Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

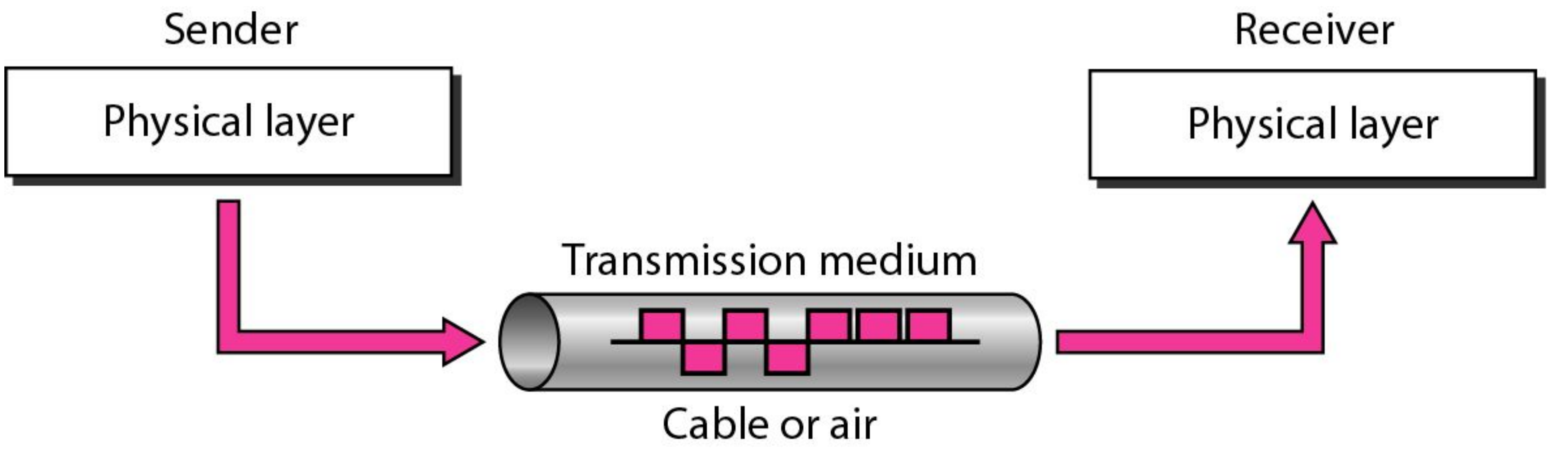
Lecture 8

Module 2- part 1

The Physical layer

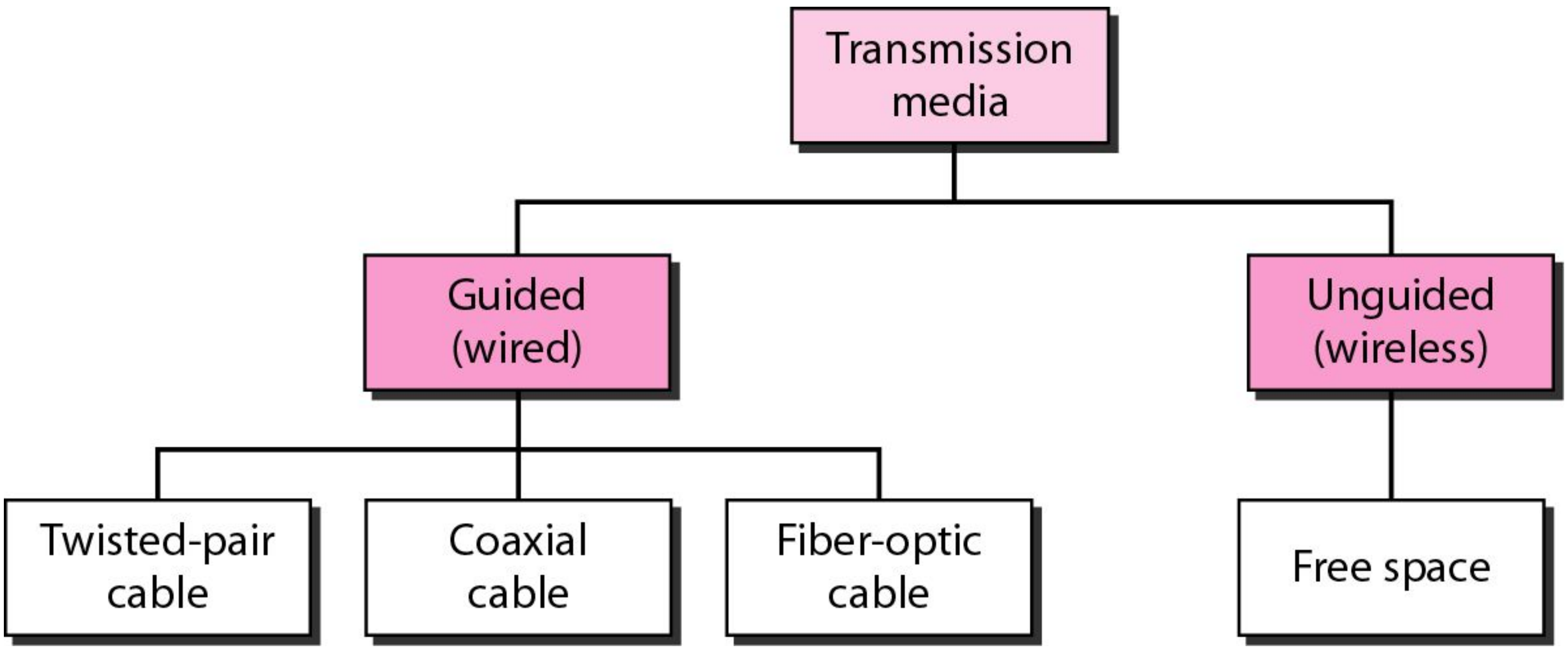
- ***Guided Media,***
- ***Unguided Media, Wireless Transmission: Electromagnetic Spectrum.***
- ***Switching: Circuit-Switched Networks, Packet Switching***
- ***Structure Of A Switch***

Transmission medium



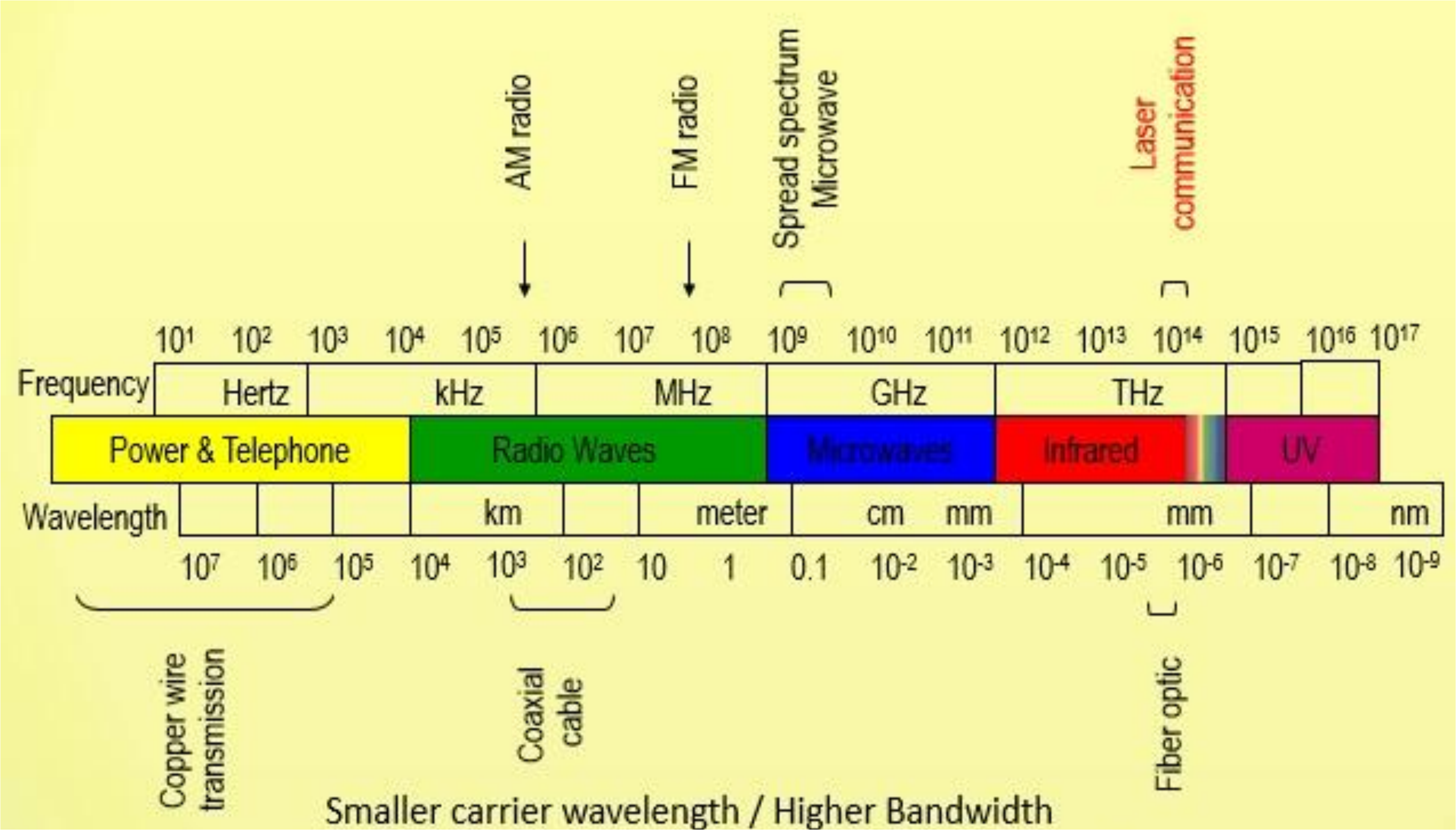
Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Classes of transmission media



Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Electromagnetic Spectrum



Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

GUIDED MEDIA

Guided media, are those that provide a conduit from one device to another

Includes twisted-pair cable, coaxial cable, and fiber-optic cable

~~Topics discussed in this section:~~

Twisted-Pair Cable

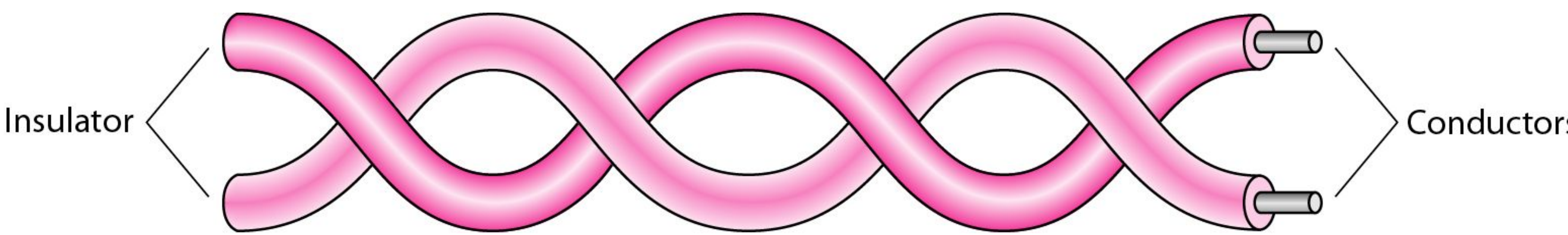
Coaxial Cable

Fiber-Optic Cable

Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

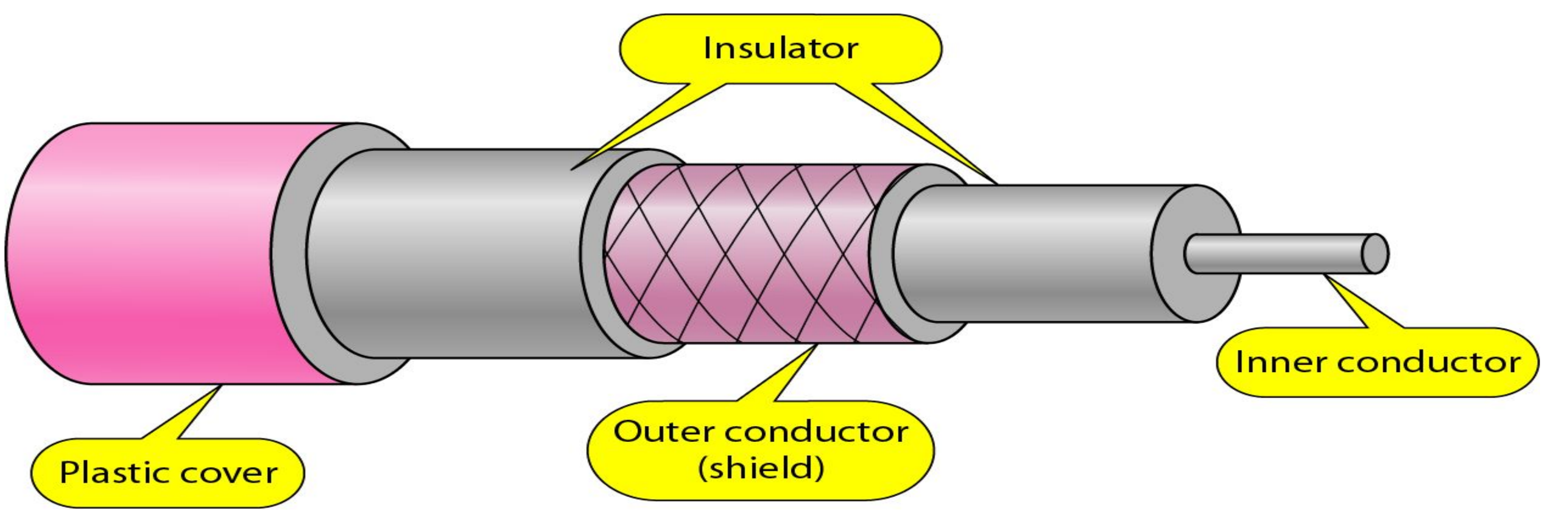
Twisted-pair cable

- Consist of two conductors (normally copper),
  - each with its own plastic insulation
  - twisted together
- One carry signal and other for ground reference
- Twisting : achieve better noise rejection
- Applications:
  - Telephone lines, DSL lines, LANs



Coaxial Cable

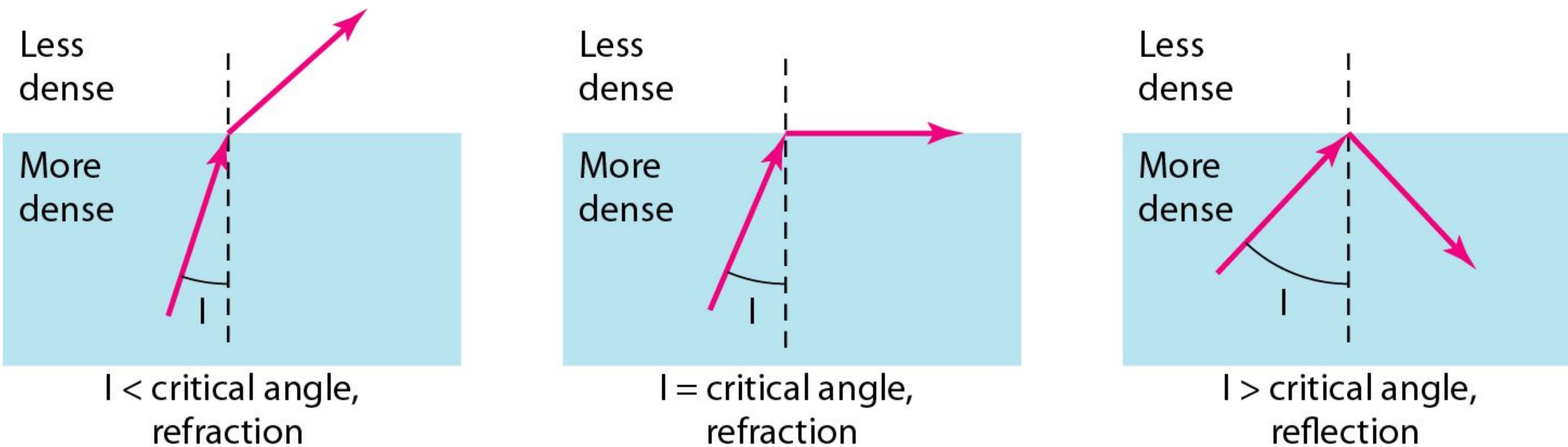
- Central core conductor of solid or stranded wire (copper) enclosed in an insulating sheath
- Outer conductor is of metal foil encases the inner conductor shielding it against noise
- The outer conductor is enclosed in an insulating sheath and the whole cable is protected by a plastic cover
- Applications: BNC connectors, Cable TV, Ethernet LANs



Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Fiber Optics Cable

- Made up of glass or plastic
- Transmits signal in the form of light
- Use **Reflection property** of light for its working



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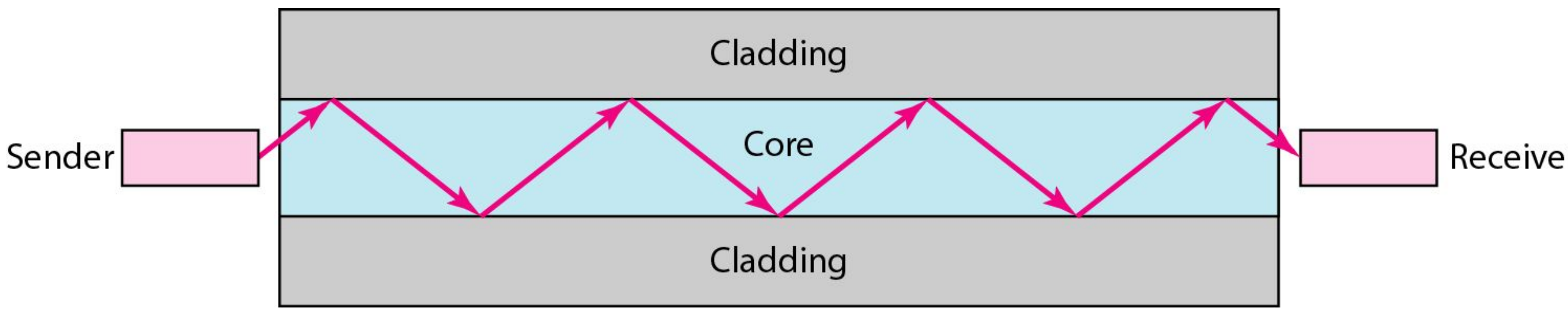
Optical fiber



Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Fiber Optics Cable- Advantages & Disadvantages

- **Advantages:**
  - Higher Bandwidth compared to coax and twisted pair cables
  - Less signal attenuation
  - Immunity to electromagnetic interference
  - Resistance to corrosive materials
  - Light weight
  - Grater immunity to tapping
- **Disadvantages:**
  - Installation and maintenance
  - Unidirectional light propagation
  - cost

Questions

1. How do guided media differ from unguided media?
2. What are the three major classes of guided media?
3. What is position of transmission media in the OSI model?
4. What is the significance of the twisting in twisted pair cable?

Computer Network & Network Design

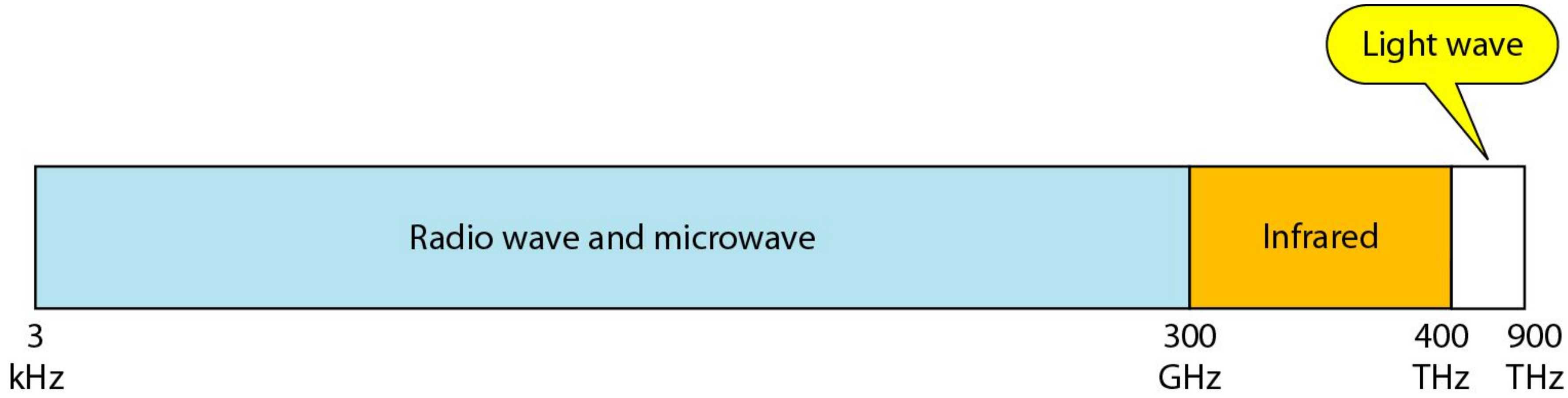
Module 2

Physical Layer & Data Link Layer

Lecture 9

UNGUIDED MEDIA

- Unguided media transport electromagnetic waves without using a physical conductor.
- Widely known as **Wireless Communication**.
- Signals are normally broadcast through free space and thus are available to anyone who has device to receive them.



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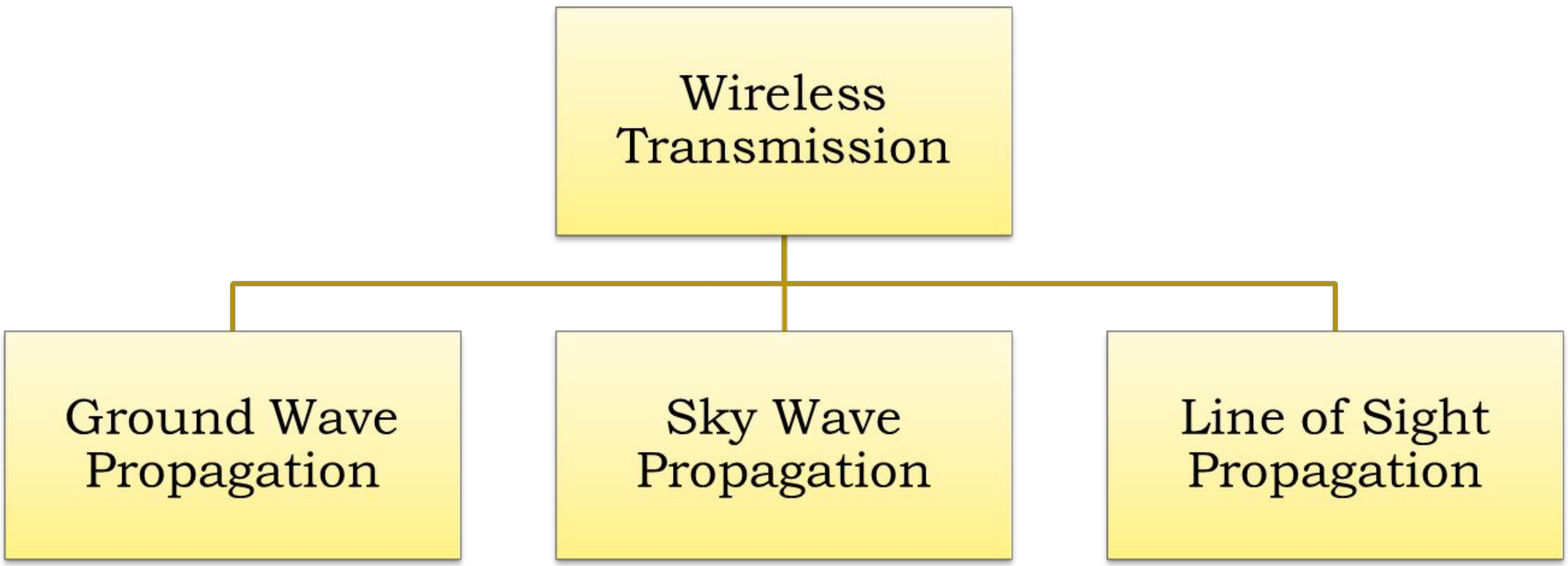
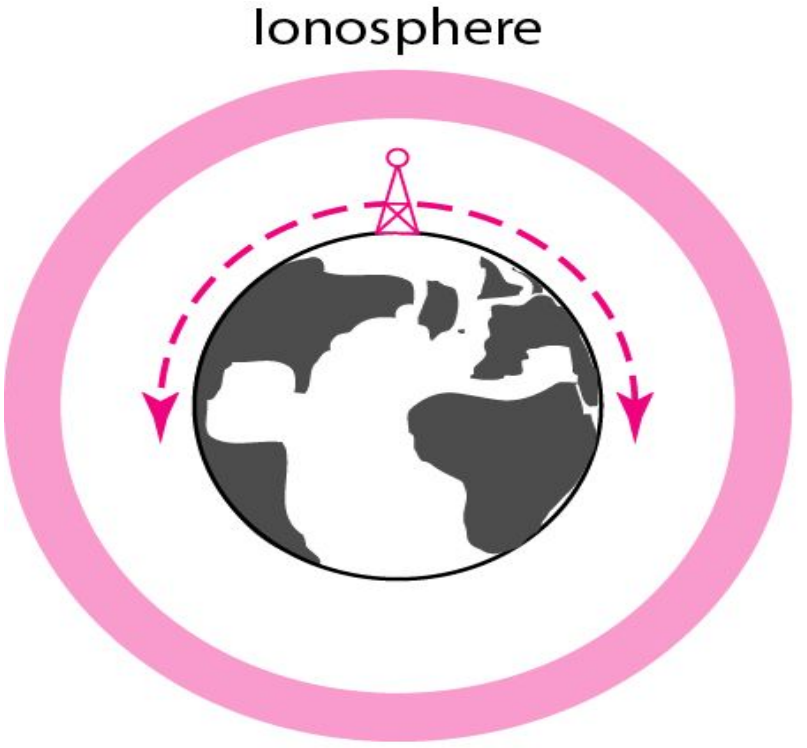
Wireless transmission



Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Ground Propagation

- Signal travel through the lowest portion of the atmosphere, following the curvature of the planet
- Distance depend on the power of signal. Greater the power greater is a distance.

