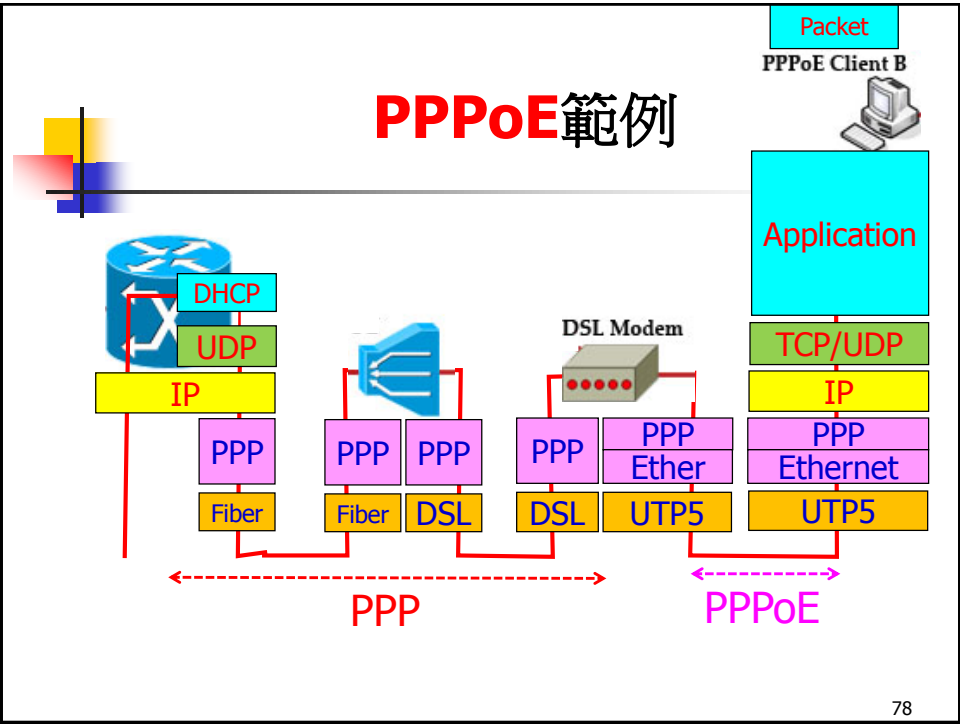
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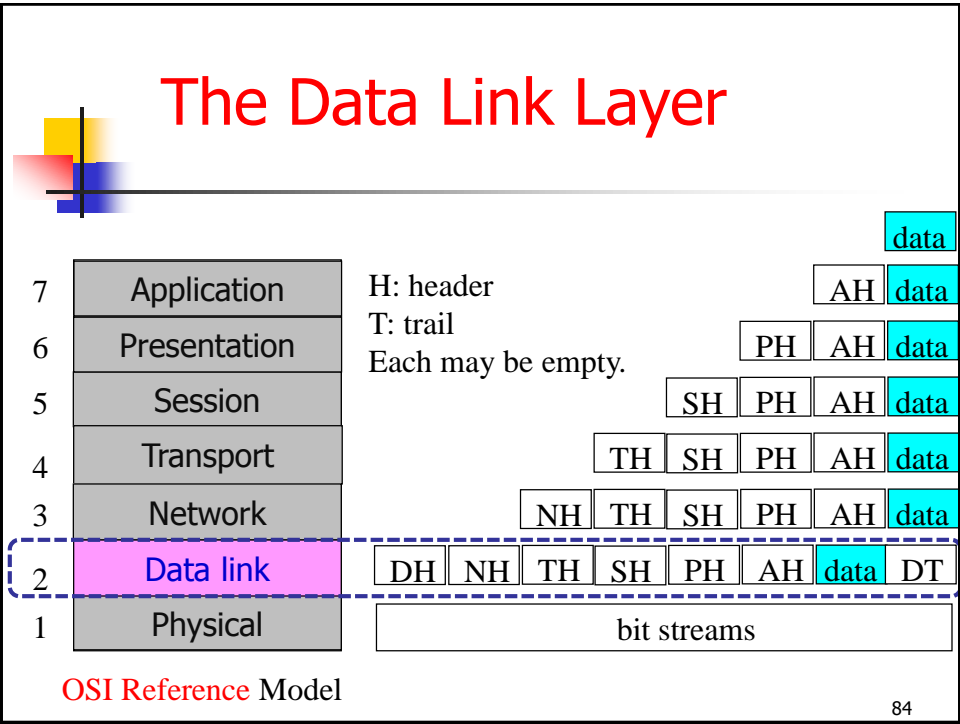
Protocol轉換範例



Adapted from 清大資工系黃能富教授

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End of Chapter 3

Questions?

Thank you!

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