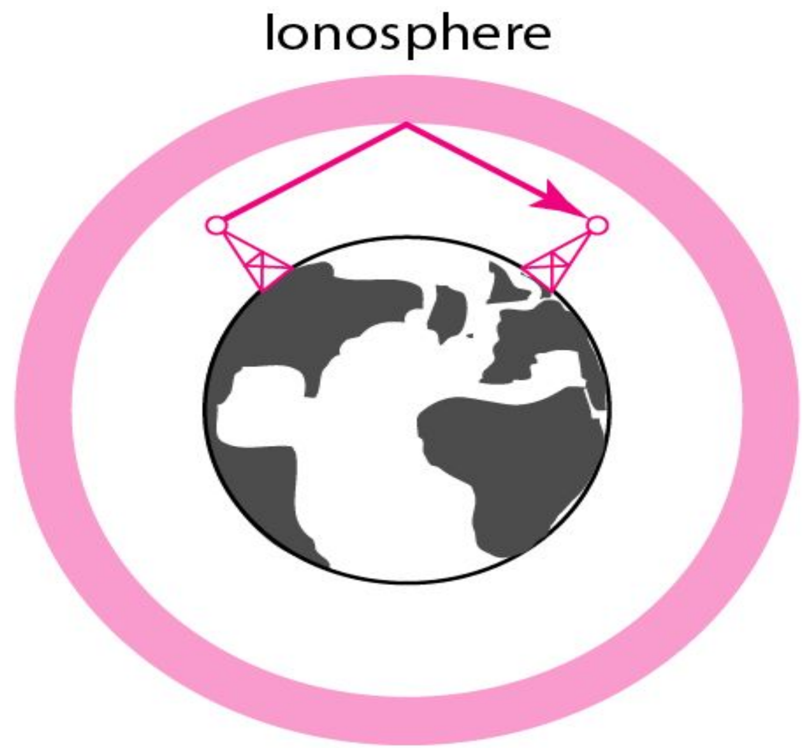


Ground propagation
(below 2 MHz)

Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Sky Propagation

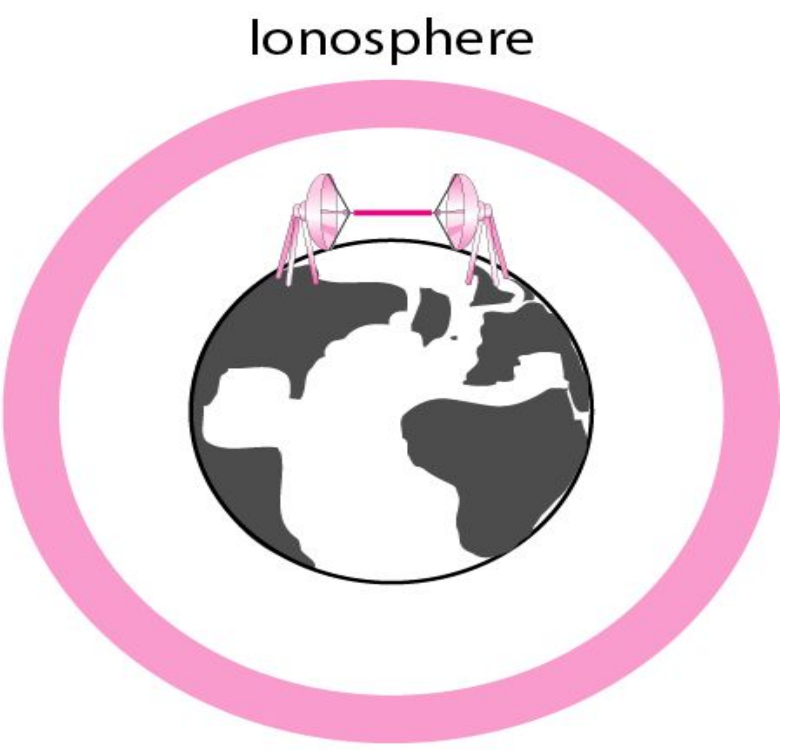
- High frequency radio waves radiate upward into the ionosphere and are reflected back to earth.
- It allows greater distances with lower output power.



Sky propagation
(2–30 MHz)

Line of sight Propagation

- Very High frequency radio waves are transmitted in straight lines directly from antenna to antenna.
- Thus distance between antenna's is less and they should be directional, facing each other.



Line-of-sight propagation
(above 30 MHz)

Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

Wireless Frequency Bands

Band	*Range*	*Propagation*	*Application*
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education.

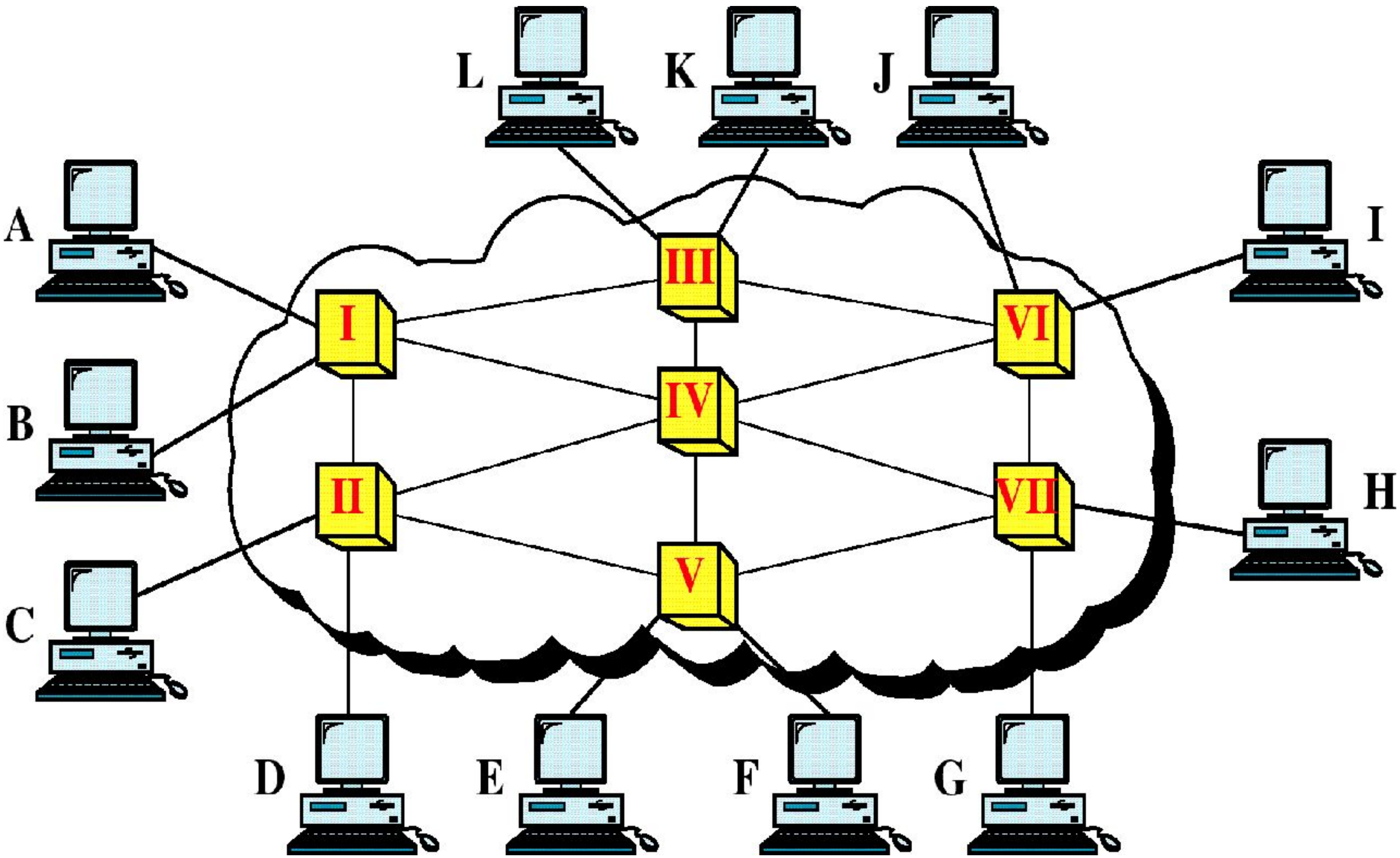
Switching

- Connection of multiple devices through network topologies (mesh, star, ring, bus) is complex for larger networks.
- Mesh and star topologies needs too much infrastructure to be cost efficient and majority of links goes idle most of the times.
- The solution is **SWITCHING**.
- A switched network has a series of interconnected nodes, called **SWITCHES**.
- Switches are hardware or software devices.
- Some are connected to communicating devices and others are used only for routing.

Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks - 4th Edition, Pearson Education

Ch8: Switching, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

A Switched Network



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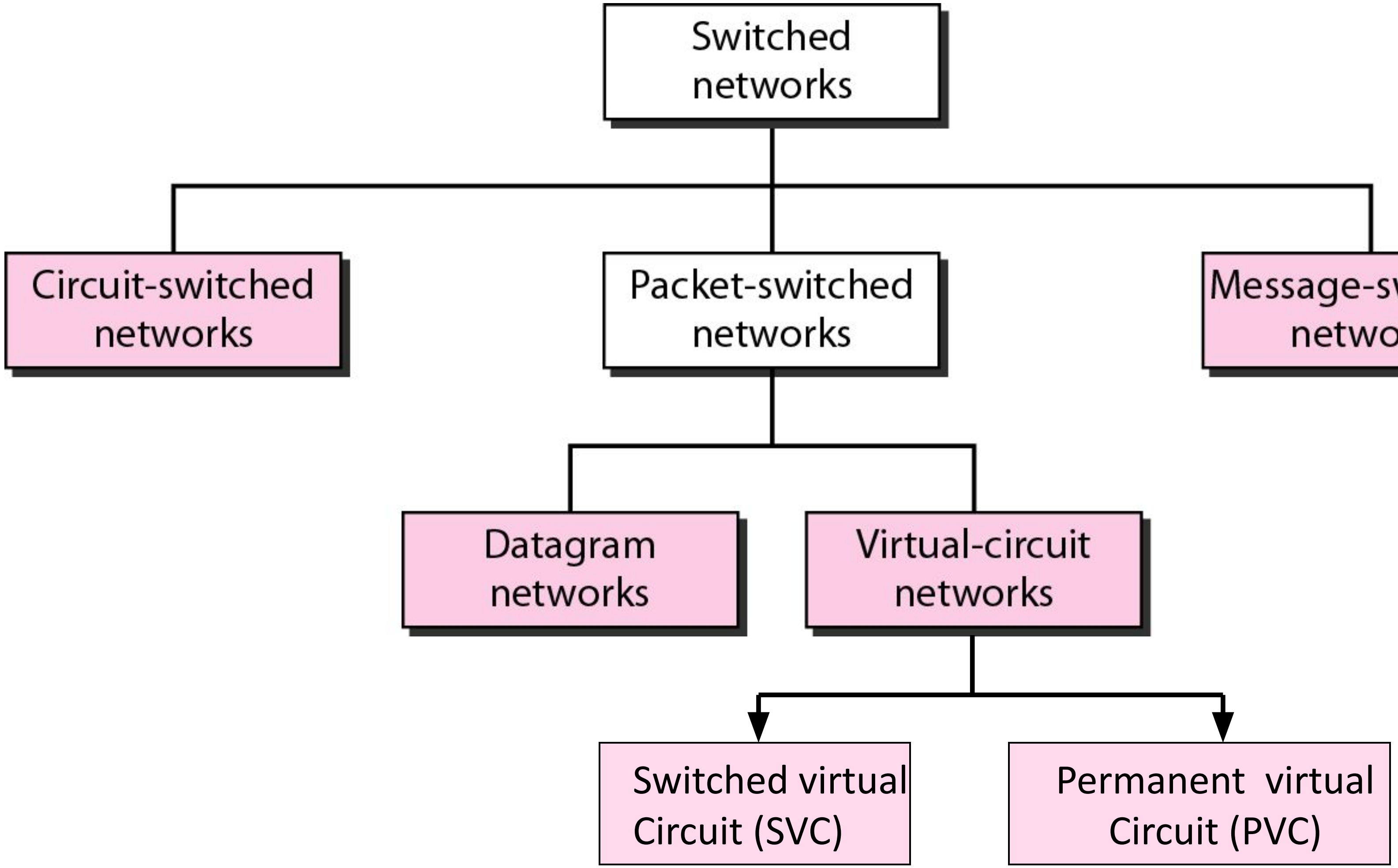
Switching Methods



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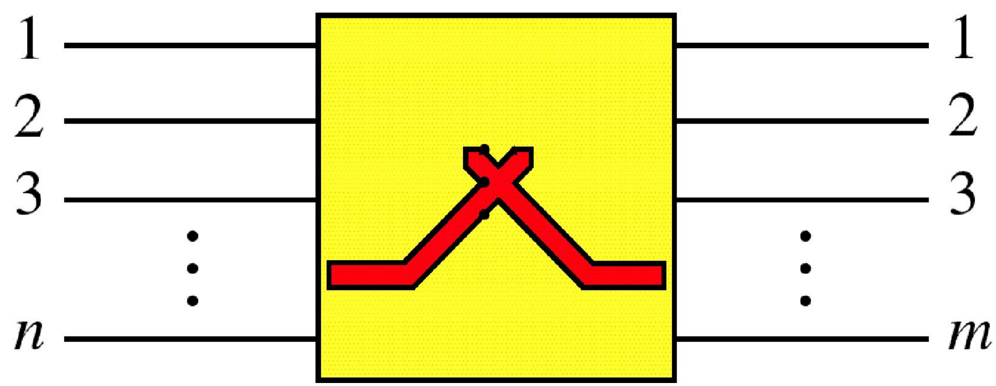
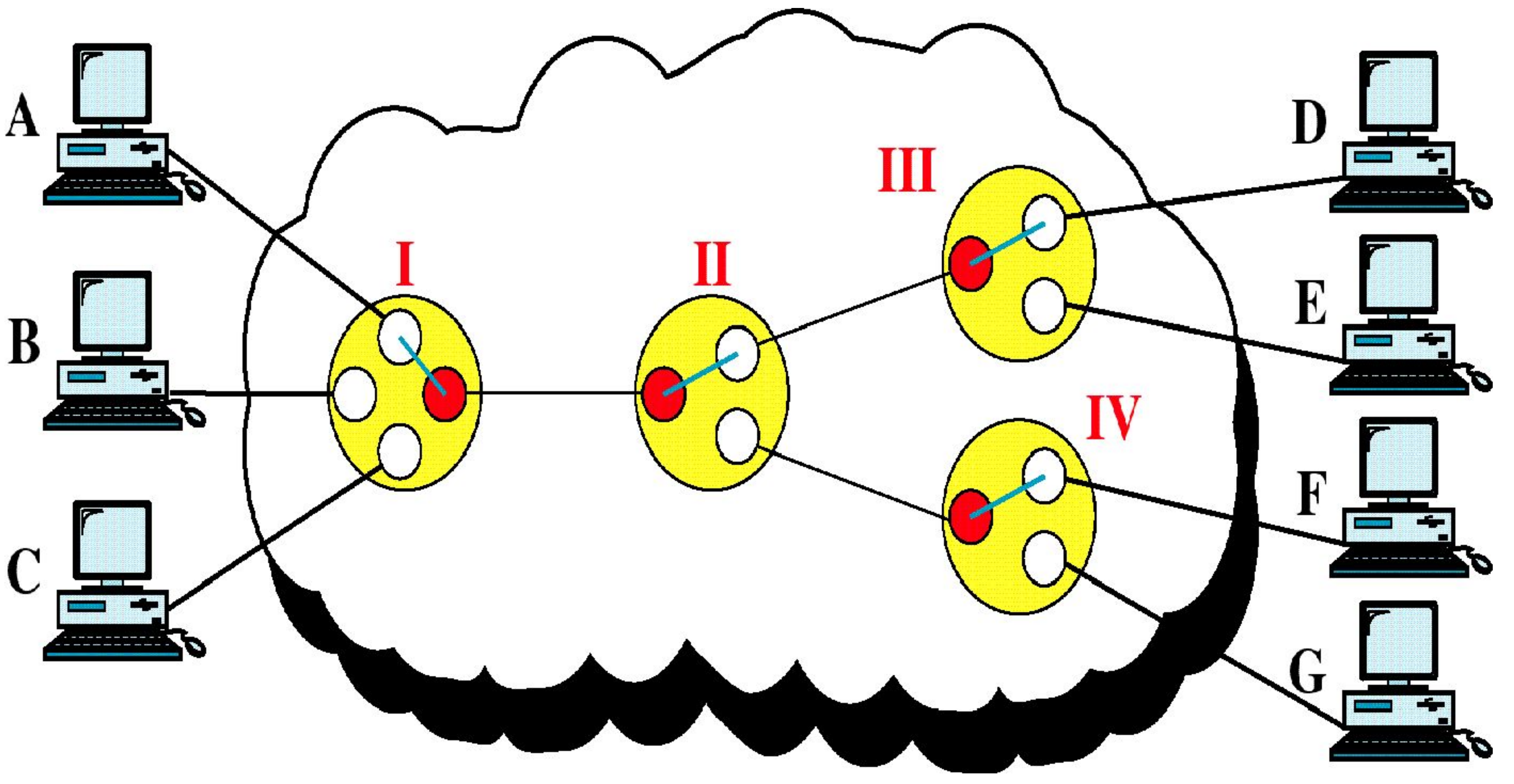
Circuit Switching

- Circuit switching creates a direct physical connection between two devices.
- It can be considered as a device with *n* inputs and *m* outputs. *m* and *n* need not match



Circuit Switched Network



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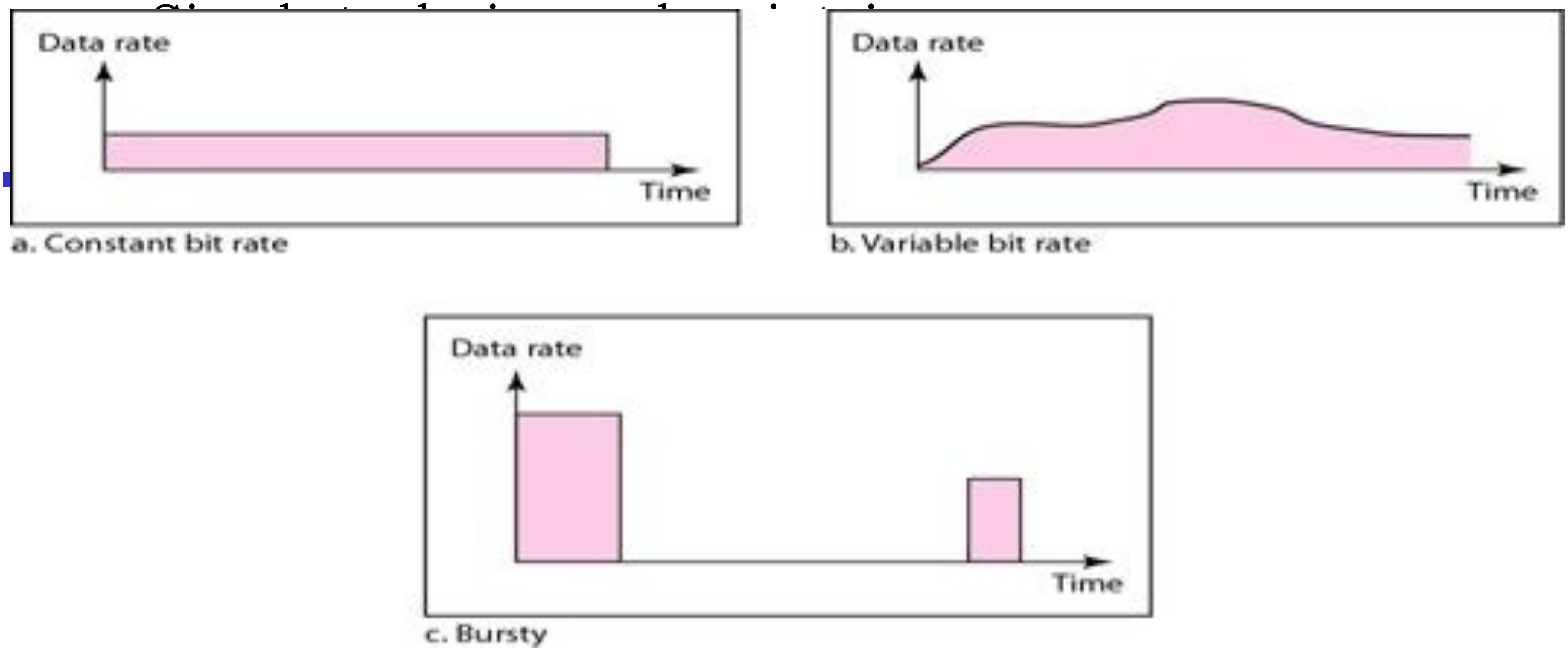
Advantages & Disadvantages

- Advantages:
  - Well suited where **dedicated links** are needed e.g. **voice communication, telephones**



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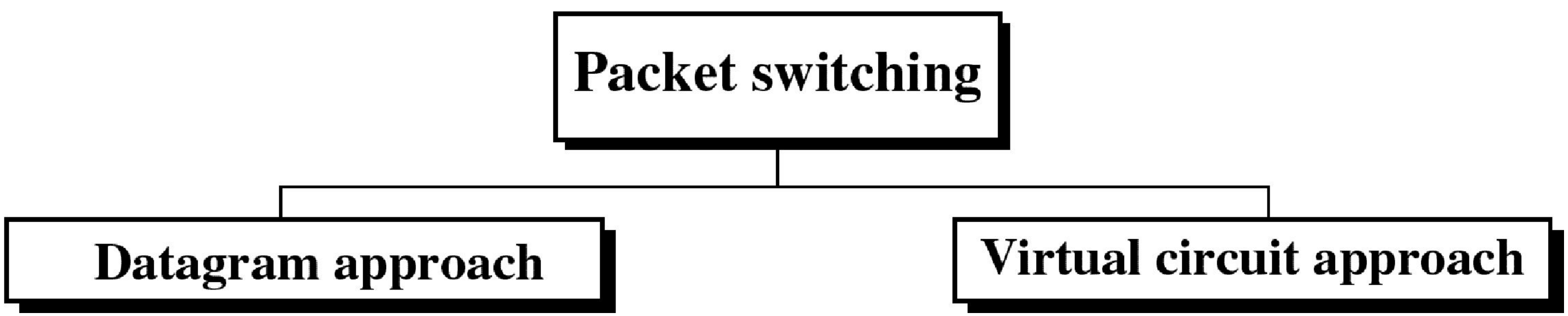
Packet Switching

- Data is transmitted in discrete units of variable length, called **packets**.
- Longer data are broken up into multiple packets.
- Each packet contains header information such as priority codes, source and destination addresses.
- Packets are sent over the network from node to node
- A packet is temporarily stored at every node and then routed according to the information in its header.



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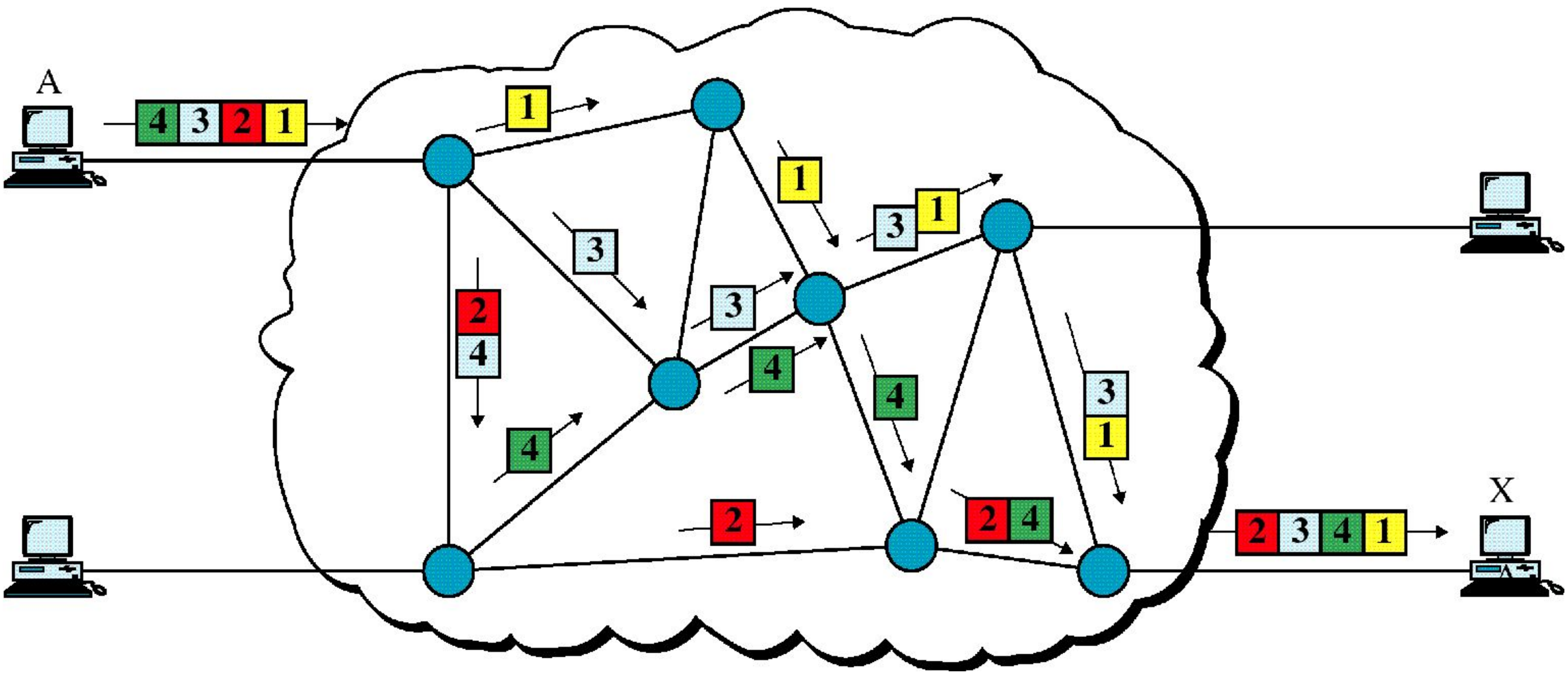
Datagram Approach

- Each packet is treated independently from others
- Network treats each packet as though it existed alone
- Packets in this technology are referred as **"Datagrams"**



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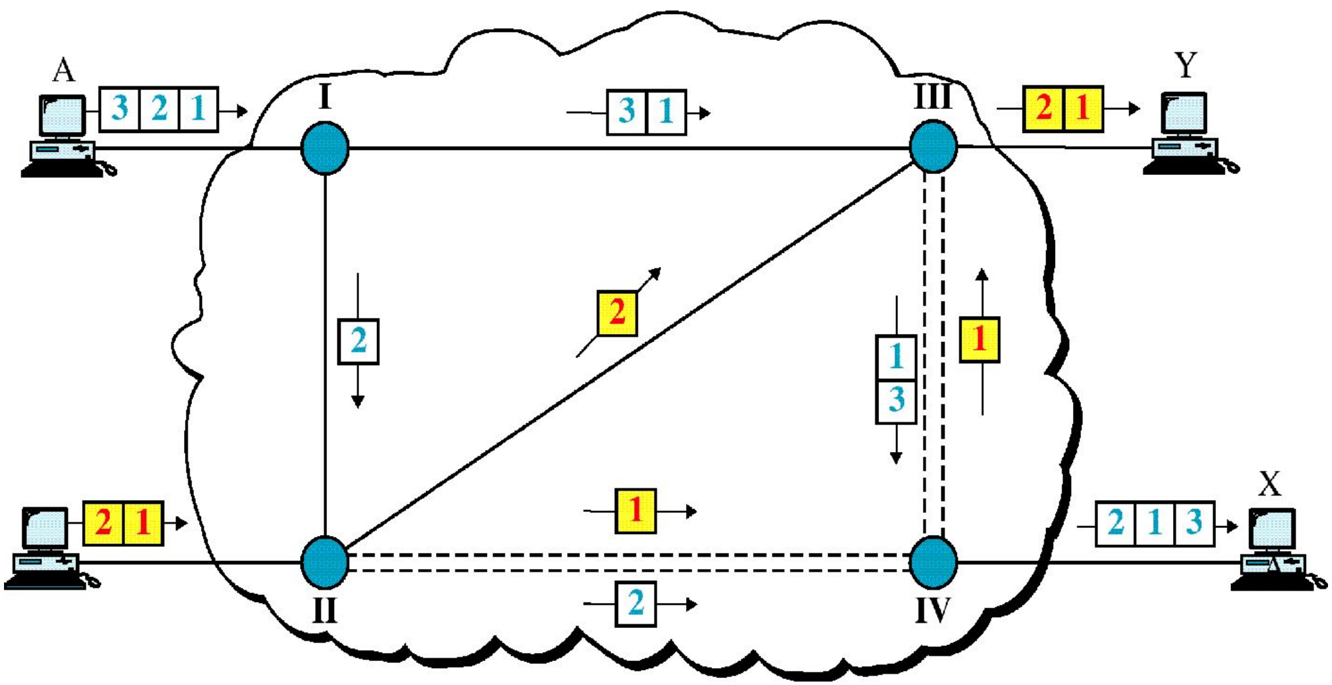
Datagram Approach- Multiple Channels

- This approach causes datagrams to arrive out of order.
- Transport layer is responsible for reordering this packets.
- Links can use multiple channel concept where multiplexing (TDM or FDM) can be used.



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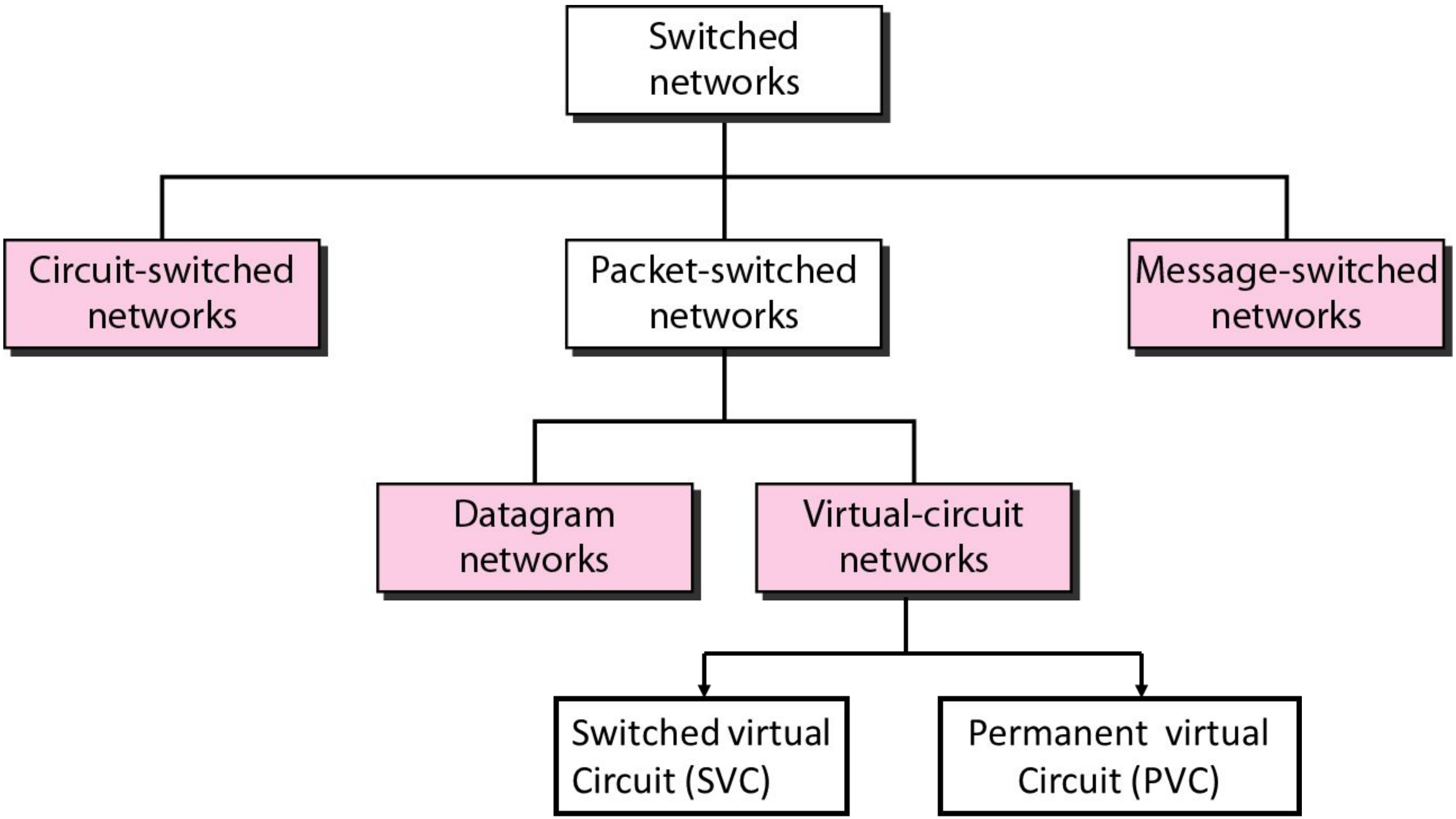
Switching Methods



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Computer Network & Network Design

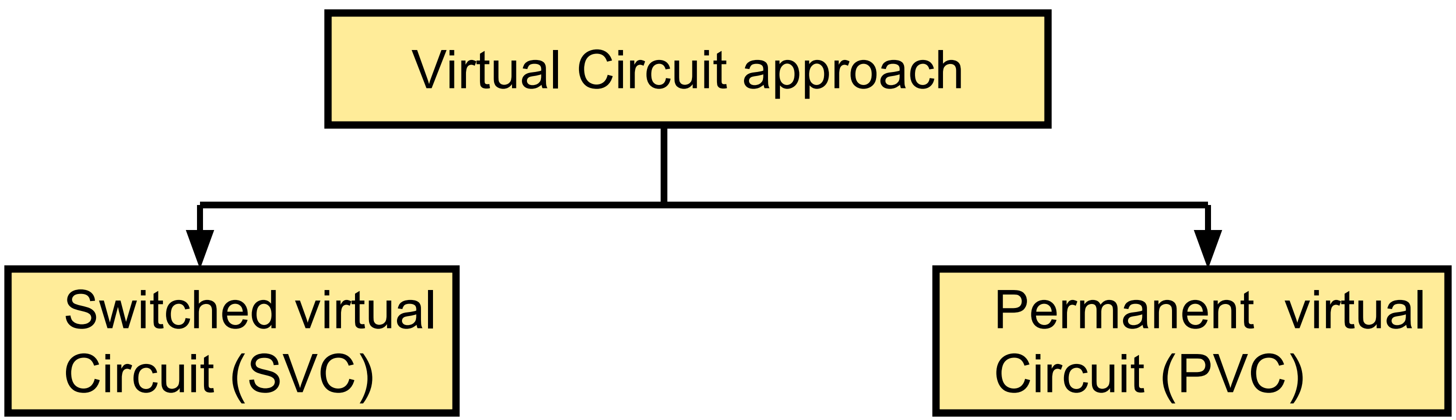
Module 2

Physical Layer & Data Link Layer

Lecture 10

Virtual Circuit Approach

- A relationship between all packets belonging to a message is preserved.
- At the beginning of the session, a single route is chosen between sender and receiver.
- During the data transmission, all packets of the transmission travel one after another along the same path.



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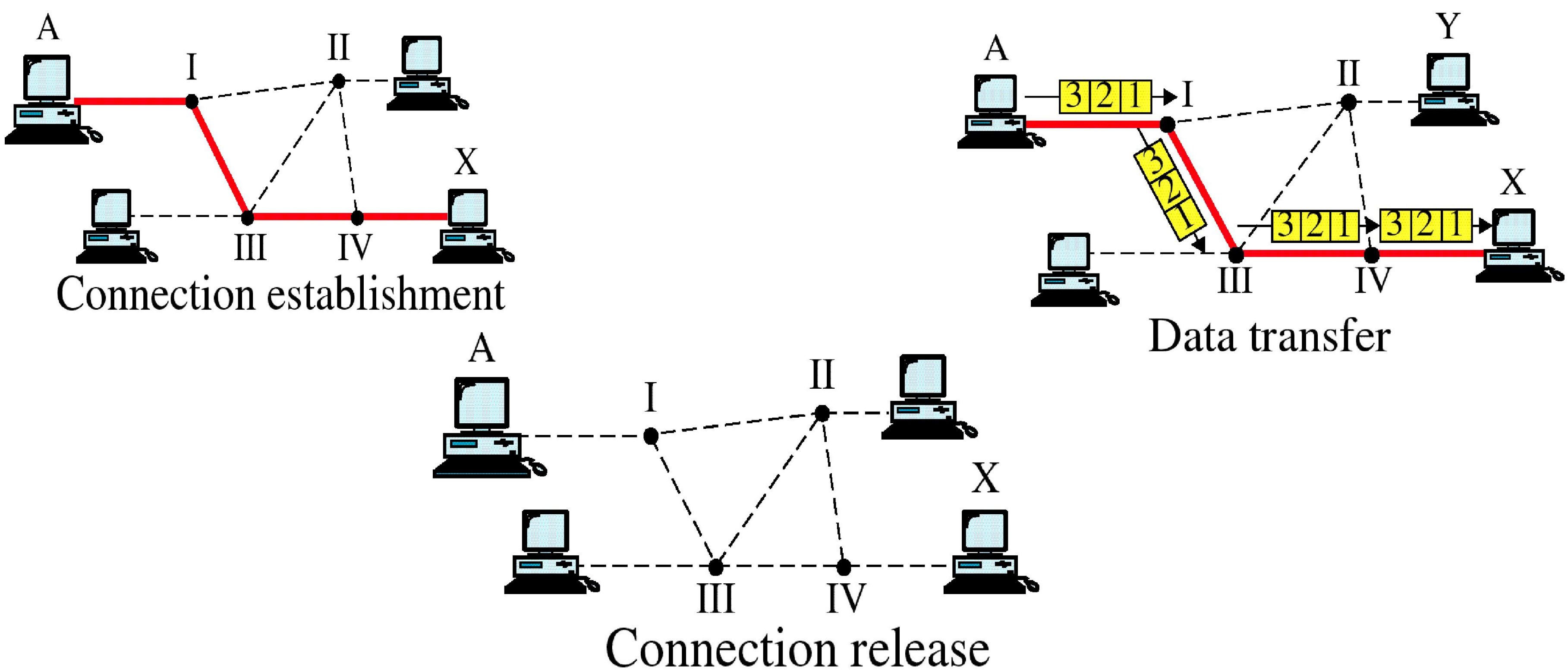
Switched Virtual Circuit Approach (SVC)

- A virtual circuit is created whenever it is needed and exists only for the duration of data transfer.
- In response to failure or congestion, a network can pick an alternate route.

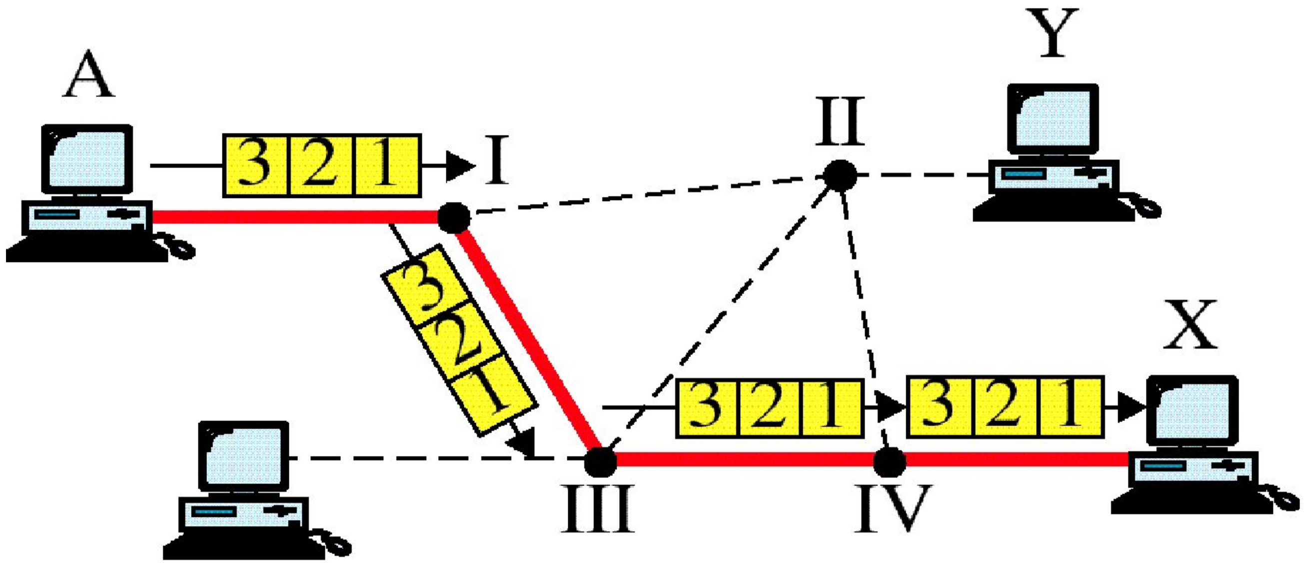


Reference: Ch2: The Physical Layer, Andrew S Tanenbaum, Computer Networks - 4th Edition, Pearson Education

Ch8: Switching, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education

Permanent Virtual Circuit Approach (PVC)

- Same virtual circuit is provided between two users on a continuous basis.
- The path is dedicated to specific users. No one else can use it.
- Two SVC users may get different route every time they request a connection, whereas two PVC users always get the same route.



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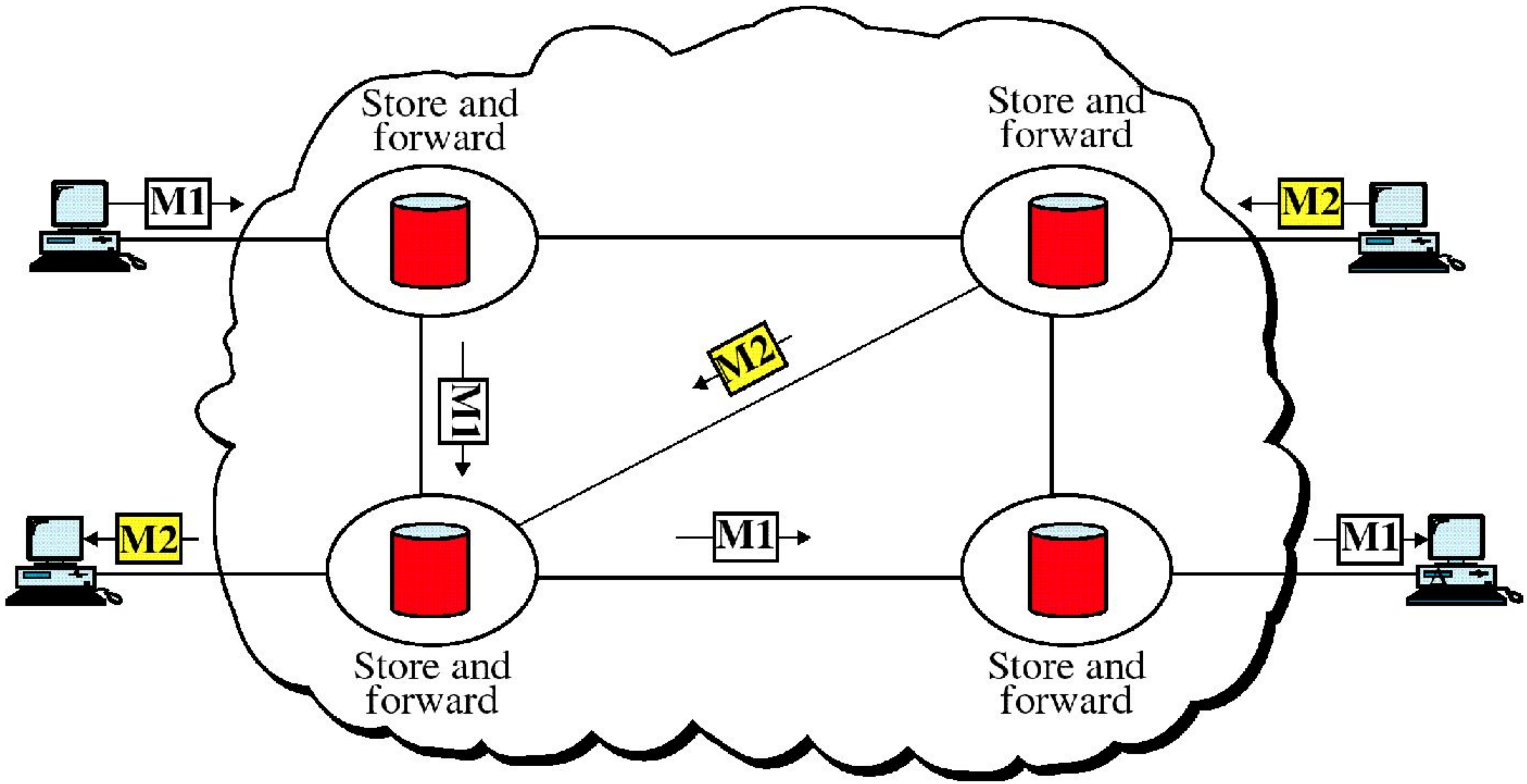
Message Switching



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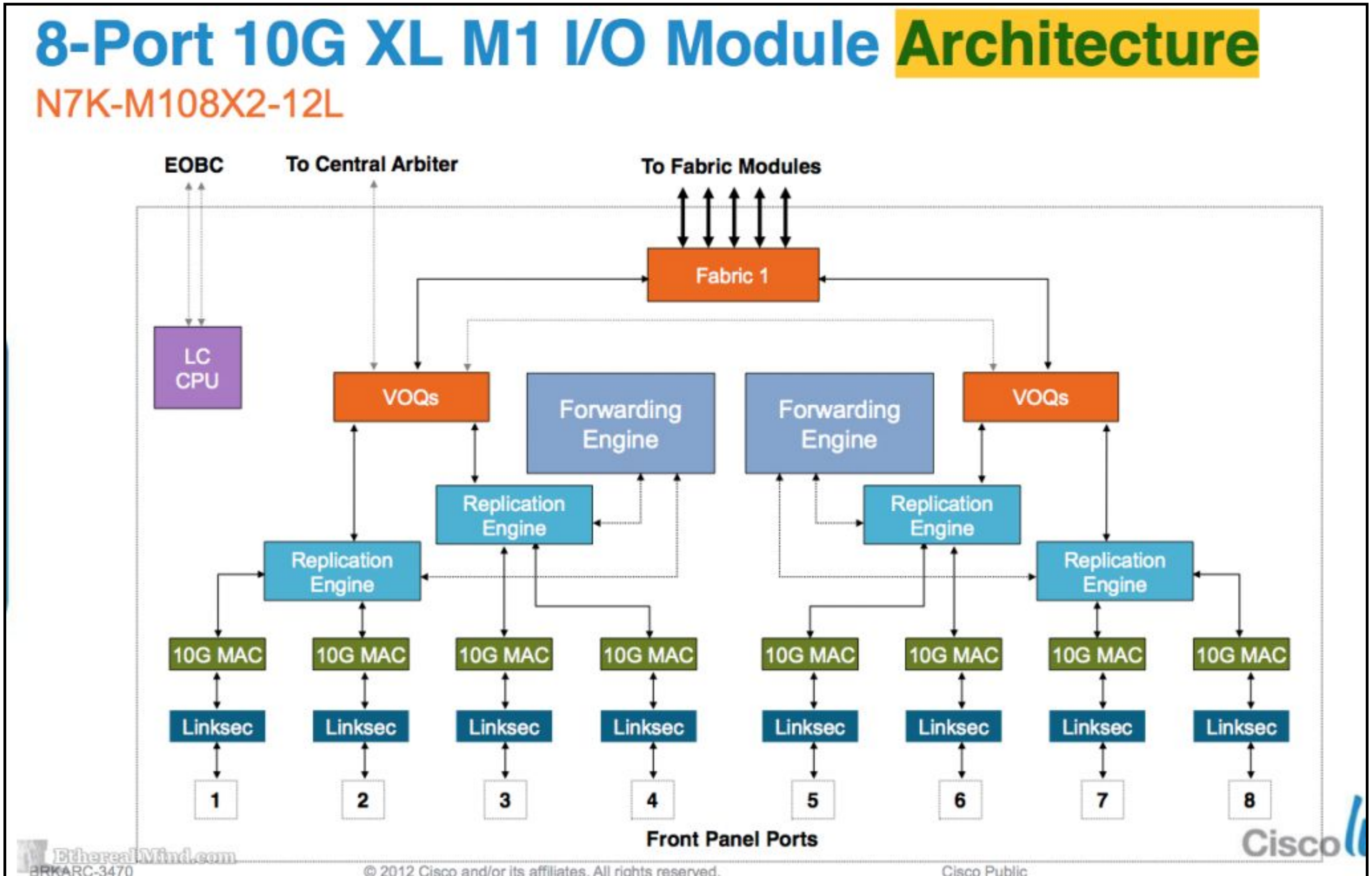
Ch8: Switching, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

Message Switching

- Each message is treated as an independent unit.
- Switches receives message, stores it till next device is ready.
- Message switches can be programmed to learn and store efficient routes.
- Advantages:
  - Efficient traffic management
  - Reduces network traffic congestion
  - Allows asynchronous communication
- Disadvantages:
  - Not suitable for real time applications, such as voice, video
  - Requires large storing capacity

How does a Switch Look like?

Switch Architecture



Reference: https://etherealmind.com/whats-happening-inside-an-ethernet-switch-or-network-switches-for-virtualization-people/

Resources for Self Learning

1. Network switch
   https://en.wikipedia.org/wiki/Network_switch

2. What’s Happening Inside an Ethernet Switch ?
   https://etherealmind.com/whats-happening-inside-an-ethernet-switch-or-network-switches-for-virtualization-people/

Module 2-Part 2

The Data Link layer

- ***DLL Design Issues (Services, Framing, Error Control, Flow Control), Error Detection and Correction(Hamming Code, Parity, CRC, Checksum)***
- ***Elementary Data Link protocols : Stop and Wait, Sliding Window(Go Back N, Selective Repeat), Piggybacking***
- ***HDLC***

DLL Design Issues

- Responsible for **hop to hop** transmission of data
- Transforms a **raw transmission** of physical layer into a **reliable link**
- **Specific Responsibilities:**
  - **Framing**: DLL divides the stream of bits received from network layer into manageable data units called frames
  - **Physical Addressing**: DLL adds a header to the frame to define addresses of sender and receiver of a frame

DLL Design Issues

- **Error Control:** DLL adds reliability to the physical layer by adding mechanisms for error correction and detection
- **Flow Control**: If the rate at which receiver is absorbing the data is not matching with the sender, DLL adds flow control mechanism
- **Medium Access Control**: when number of devices are connected to same link, it is necessary to determine which device has control over the link

FRAMING

The data link layer needs to pack bits into frames, so that each frame is distinguishable from another.

Topics discussed in this section:

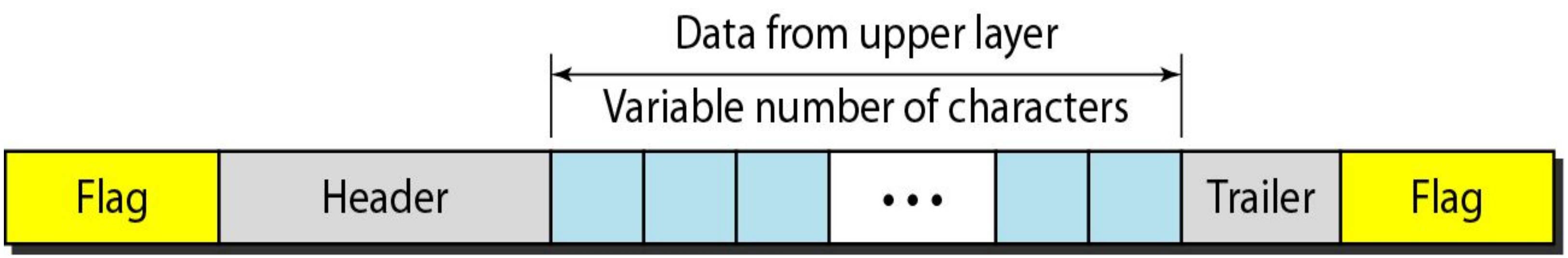
Fixed-Size Framing
Variable-Size Framing

Types of Framing

- Fixed Size Framing
  - No need of frame delimiter
  - The size defines the frame boundary
  - E.g. – ATM (asynchronous transfer mode) Wide Area Networks
- Variable Size Framing
  - Need to define start and end of the frame
  - Two approaches are used
    - Character - Oriented Protocols
    - Bit – Oriented Protocols

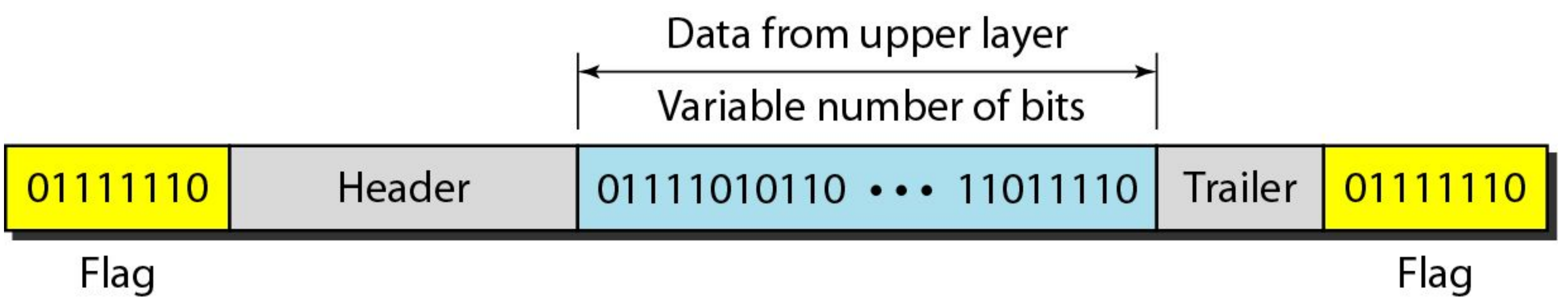
Types of Framing

- Character – oriented protocol
  - Data as well as header, control information, trailer are all 8 bit characters
  - Use 8-bit flag at beginning and at end for frame separation

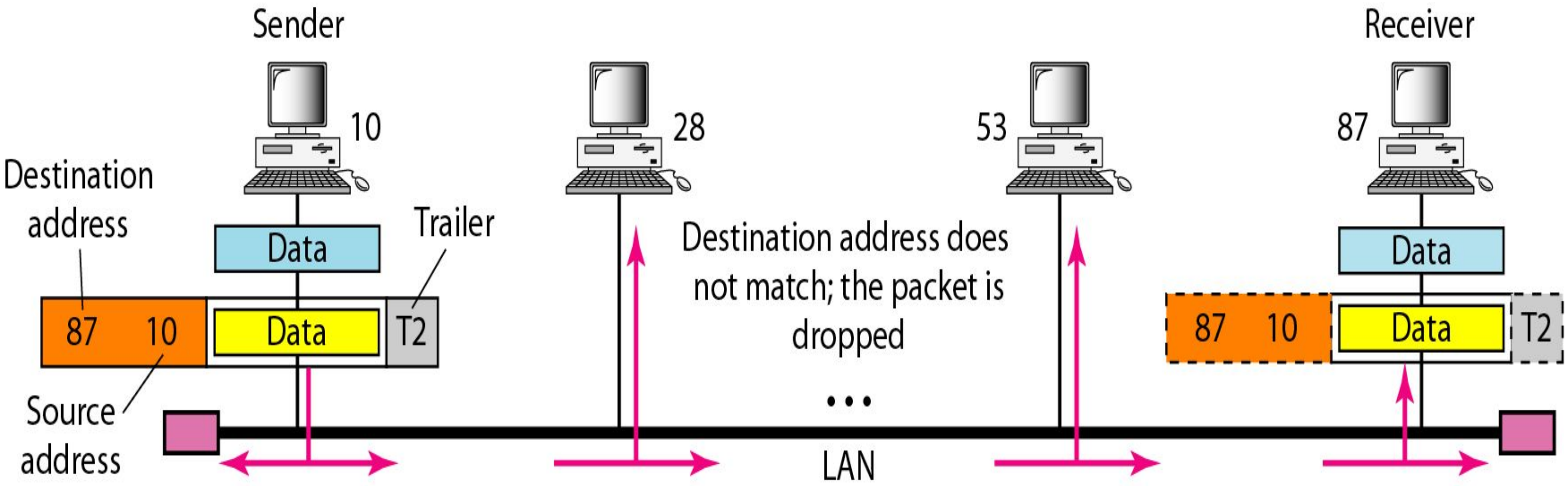


Types of Framing

- Bit – oriented protocol
  - The data section of a frame is a sequence of bits
  - Delimiters are required for frame separation
  - Most protocols use a special 8 bit pattern flag '01111110' as delimiter



PHYSICAL ADDRESSING (MAC ADDRESS)



07:01:02:01:2C:4B

A 6-byte (12 hexadecimal digits) physical address

Note

Transmission medium causes data corruption

Thus, many applications require this errors be detected and corrected

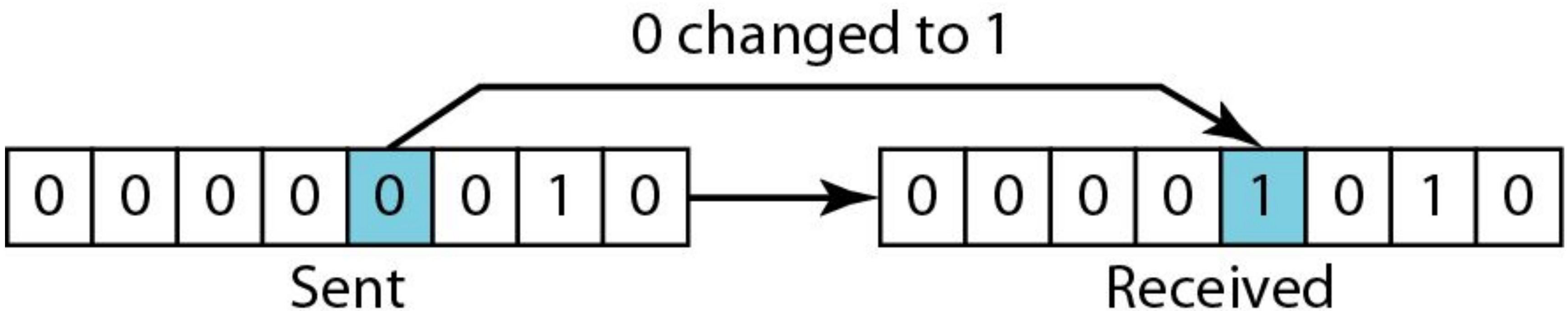
ERROR CONTROL

Let us first discuss some issues related, directly or indirectly, to error detection and correction

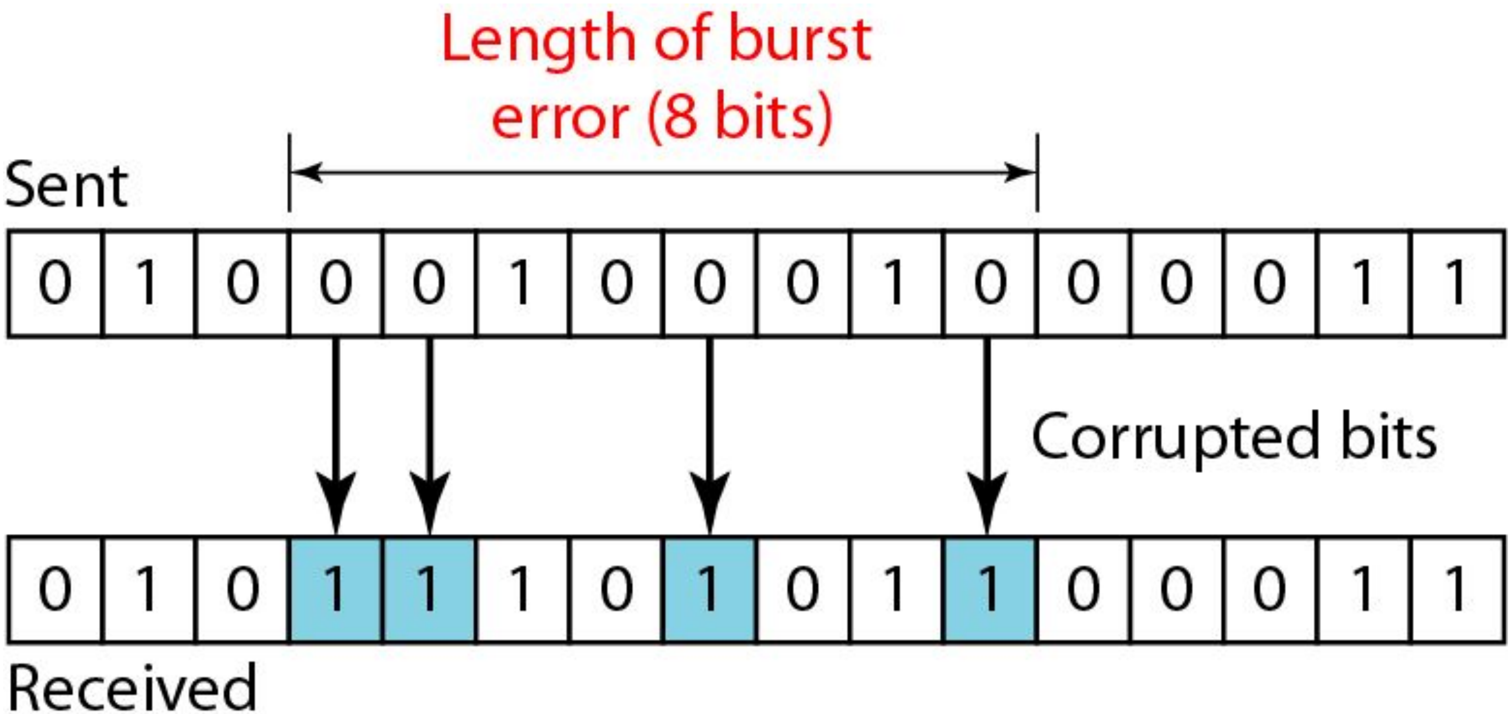
Topics discussed in this section:

Types of Errors
Redundancy
Detection and Correction methods (Coding)
Forward Error Correction
Backward Error Correction (Retransmission)

Single-bit error



Burst error



- A burst error is more likely to occur than a single-bit error.
- Number of bits affected depends on the data rate and duration of noise.

Note

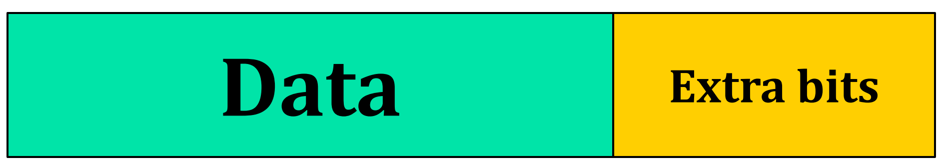
In a single-bit error, only 1 bit in the data unit has changed

A burst error means that 2 or more bits in the data unit have changed

To detect or correct errors, we need to send extra (redundant) bits with data

Redundancy

- Redundancy is extra bits added to the original data
- This extra bits are used for detection and/or correction of errors
- Redundancy is added by sender and removed by receiver



Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

Lecture 11

Error Detection & Correction

- Basic concept is addition of redundancy
- Achieved by various coding schemes
- Two broad categories of coding schemes
  - Block coding
  - Convolution coding
- Error Detection Techniques
  - Detect the error. Output is YES or NO
  - Not interested in number of errors
- Error Correction Techniques
  - Detect the error and find number and location of errors
  - Complex compared to error detection

Types of Error Correction

- **Forward Error Correction**
  - Use redundant bits transmitted along with data
  - At receiver, these redundant bits are used for detecting & correcting the errors
- **Backward Error Correction (Retransmission)**
  - Use redundant bits only to detect errors
  - Some mechanism is required to acknowledge transmitter about the error
  - The **erroneous frame** is then sent back by the transmitter

ERROR DETECTION

Add the redundancy in such way that it will simply detect the error

Topics discussed in this section:

LRC &VRC (2D Parity)
Checksum
CRC
Hamming Code

LRC (Longitudinal Redundancy Check) & VRC (Vertical Redundancy Check) [2D Parity]

- Adds single bit to the message.
- The redundant bit is calculated such that the parity of entire code is either Even or Odd.
- At the receiver side again, parity is checked for even or odd
- E.g. –

Letter	ASCII Code (7-bit)	LRC Bit (to make parity even)
H	1 0 0 1 0 0 0	0
E	1 0 0 0 1 0 1	1
L	1 0 0 1 1 0 0	1
L	1 0 0 1 1 0 0	1
O	1 0 0 1 1 1 1	1
VRC Bit	1 0 0 0 0 1 0	0

CHECKSUM

It is the simplest error detection method.
Still used in Internet by several protocols due to its simplicity.

Topics discussed in this section:

Idea
One's Complement

Checksum Idea

$$\begin{array}{r} 7 \\ 11 \\ 12 \\ 0 \\ \underline{6} \\ 36 \end{array} \longleftarrow \text{sum}$$

$$\begin{array}{r} \underline{-36} \\ 0 \end{array} \longleftarrow \text{1's compliment}$$

To find Checksum: Add all the data and send along with the negative of sum

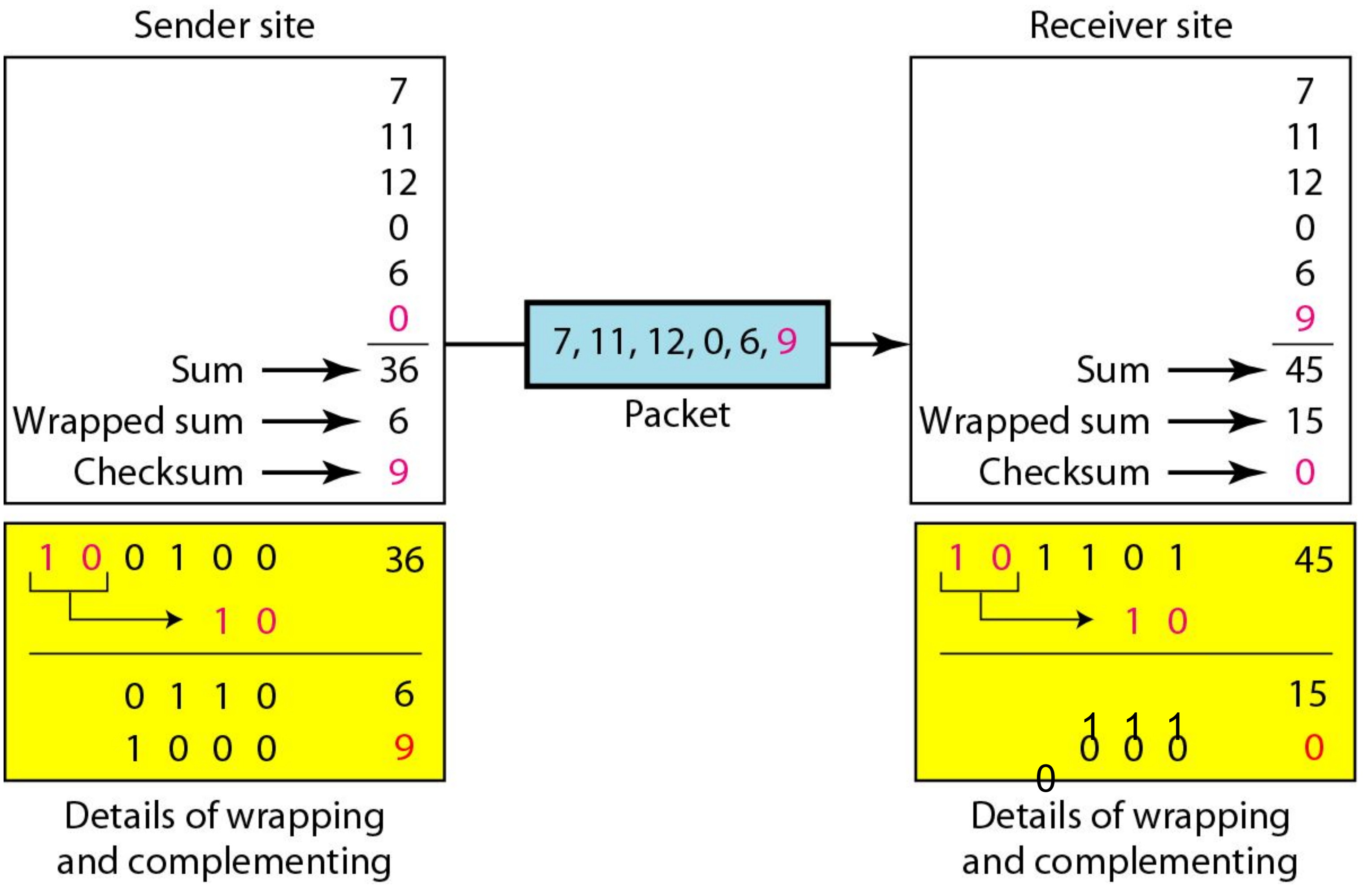
E.g. – Find checksum for data **10101001 00111001**

One’s Complement

Invert all bits. Each 1 becomes a 0, and each 0 becomes a 1.

Original Value	One's Complement
0	1
1	0
1010	0101
1111	0000
11110000	00001111
10100011	01011100
11110000 10100101	00001111 01011010

Checksum Example



Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

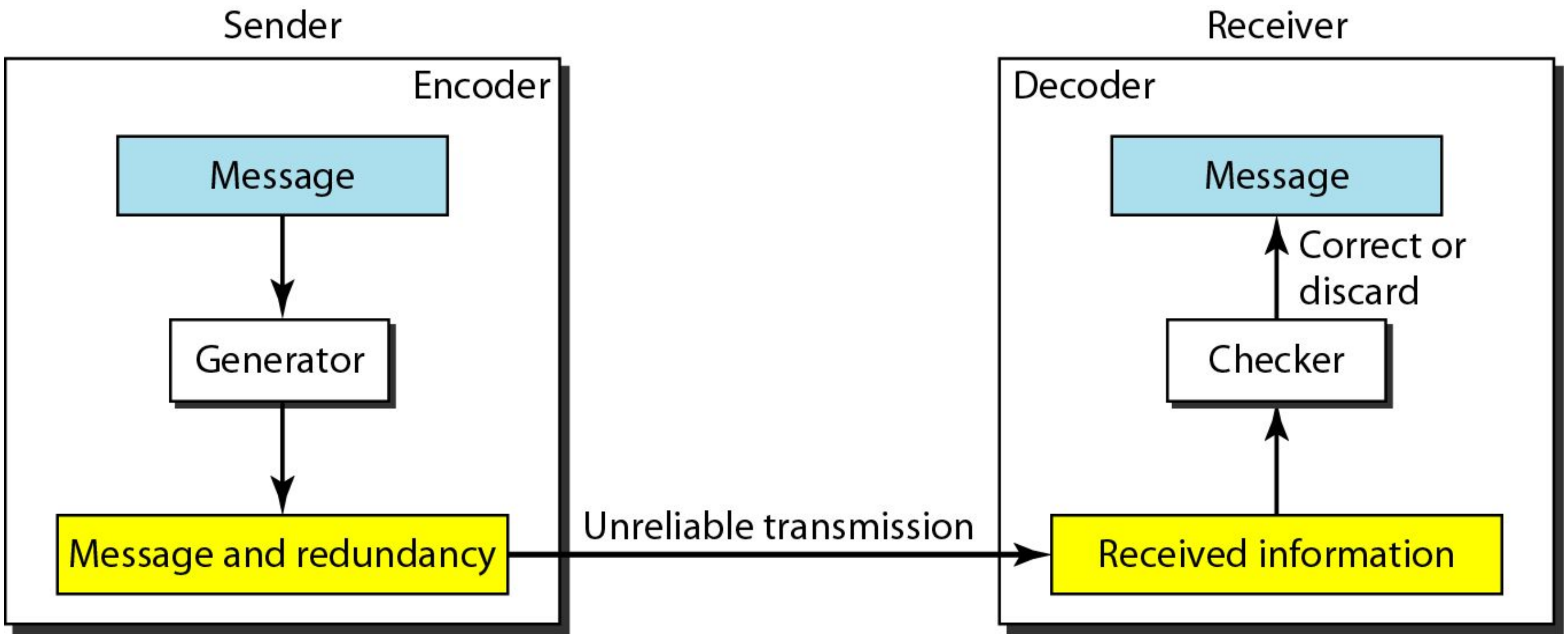
Lecture 12

CRC : Cyclic Redundancy Check

- Type of special Linear Block Codes called "Cyclic Codes"
- Used widely in various LANs and WANs
- The encoder defines:
  - Size of dataword as "d" bits
  - Size of codeword as "n" bits
  - Generator word/polynomial/matrix/Divisor
- Encoding steps:
  - Appends dataword with k=(n-d) zeros
  - Divide appended dataword with Divisor/generator
  - Add Remainder of division to appended dataword to give **codeword**

CRC : The structure of encoder and decoder

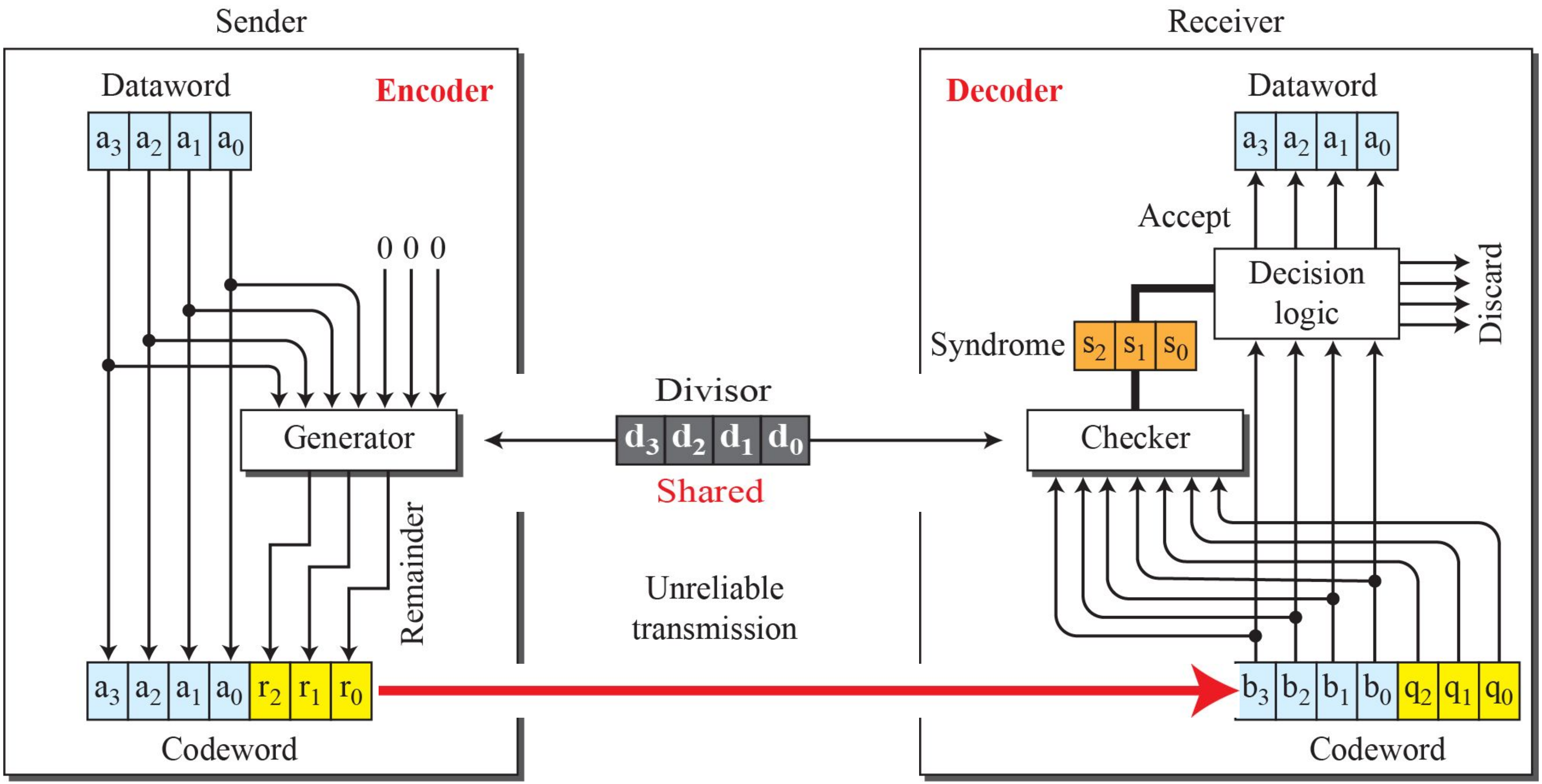
- Decoding Steps (Error detection):
  - Divide the received codeword with generator/divisor
  - If remainder/syndrome is zero, data is valid
  - If syndrome is non-zero, data has errors



Note

The divisor in a cyclic code is normally called the generator polynomial or simply the generator.

CRC Encoding & Decoding



CRC : Cyclic Redundancy Check

Let's solve some examples

1) n=7, Generator word = 1011, dataword=1001

   remainder =110

   Codeword =1001110

2) n=7, Generator word = 1101, dataword=1001

   remainder = 011

   Codeword =1001011

3) n=9, Generator word = 1101, dataword=100100

   remainder = 001

   Codeword =100100001

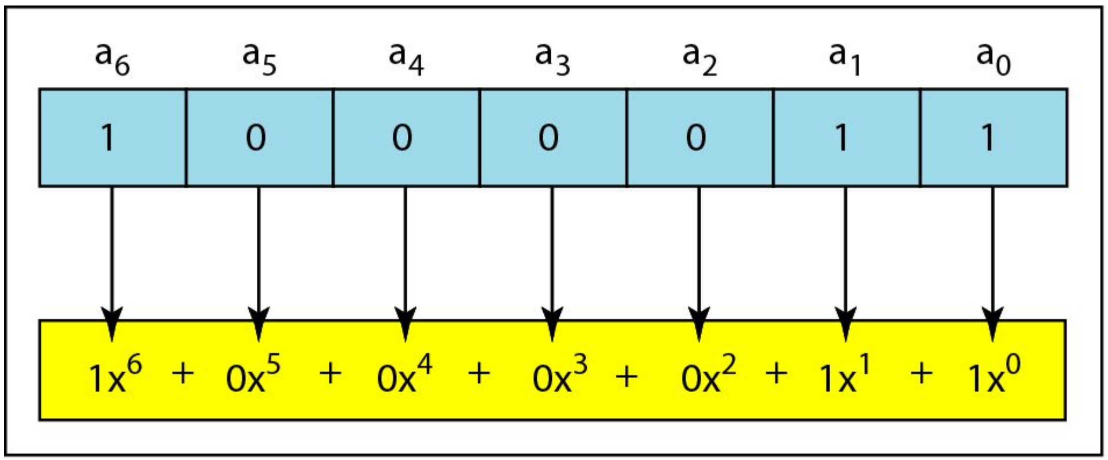
Computer Network & Network Design

Module 2

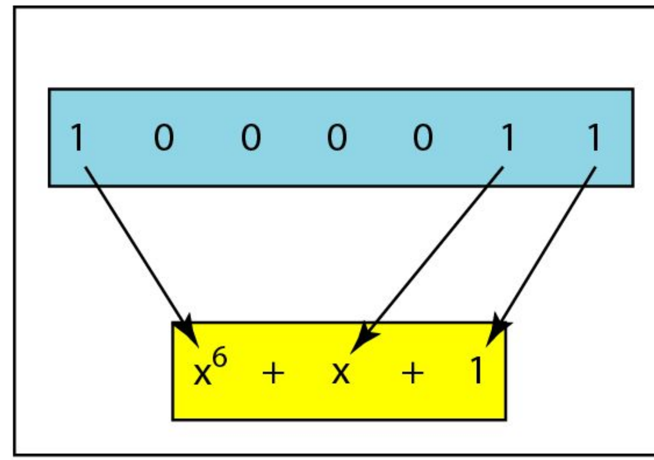
Physical Layer & Data Link Layer

Lecture 13

CRC - *A polynomial approach*

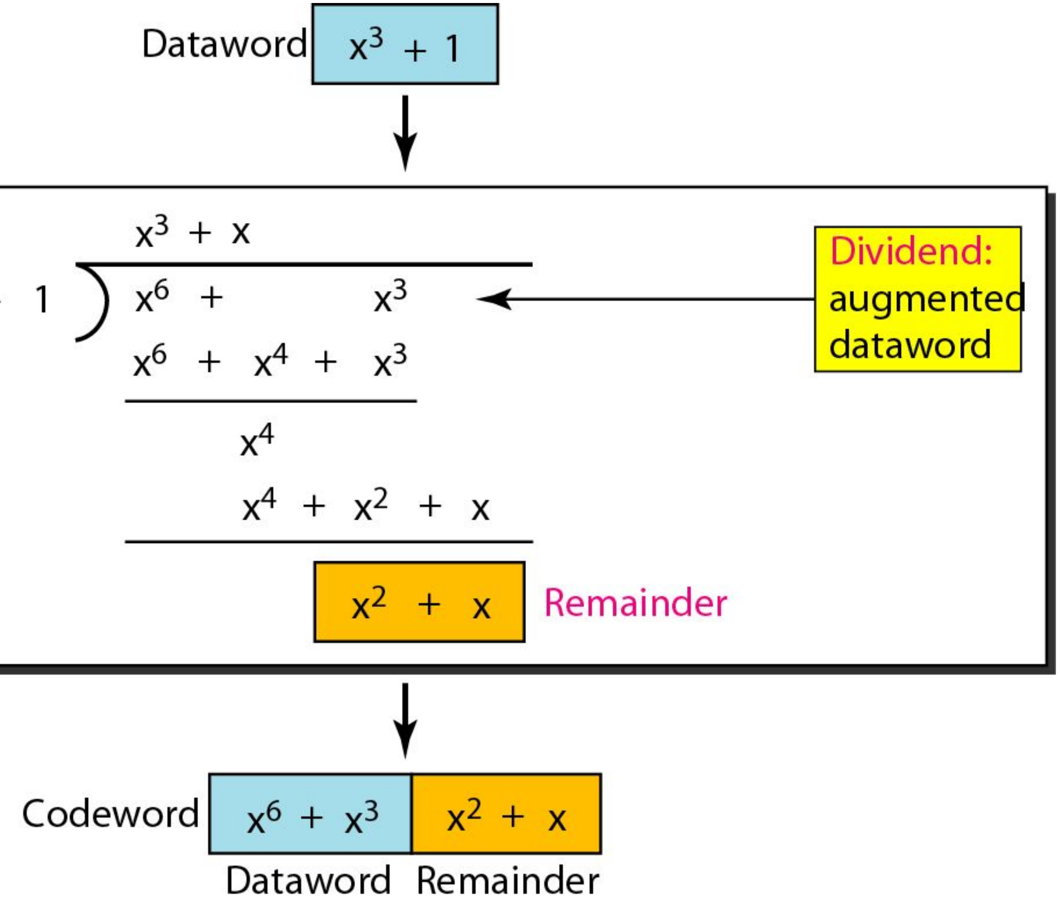


a. Binary pattern and polynomial



b. Short form

CRC division using polynomials



Standard Generator polynomials

Name	*Polynomial*	*Application*
CRC-8	$x^8 + x^2 + x + 1$	ATM header
CRC-10	$x^{10} + x^9 + x^5 + x^4 + x^2 + 1$	ATM AAL
CRC-16	$x^{16} + x^{12} + x^5 + 1$	HDLC
CRC-32	$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$	LANs

Ref: https://datatracker.ietf.org/doc/html/rfc3385

Hamming Code- Error correcting code

- Defined in terms of (n,k) and d_{min}
- d_{min} decides the error detection and correction capability
- Number of error detected = d_{min}-1
- Number of error corrected = (d_{min}-1)/2
- Uses set of equations for generating redundancy bits
  - E.g. for (7,4) Hamming code with d_{min}= 3
  - Equations are:

$$r_0 = a_2 + a_1 + a_0$$

$$r_1 = a_3 + a_2 + a_1$$

$$r_2 = a_1 + a_0 + a_3$$

'+' is mod-2 addition performed with XOR

Hamming Code- Error correcting code

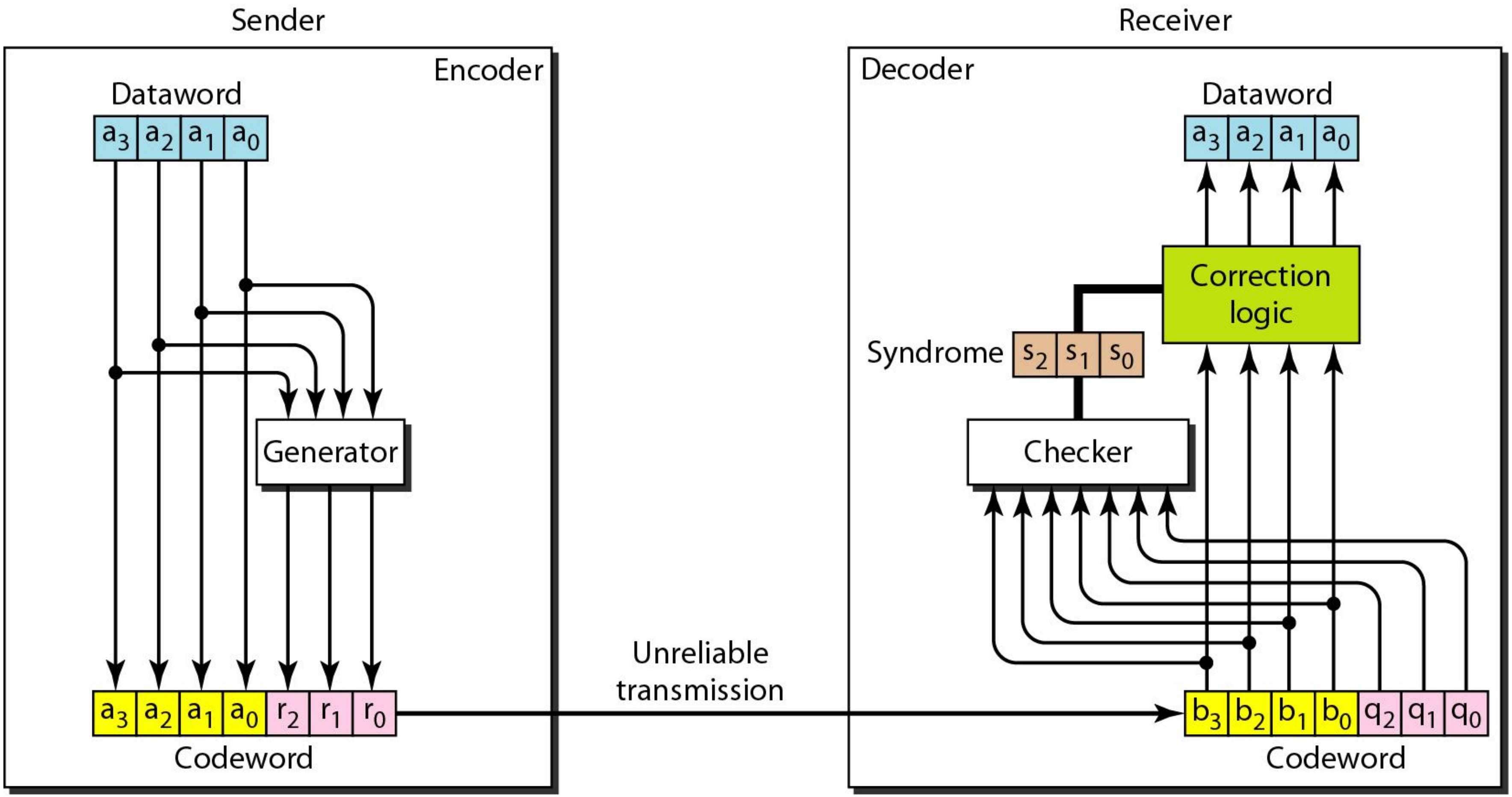
- Set of equations for detection:

$$s_0 = b_2 + b_1 + b_0 + q_0$$
$$s_1 = b_3 + b_2 + b_1 + q_1$$
$$s_2 = b_1 + b_0 + b_3 + q_2$$

- Logical decision made by the correction logic analyzer

Syndrome	000	001	010	011	100	101	110	111
Error	None	q_0	q_1	b_2	q_2	b_0	b_3	b_1

The structure of the encoder and decoder for a Hamming code



Hamming Code- Error correcting code

- Example:

1) For Hamming code C(7,4) with d_{min} =3, Find the codeword for data 0100. Find transmitted codeword. If the received codeword is 0100011, find syndrome, detect and correct the error, and find final dataword.
2) Dataword=0111. received codeword= 0011001
3) Dataword=1101. received codeword= 0001000

$$r_0 = a_2 + a_1 + a_0 \qquad s_0 = b_2 + b_1 + b_0 + q_0$$

$$r_1 = a_3 + a_2 + a_1 \qquad s_1 = b_3 + b_2 + b_1 + q_1$$

$$r_2 = a_1 + a_0 + a_3 \qquad s_2 = b_1 + b_0 + b_3 + q_2$$

Syndrome	000	001	010	011	100	101	110	111
Error	None	q_0	q_1	b_2	q_2	b_0	b_3	b_1

Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

Lecture 14

DLL Responsibilities

- Framing
- Physical Addressing
- Error Control
- Flow Control
- Medium Access Control

FLOW AND ERROR CONTROL

The most important responsibilities of the data link layer are flow control and error control.

Collectively, these functions are known as Data link control.

Topics discussed in this section:

Flow Control
Error Control

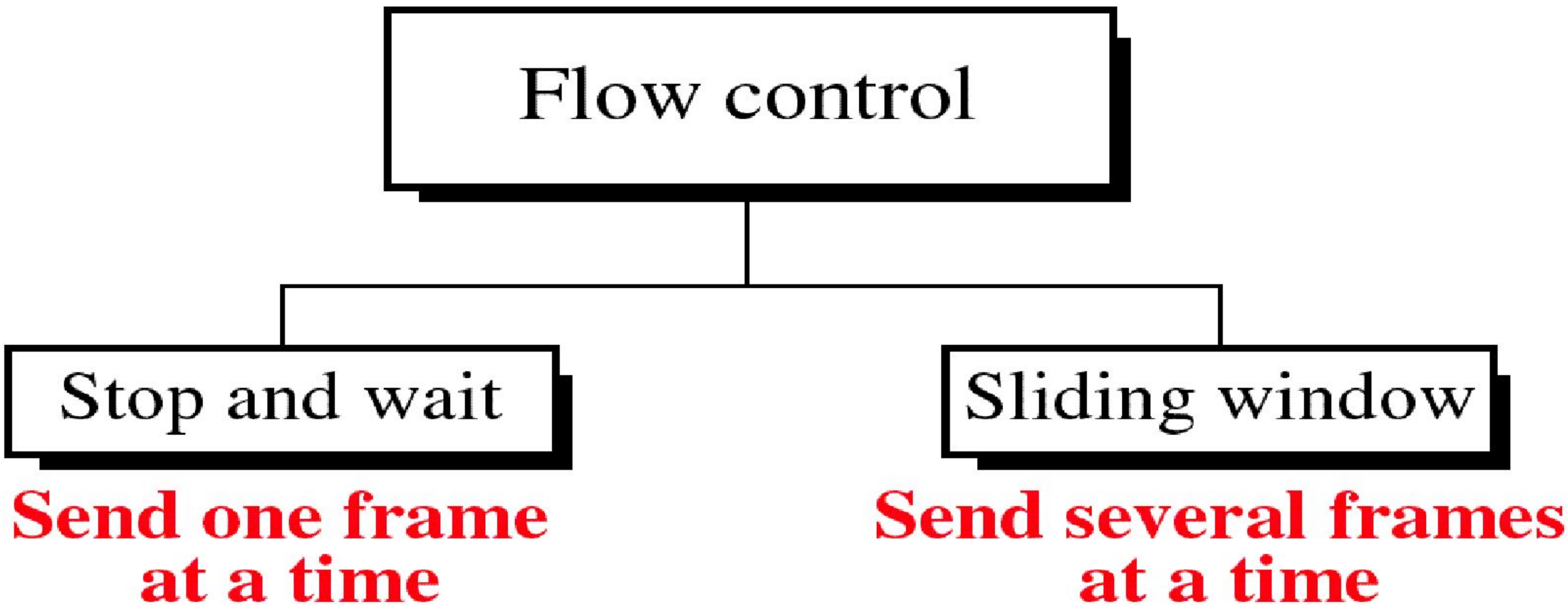
Flow Control

- The rate of receiving data is always slower than transmission due to checking and processing required at receiver
- The receiving device must always tell sending device to send the data, stop or to slow down
- Coordinates with the help of ACKNOWLEDGEMENT (ACK).
- Receivers always keep a block of memory called "Buffer" to store received data until it is processed

Note

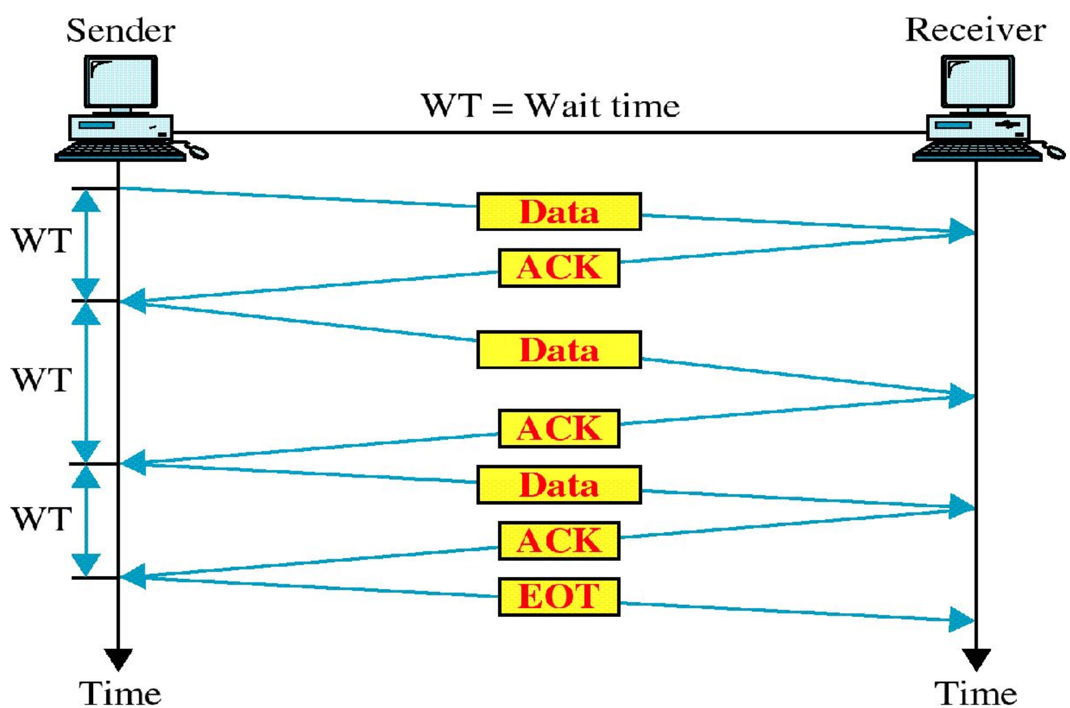
Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgement

Flow Control - Protocols



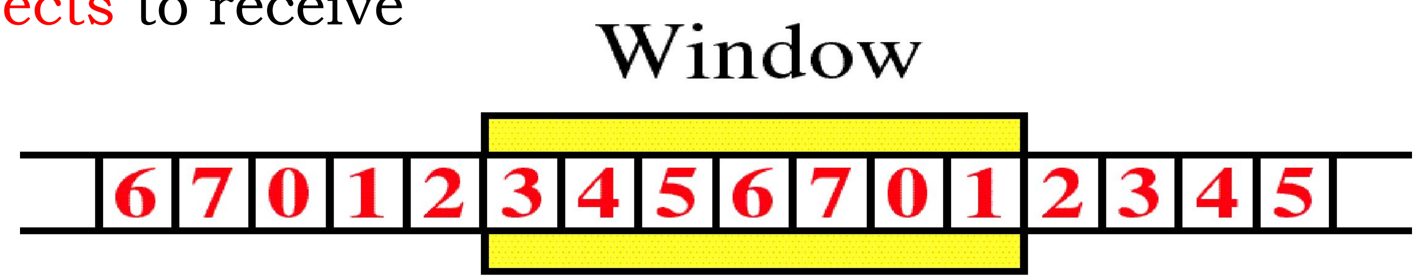
Stop-and-wait

- The sender waits for an ACK after every frame it sends
- Only after receiving ACK, the next frame is send
- Advantage: simplicity
- Disadvantage: slow, inefficient



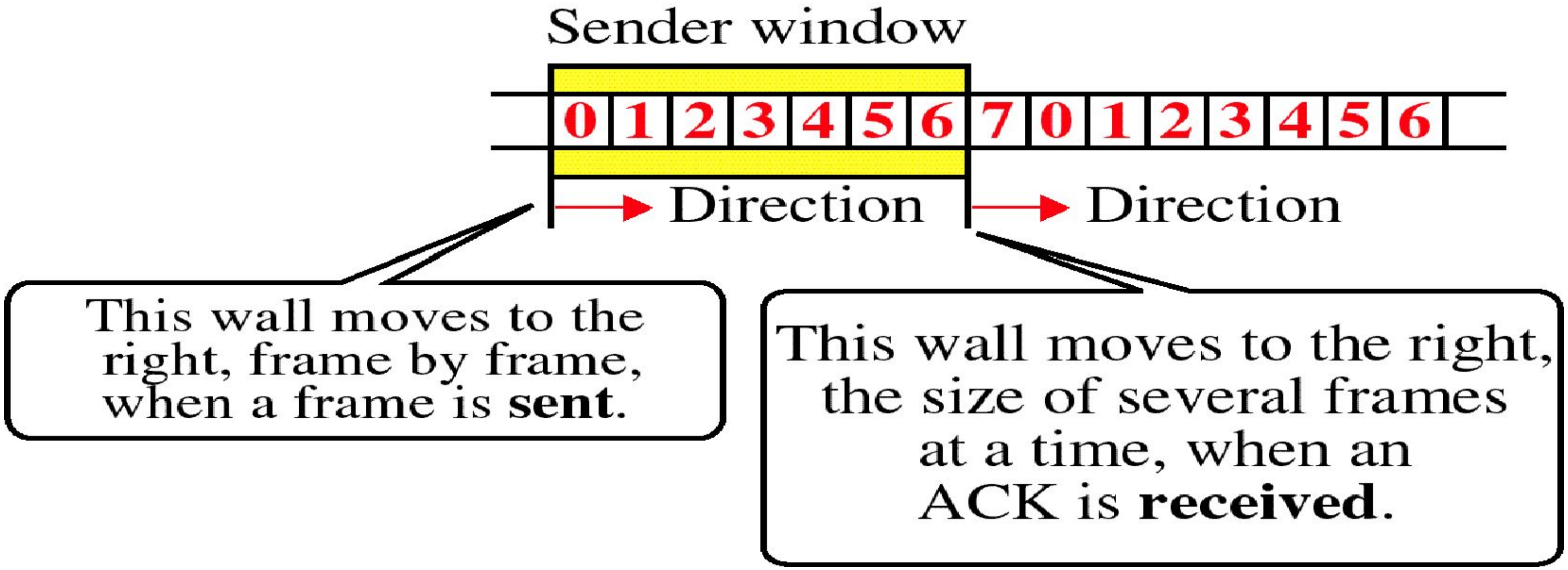
Sliding Window

- Sender can transmit several frames before needing an ACK
- Thus link carry several frames at once, increasing the efficiency
- Receiver acknowledges multiple frames using single ACK
- Sliding Window:
  - This virtual window hold frames at either end
  - Frames are numbered modulo-n. E.g.- for n=8 frames numbers are 0,1,2,3,4,5,6,7,0,1,2,3,-----
  - **Size of the window is (n-1)**
- ACK's number always indicate the next frame receiver expects to receive



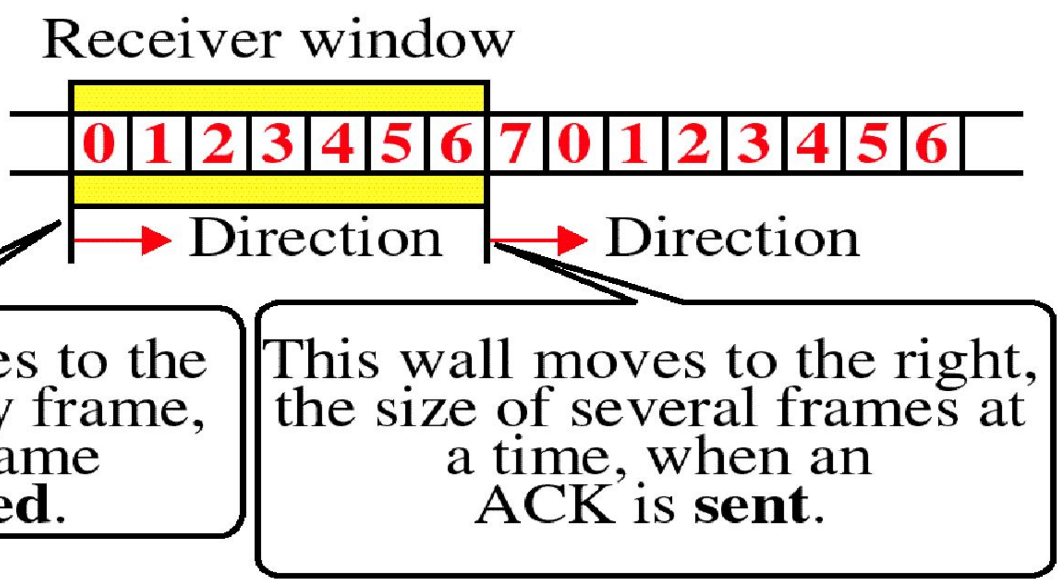
Sender Sliding Window

- At the beginning of a transmission, this window contains n-1 frames
- As frames are sent out, the left boundary moves inward, shrinking the size of window
- Once an ACK arrives, the window expands to allow number of new frames equal to the number of frames acknowledged by that ACK

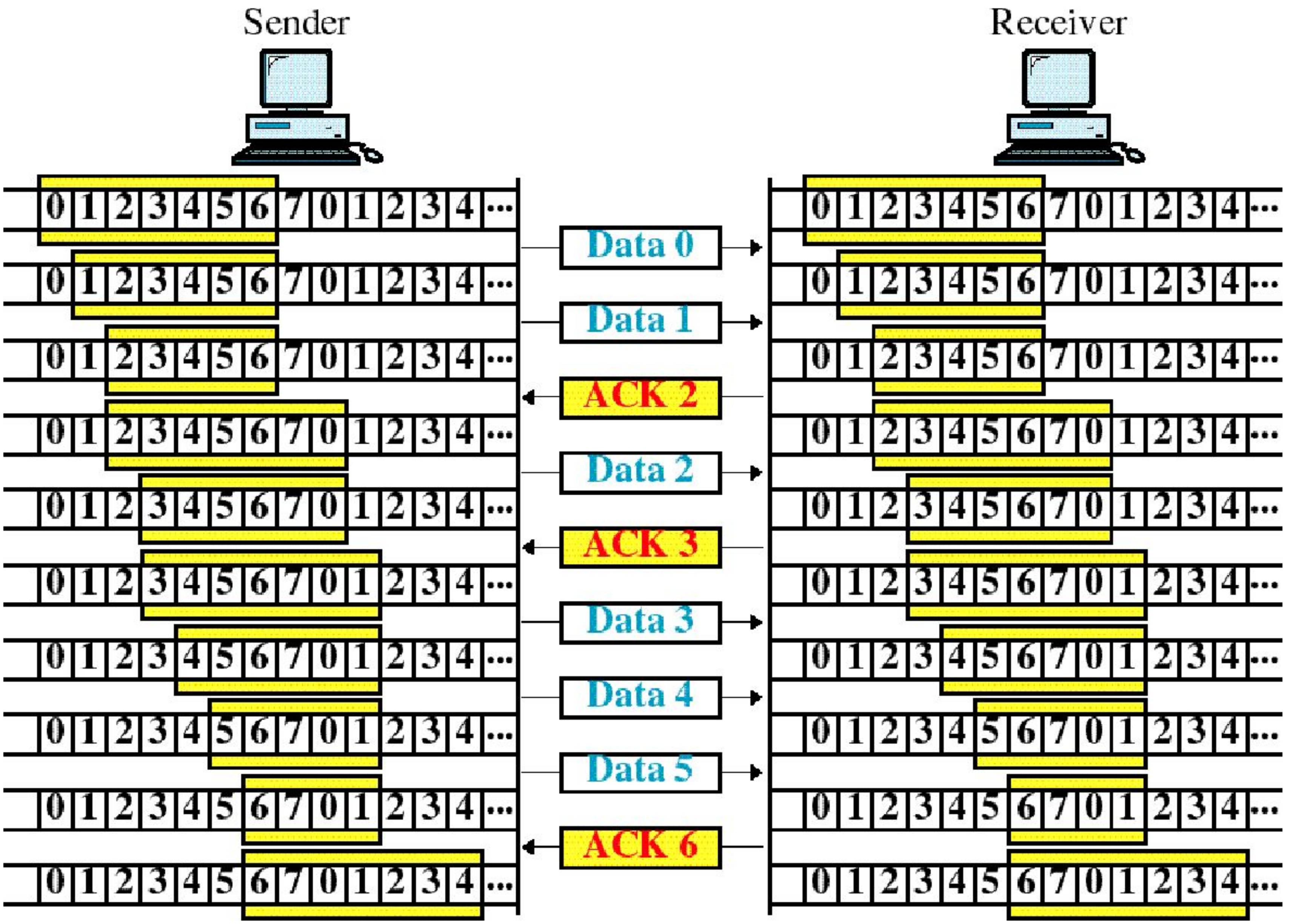


Receiver Sliding Window

- At the beginning of transmission, this window contains n-1 spaces
- As new frames come in, the size of this window shrinks
- This window always holds number of frames that may still be received before an ACK is sent
- When ACK is sent, the window expands to include places for number of frames equal to the number of frames acknowledged

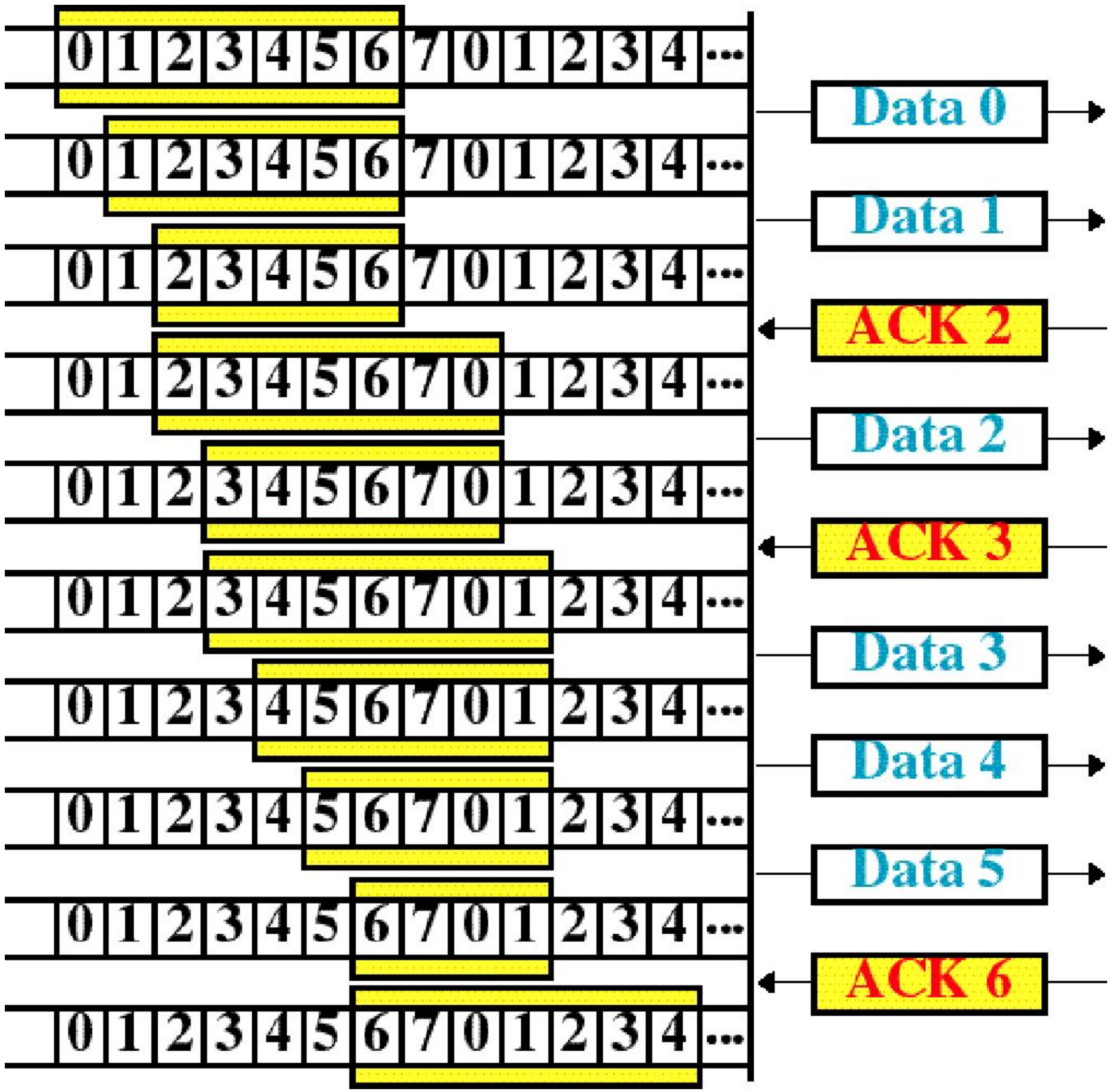


Sliding Window Example



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

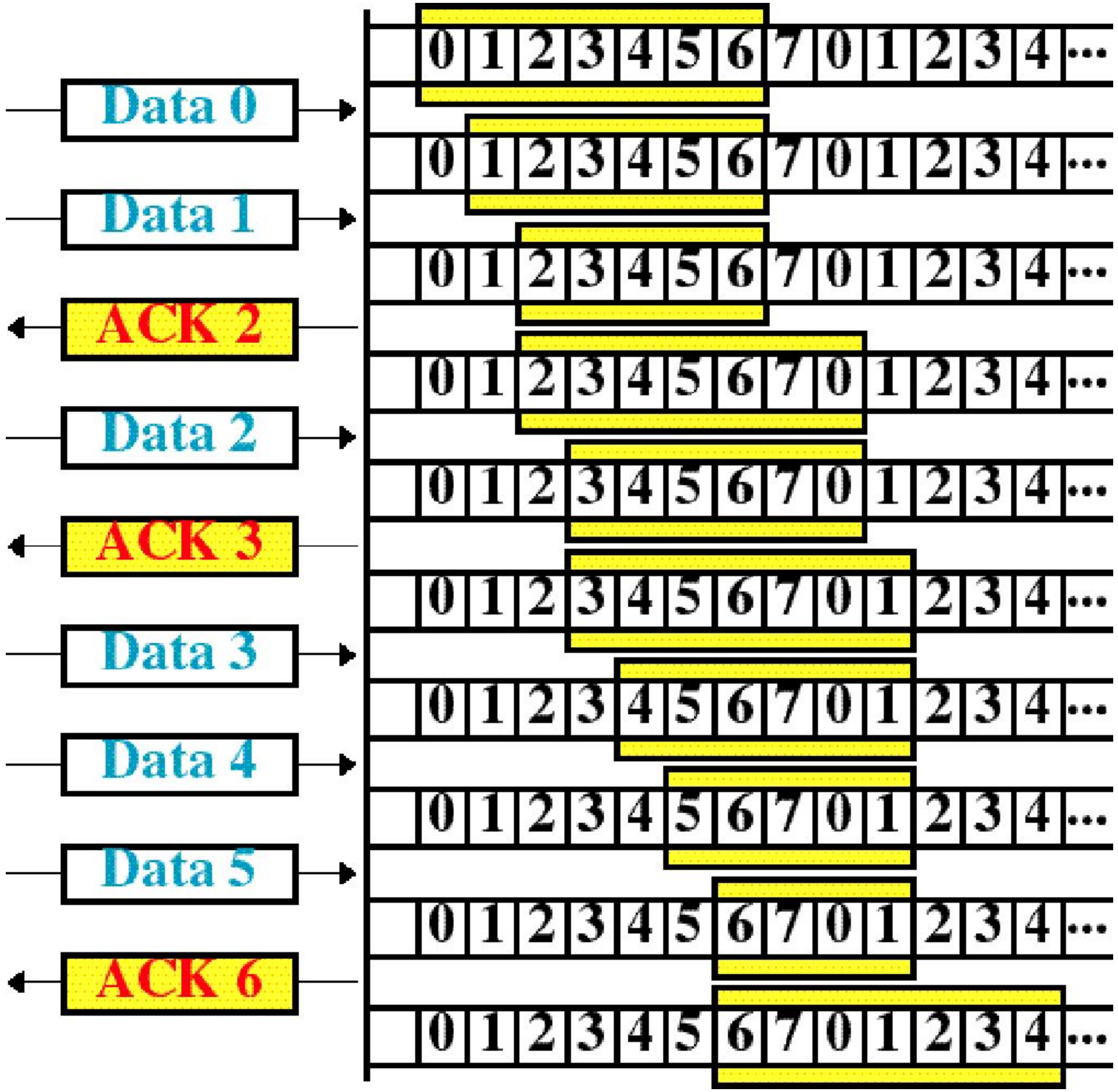
Sende



Reference: *Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education*

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

Receive



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

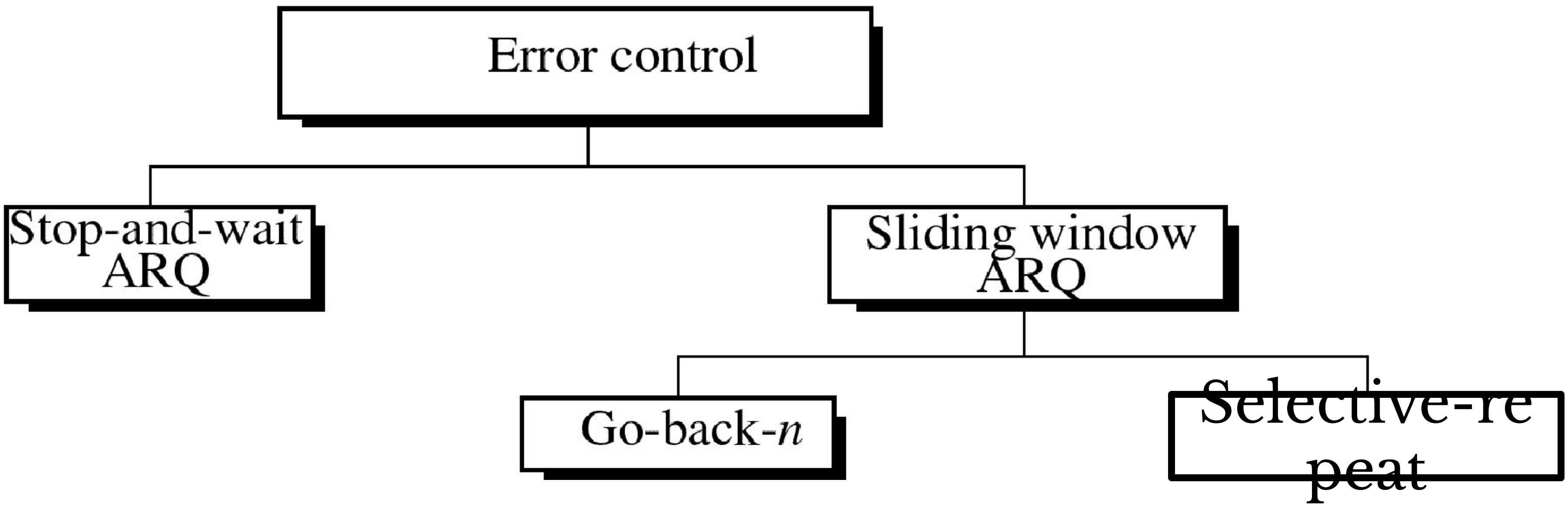
Error Control with ARQ

- Includes error detection and correction
- DLL uses backward error correction methods
  - It use redundancy bits only for detection of errors
  - Implement methods for retransmission of **damaged** or **lost** frames
- The method used to acknowledge transmitter is called **"Automatic Repeat request (ARQ)"**

Note

Error control in the data link layer is based on automatic repeat request, which is the retransmission of data.

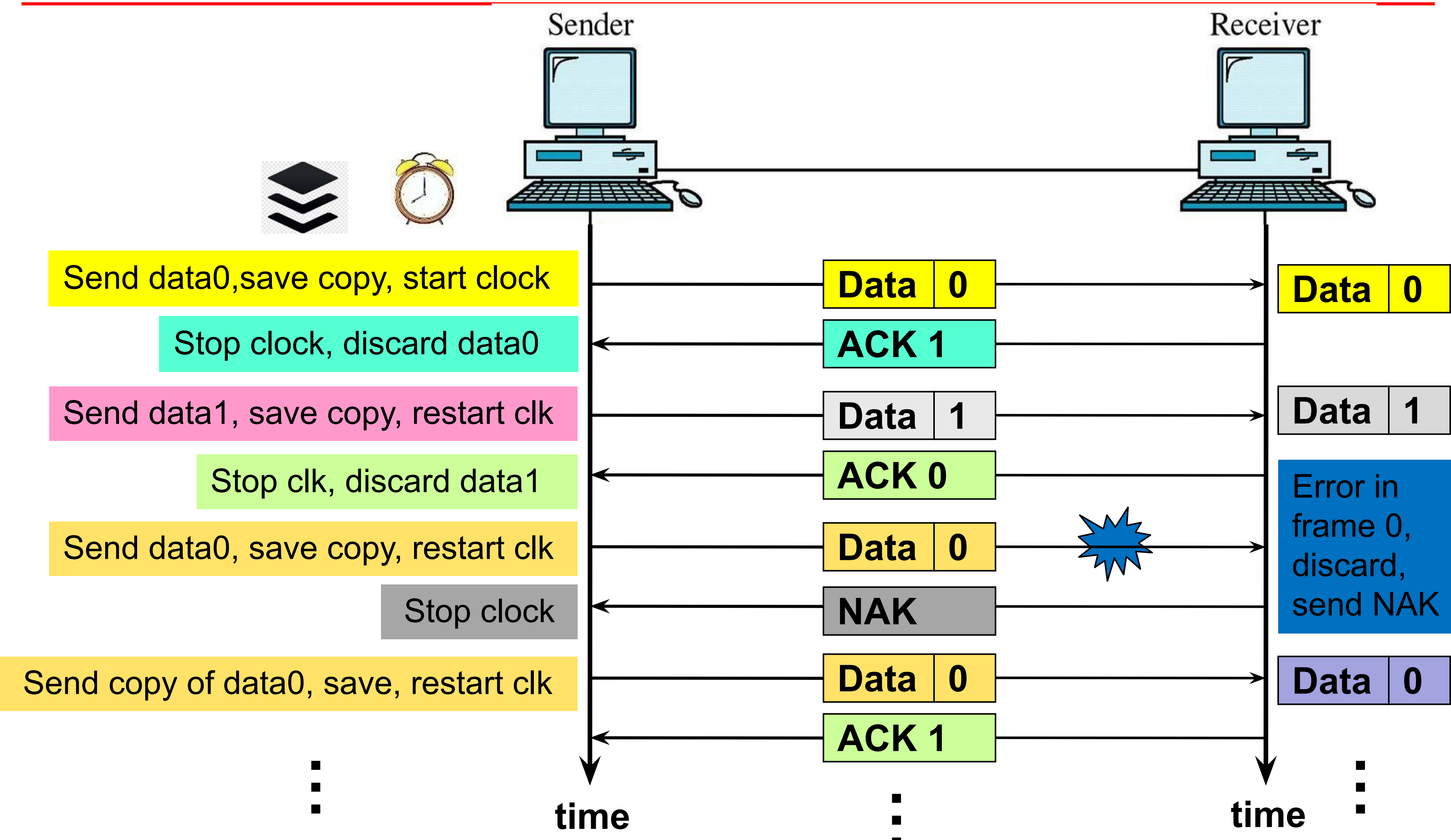
Error Control Protocols



Stop-and-Wait ARQ

- For retransmission, four features are added to Stop and wait flow control mechanism,
    1. Sending device **keeps the copy of last frame transmitted** until it receives an ACK for that frame. This allows retransmission of lost or damaged frames until they are received correctly
    2. Both **data and ACK frames are numbered alternately 0 and 1**. A data 0 frame is acknowledged by an ACK 1 frame
    3. **If error** occurs, a **NAK frame is returned**. NAK is **not numbered**
    4. The **sending device is equipped with a timer**. If an expected ACK is not received within an allotted time period, the sender assumes that the last data frame was lost and sends it again

Damaged Frame *in Stop-and-Wait ARQ*



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

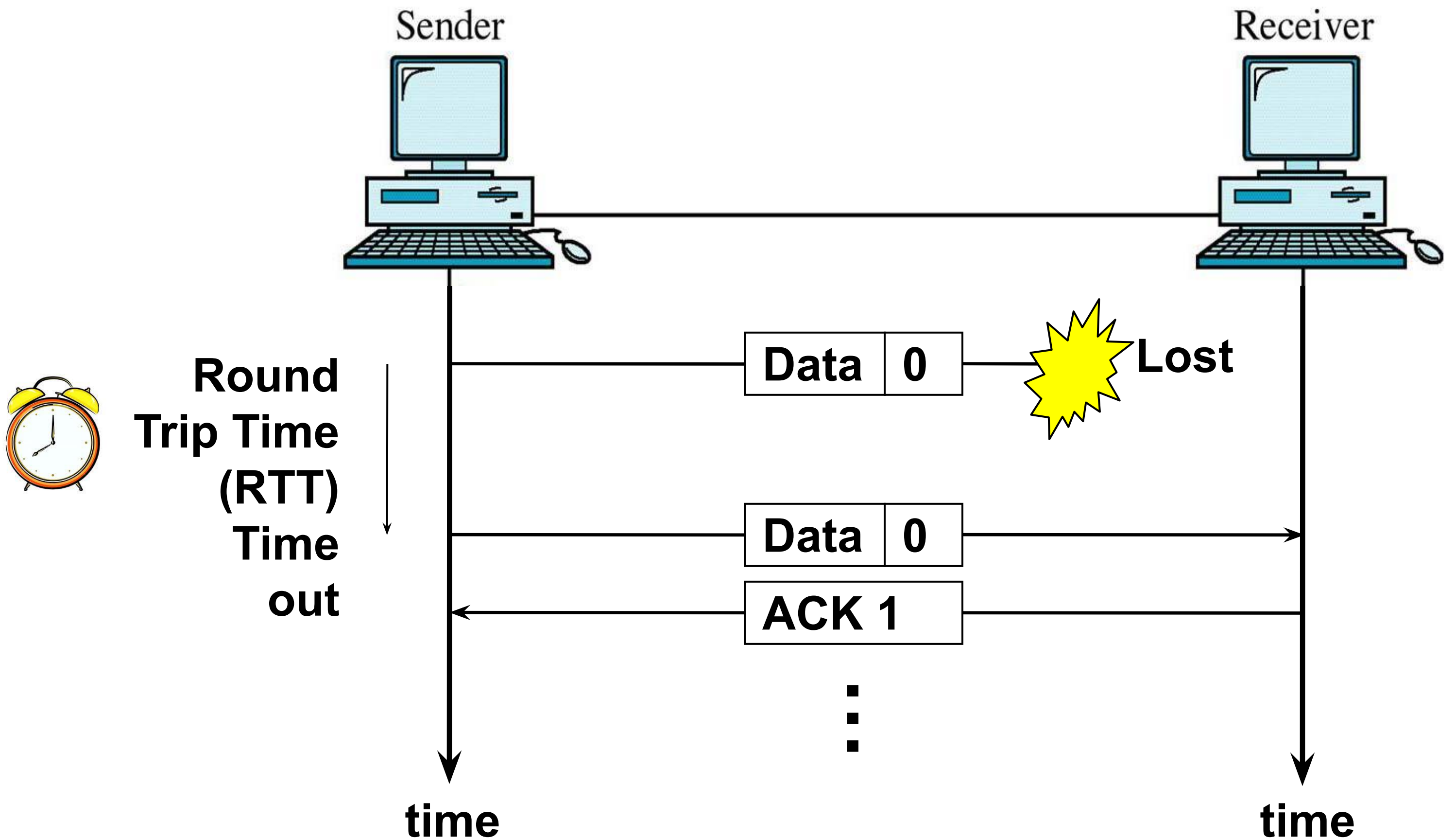
Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

Lecture 15

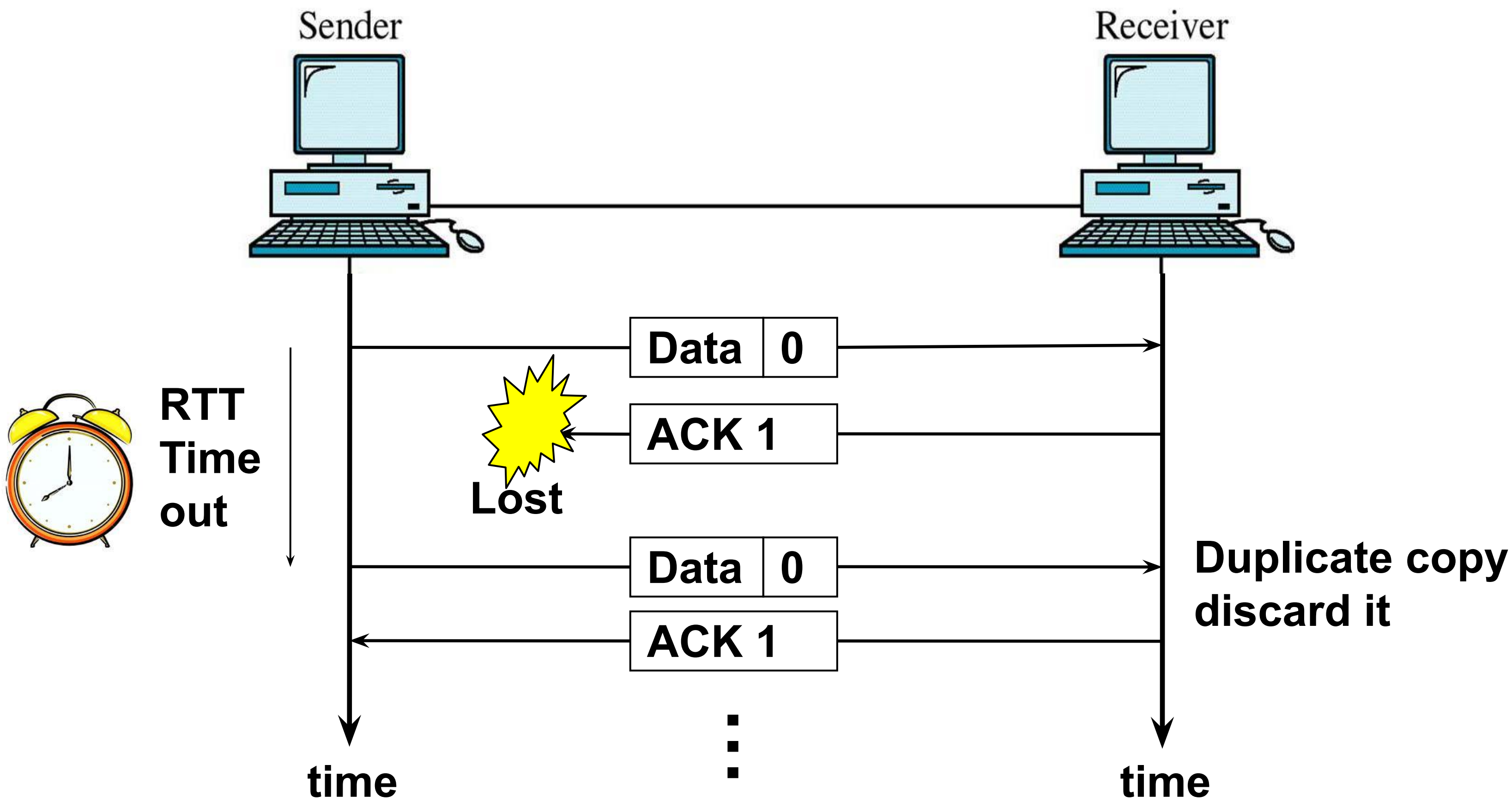
Lost data frame *in Stop-and-Wait ARQ*



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

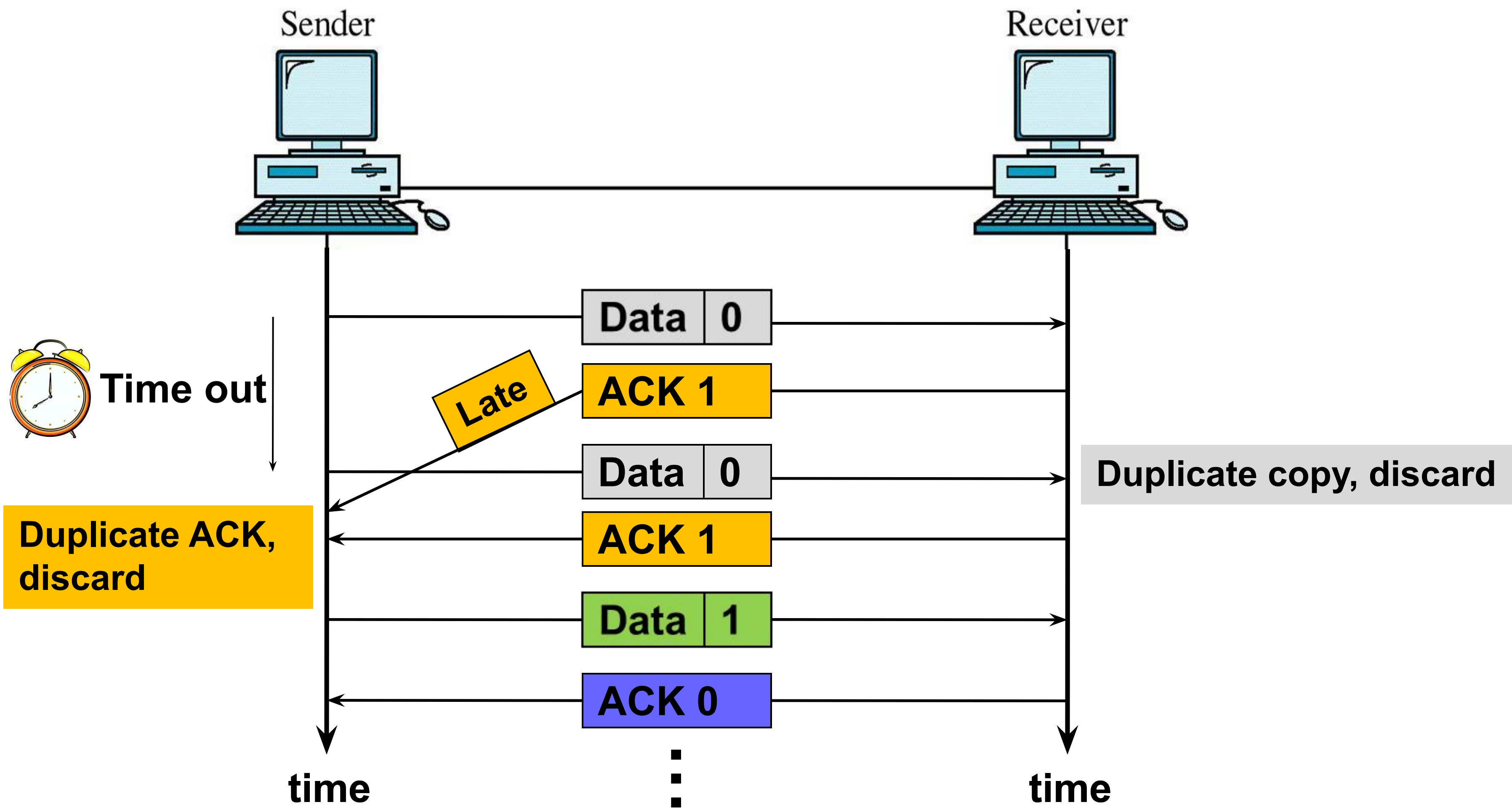
Lost ACK frame *in Stop-and-Wait ARQ*



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

Late ACK frame *in Stop-and-Wait ARQ*



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education.

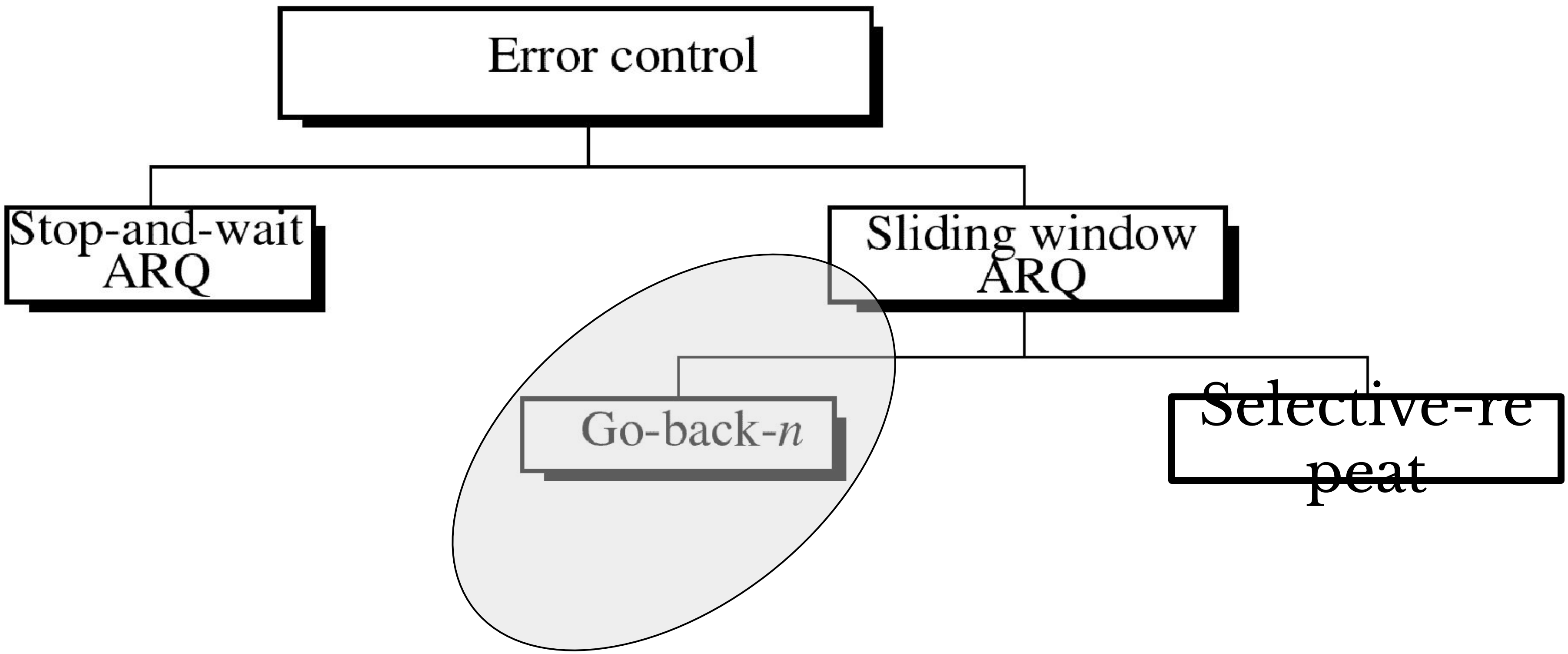
Sliding Window ARQ

- For retransmission, three features are added to sliding window flow control
  1. Sending device keeps the copy of all transmitted frames until it receives an ACK for those frames
     - E.g. – If frames 0 through 6 are transmitted, ACK 3 is received, sender keeps copy of 3 through 6 until their ACK.
  2. NAK is incorporated & numbered. NAK carry number of a damaged frame. NAK works as both positive and negative acknowledgement
     - E.g. – If NAK 4 is received, means frames 0,1,2,3 are received intact and frame 4 is damaged

Sliding Window ARQ

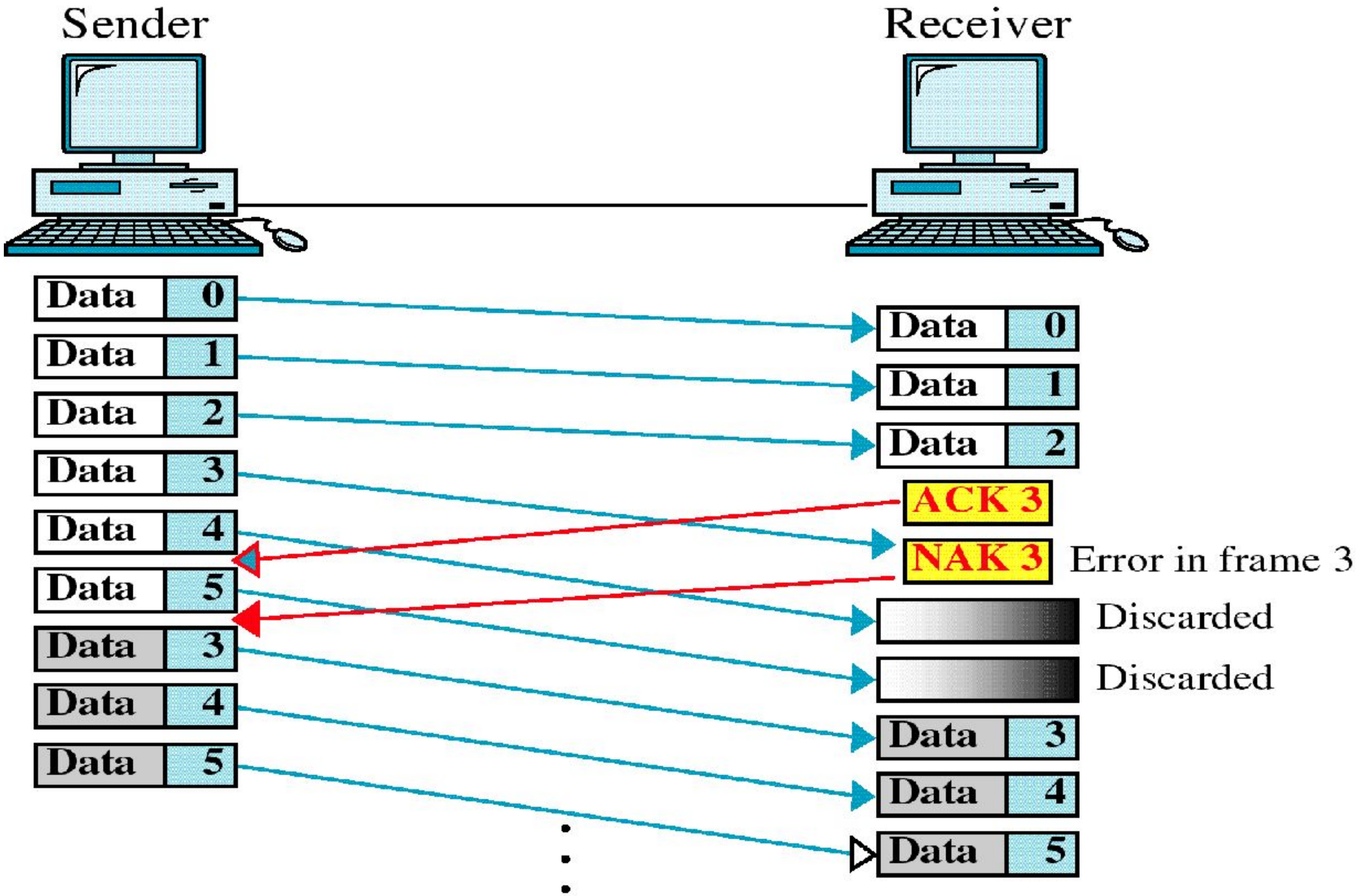
3. Sender is equipped with timer to handle lost ACK's
   - Here **n-1** frames may be send before **ACK** is received, thus if n-1 frames are waiting for ACK, the sender starts a timer and waits before sending any more. After **time out** sender transmits one or all **frames again**
   - After time out sender does not know whether the lost frames are **data, ACK or NAK**
   - By **retransmission** two possibilities are covered, **lost data** and **lost NAK**
   - If ACK is lost, receiver can recognize it by the frame number (duplicated) and discard the data

Go-Back-n Sliding Window ARQ



- **Go-Back-n Retransmission : If one frame is lost or damaged, all frames sent since the last frame acknowledged are retransmitted**

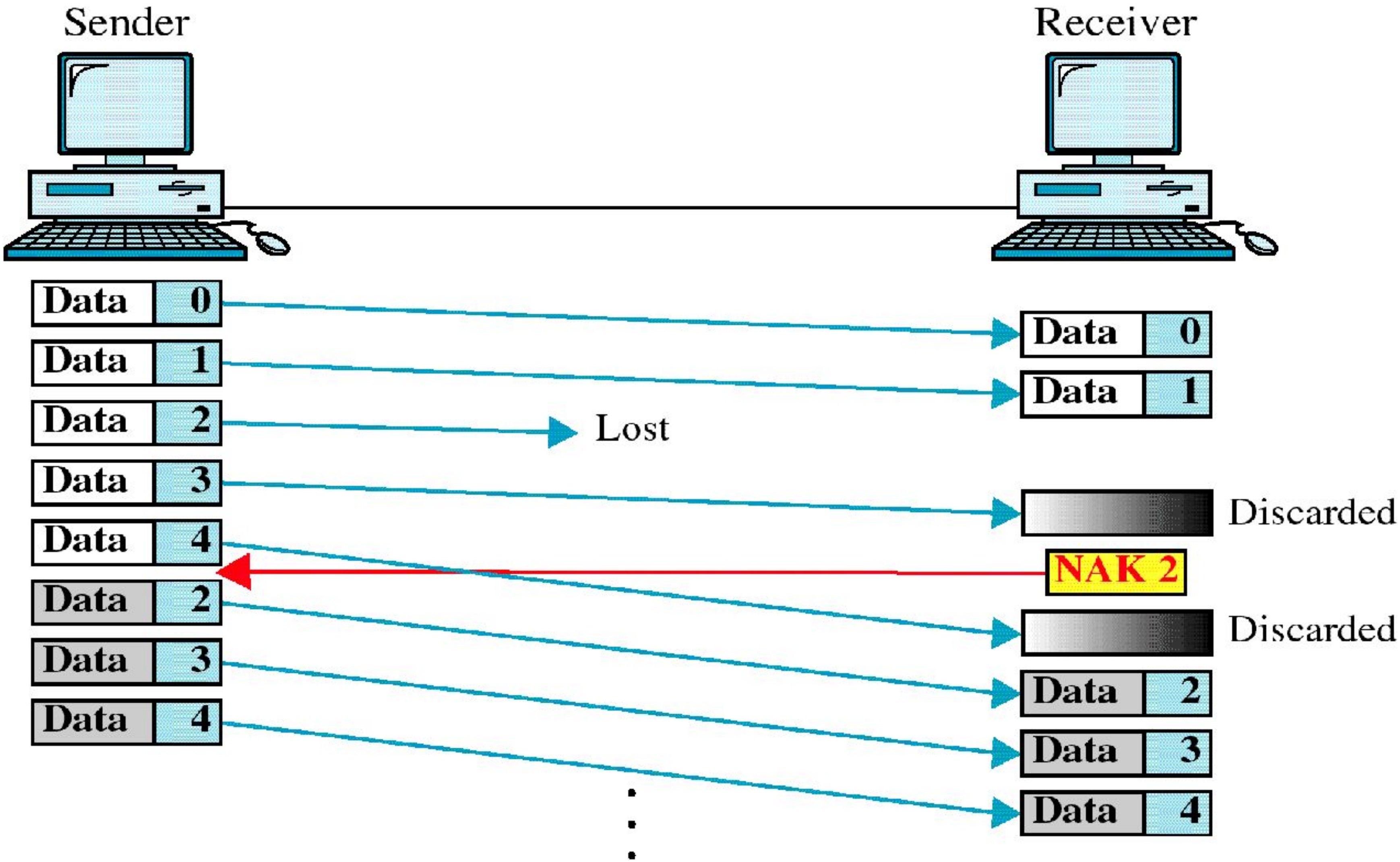
Damaged frame in Go-Back-n Sliding Window ARQ



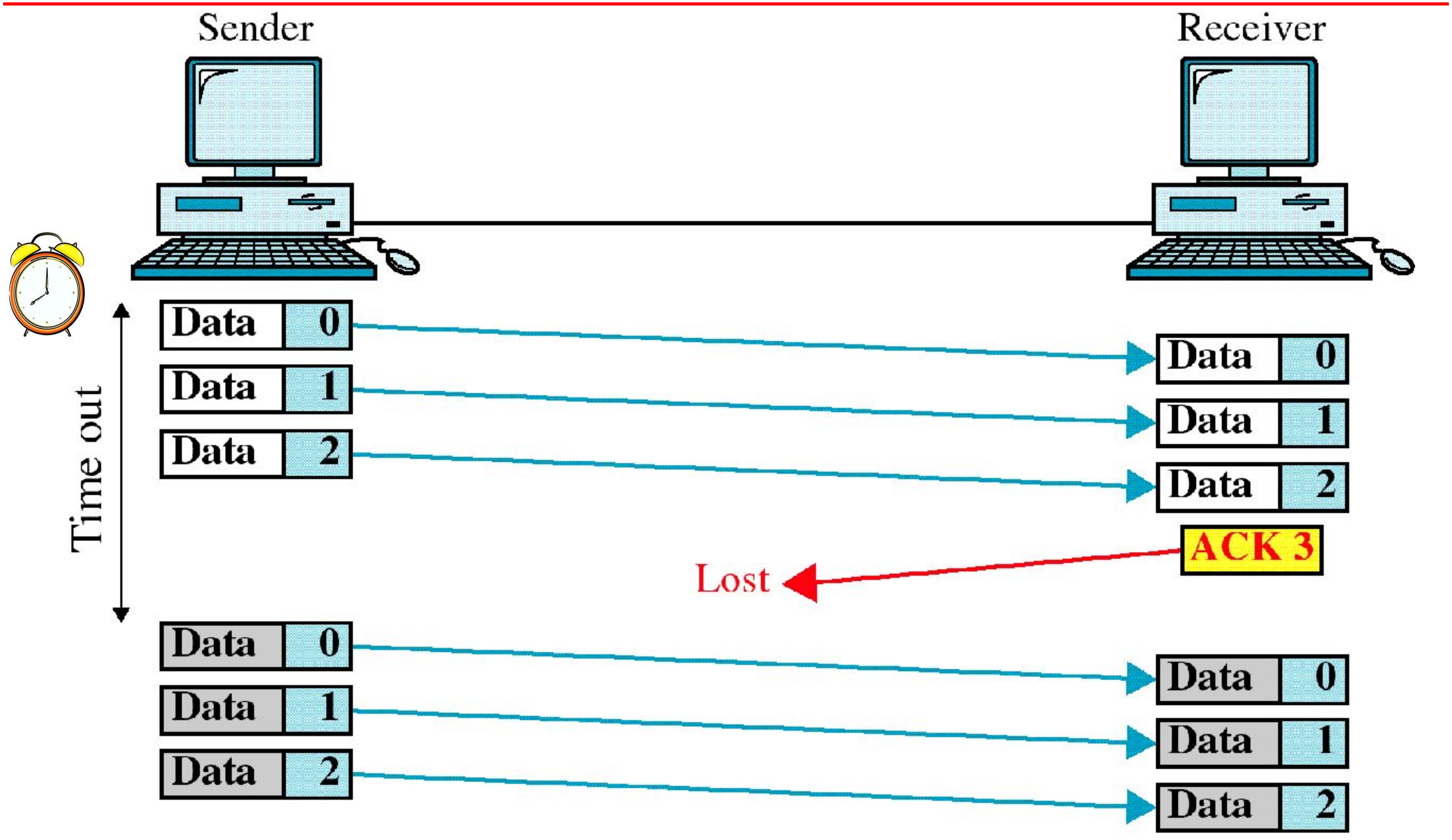
Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc-Graw Hill education

Lost Frame in Go-Back-n Sliding Window ARQ



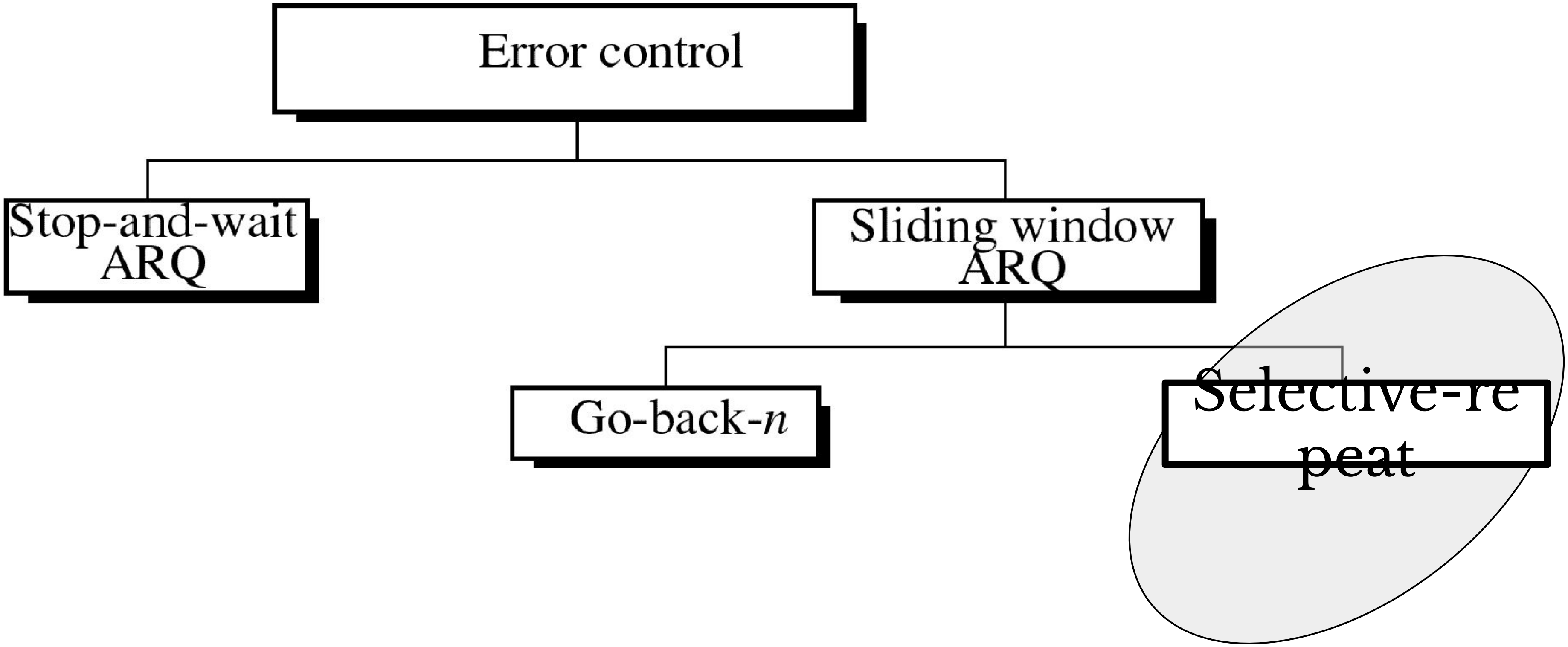
Lost ACK in Go-Back-n Sliding Window ARQ



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education

Go-Back-n Sliding Window ARQ



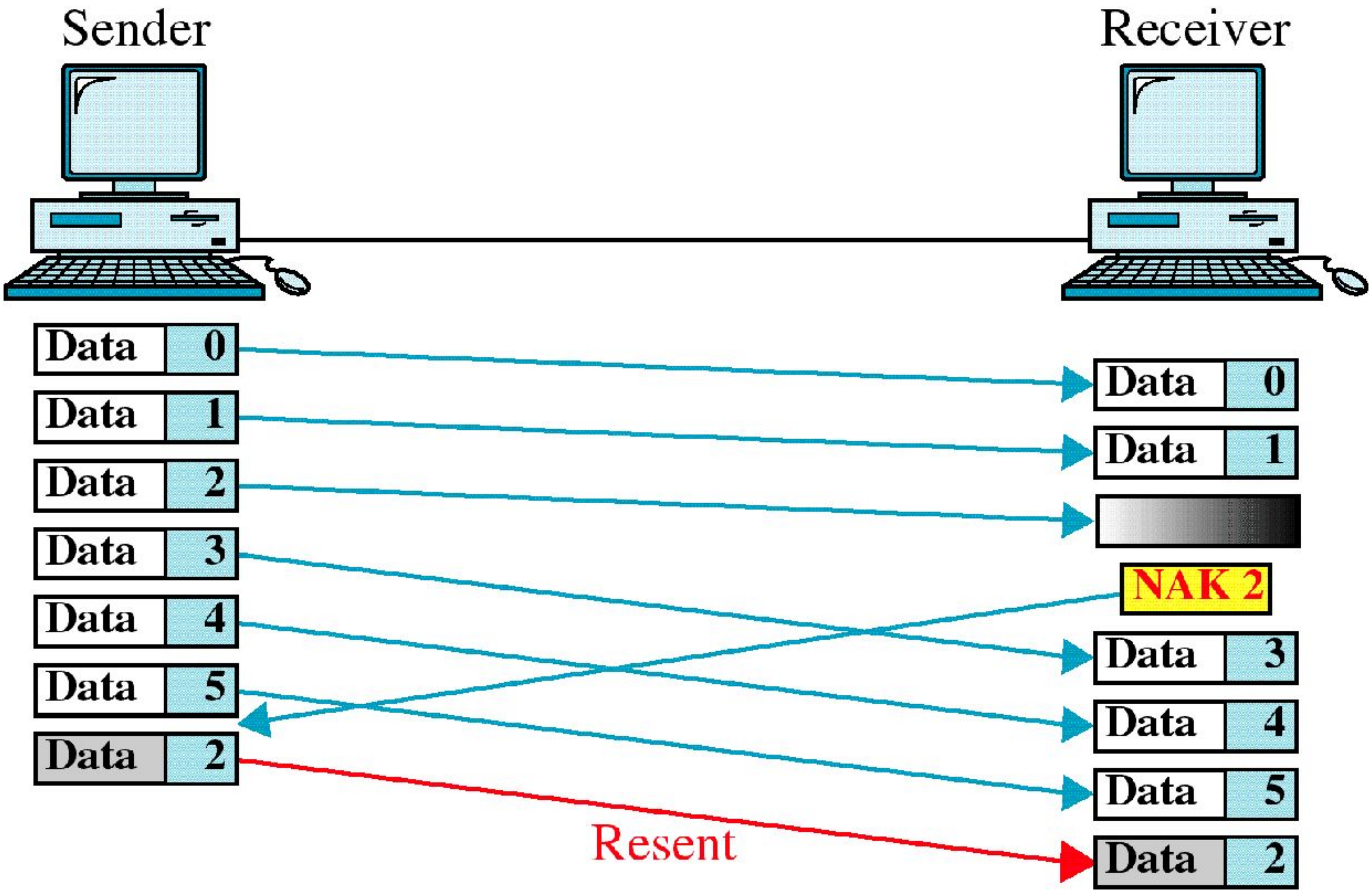
Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education

Selective-Repeat Sliding Window ARQ

- Only specific damaged or lost frame is retransmitted
- If NAK is received, the frame is resent out of sequence
- The receiving device needs to sort the frames in proper place
- To make such selectivity possible following steps are incorporated
  - Receiver contains **sorting logic** to reorder the frames after NAK is sent
  - Sender must have **searching mechanism** to find requested frame
  - A **Buffer in receiver** keeps all previously received frames on hold until all retransmissions have been sorted
  - **Like NAK, ACK here refers to frame received instead of the next expected frame**
  - **Due to complexity, the window size is kept smaller equal to (n+1)/2**

Damaged frame in Selective Repeat ARQ



Reference: Ch3: The Data Link Layer, Andrew S Tanenbaum, Computer Networks -, 4th Edition, Pearson Education

Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education

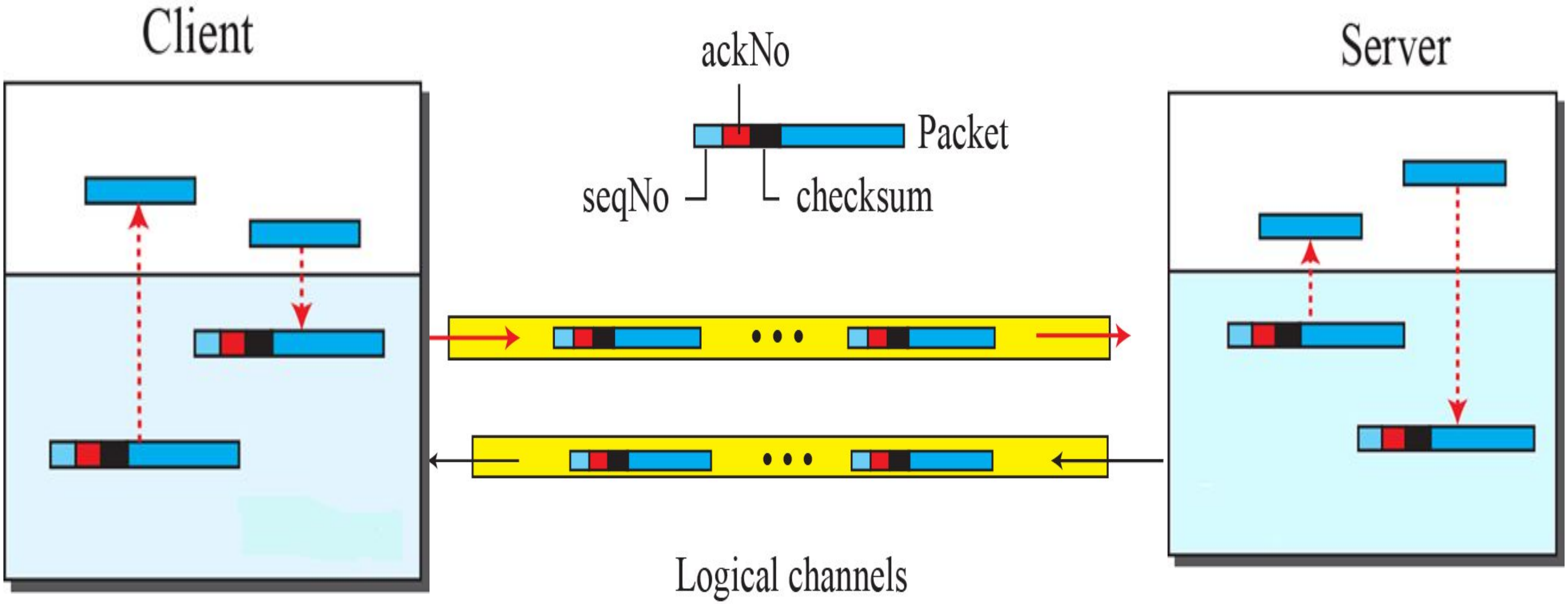
Selective-Repeat ARQ

- Lost frame
  - If a frame is lost, the next frame will arrive out of order.
  - The receiver will try to reorder the frames and will find discrepancy
  - It will return NAK
  - Receiver will find discrepancy, only if other frames follow
  - If the lost frame is last in transmission, the receiver does nothing. The sender treats this silence like a lost acknowledgement.
- Lost acknowledgment
  - Same as go-back-n ARQ.
  - It uses timer and after time out resend all unacknowledged frames.
  - In most cases, the receiver will recognize any duplication and discard them.

Piggybacking

- The flow and error control protocols are unidirectional.
- Data frames flow in only one direction and control, ACK, NAK frames flow in other direction.
- In actual communication networks, data frames and control, ACK, NAK needs to flow in both the direction.
- A technique, "piggybacking" is used to improve the efficiency of protocols.
- When the frame is carrying data from A to B, it can carry control information for B and vice versa.

Piggybacking



Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 312,339, 343

Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

Lecture 16

HDLC

High-level Data Link Control (HDLC) ***is a*** ***bit-oriented*** ***protocol for communication over point-to-point and multipoint links. It implements the ARQ mechanisms.***

Topics :

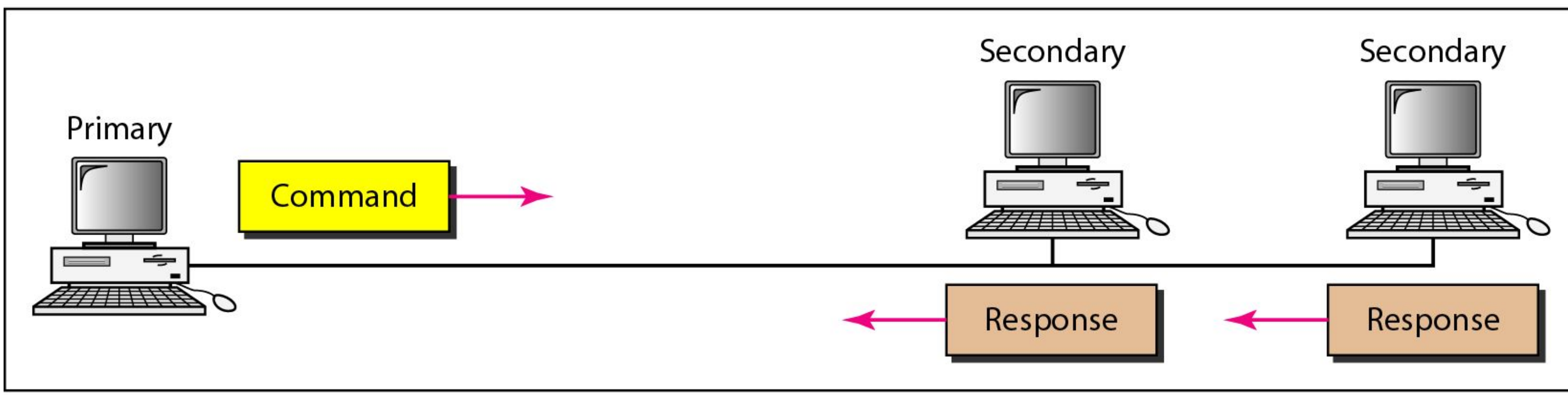
Configurations and Transfer Modes
Frames
Control Field

Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 340

Configurations and Transfer Modes - HDLC

Normal response mode

a. Point-to-point



b. Multipoint

Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 340

Configurations and Transfer Modes - HDLC

Asynchronous balanced mode

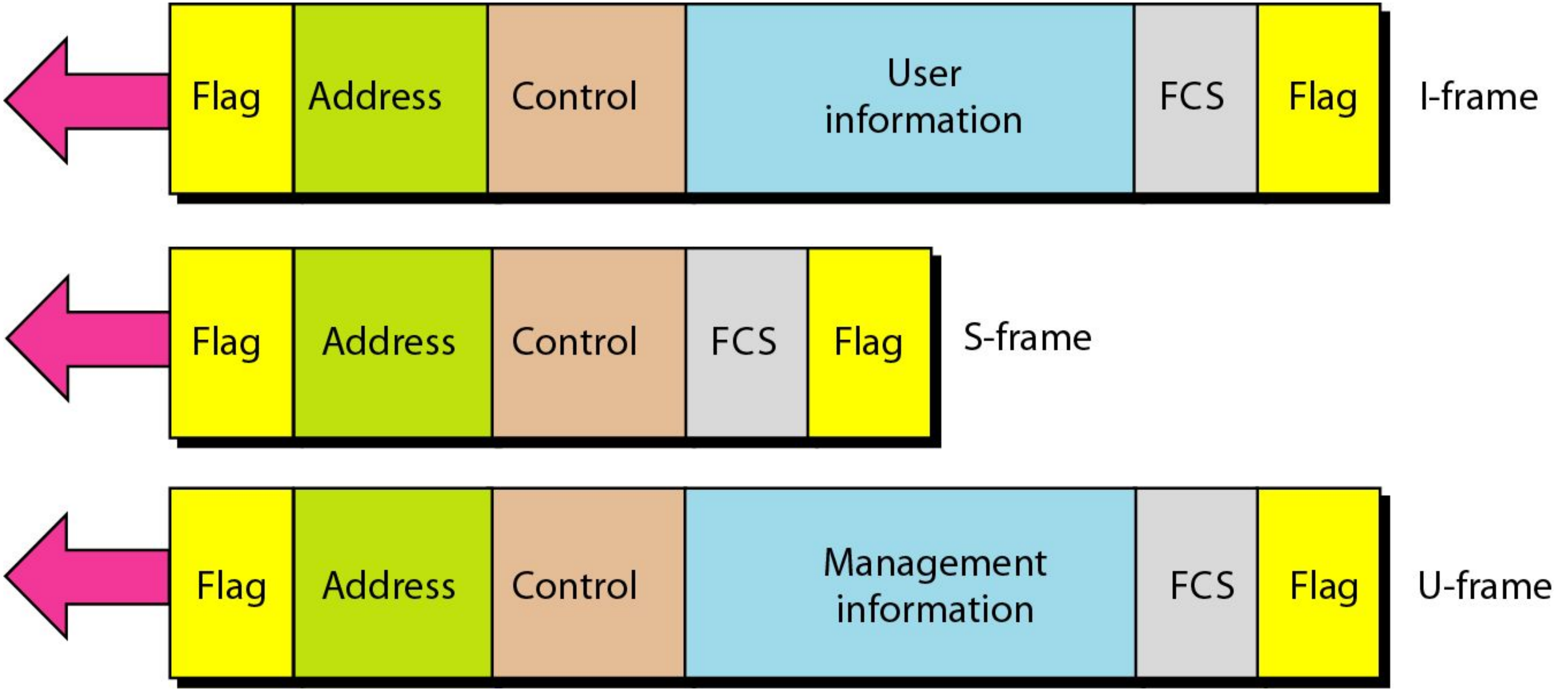
HDLC frames

Different frame structures support mode and configurations of HDLC

1. **Information Frames:** used for transport of user data and control information.
2. **Supervisory Frames:** used for transport of only control information.
3. **Unnumbered Frames:** reserved for system management.

Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 340

HDLC frames

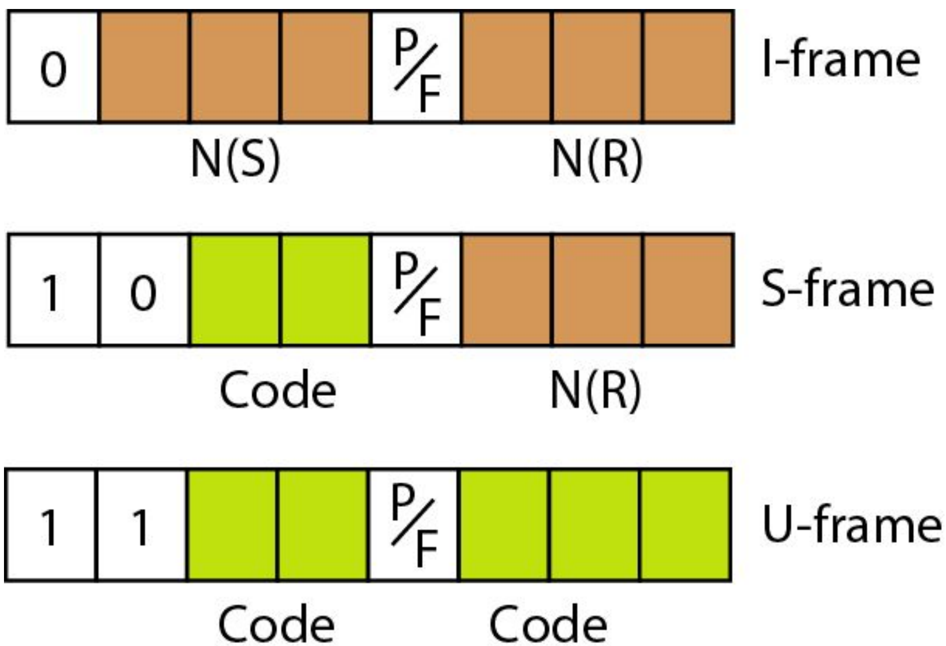


Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 340

HDLC frames

1. **Flag Field:** an 8 bit sequence with bit pattern 01111110. Identify beginning and end of the frame
2. **Address Field:** Address of secondary station. For primary station it contains *to* address. For secondary station it contains *from* address
3. **Control Field:** used for flow control and error control
4. **Information Field:** contains user data from network layer
5. **FCS field:** Frame check sequence is error detection field in HDLC, holds CRC information of 2-4 byte

Control field format for the different frame types

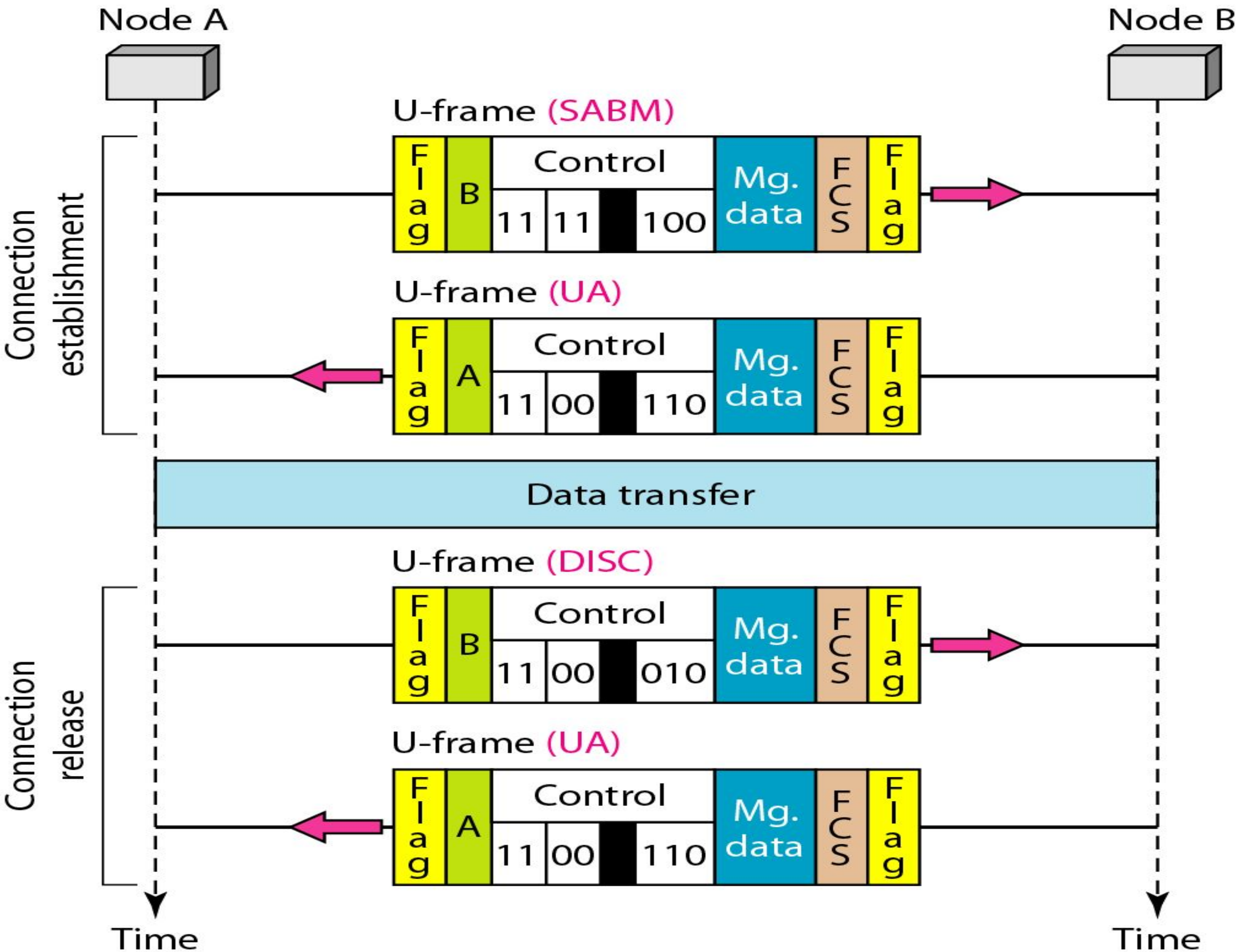


U-frame control command and response

Code	*Command*	*Response*	*Meaning*
00 001	SNRM		Set normal response mode
11 011	SNRME		Set normal response mode, extended
11 100	SABM	**DM**	Set asynchronous balanced mode or **disconnect mode**
11 110	SABME		Set asynchronous balanced mode, extended
00 000	UI	**UI**	Unnumbered information
00 110		**UA**	**Unnumbered acknowledgment**
00 010	DISC	**RD**	Disconnect or **request disconnect**
10 000	SIM	**RIM**	Set initialization mode or **request information mode**
00 100	UP		Unnumbered poll
11 001	RSET		Reset
11 101	XID	**XID**	Exchange ID
10 001	FRMR	**FRMR**	Frame reject

Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 340

HDLC: Example of connection and disconnection



Reference: Ch11: Data Link Control, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 340

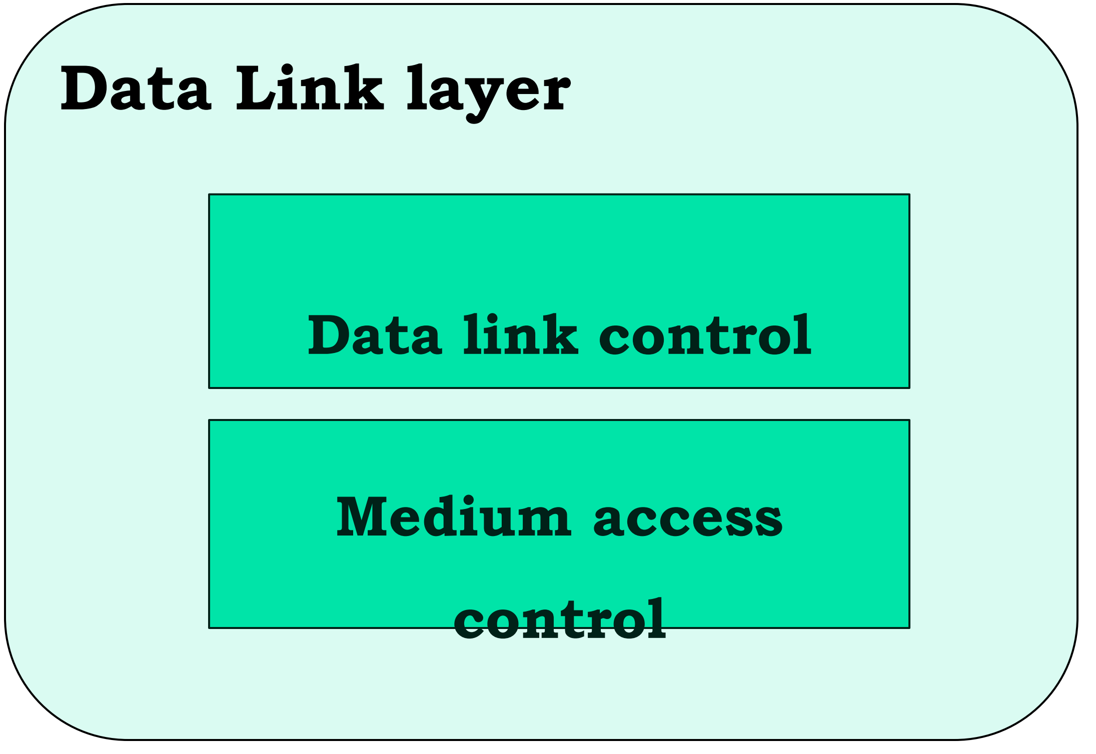
Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

Lecture 17

Data link layer divided into two functionality-oriented sublayers

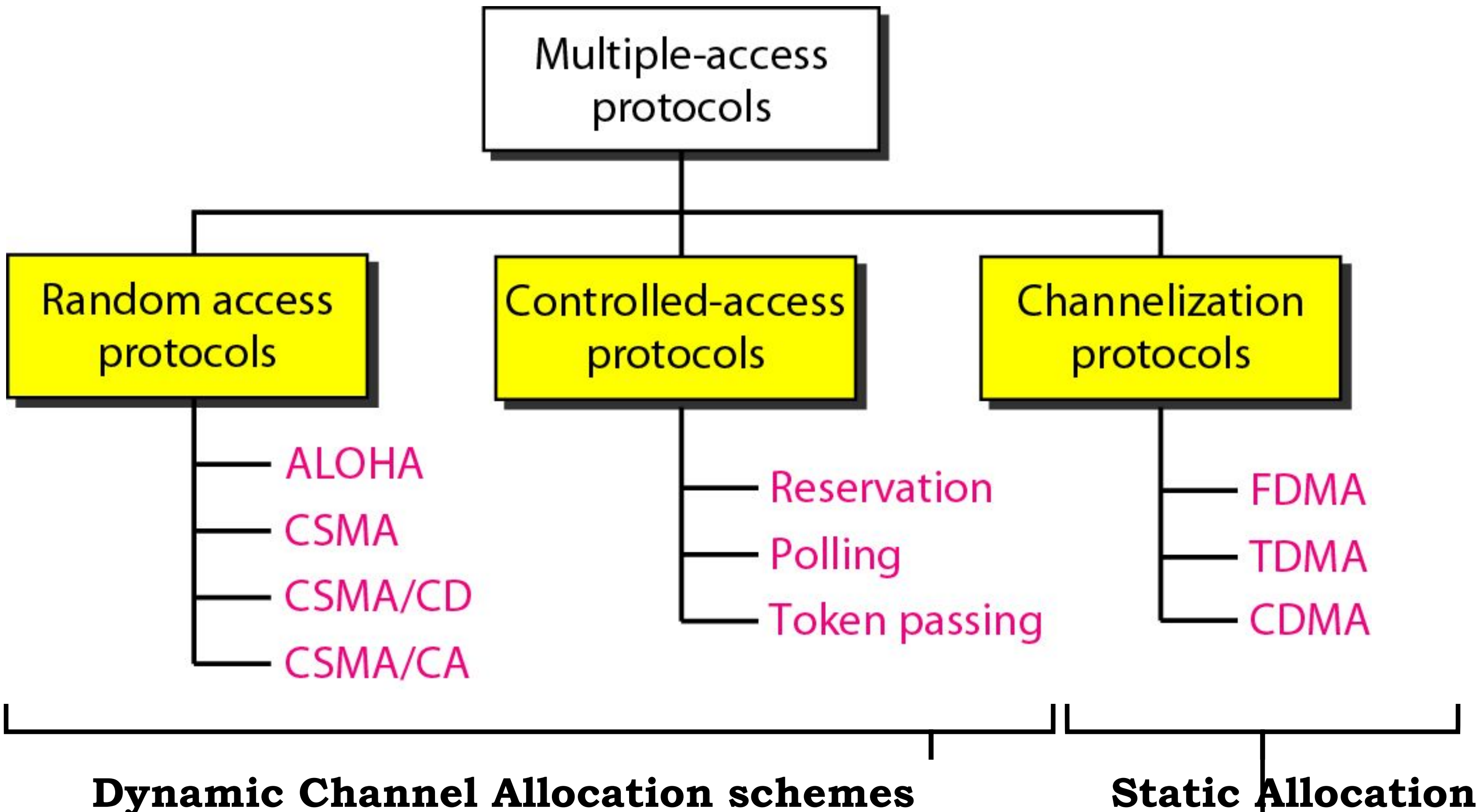


Reference: Ch12: Multiple Access, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 363

Medium Access

- In networking usually **devices share the links** among the available devices
- The **link** between the devices is known as a ‘**medium**’
- Thus it is important for any device on network, to **check availability of medium** before transmitting
- Many formal protocols are devised to handle this problem of shared medium

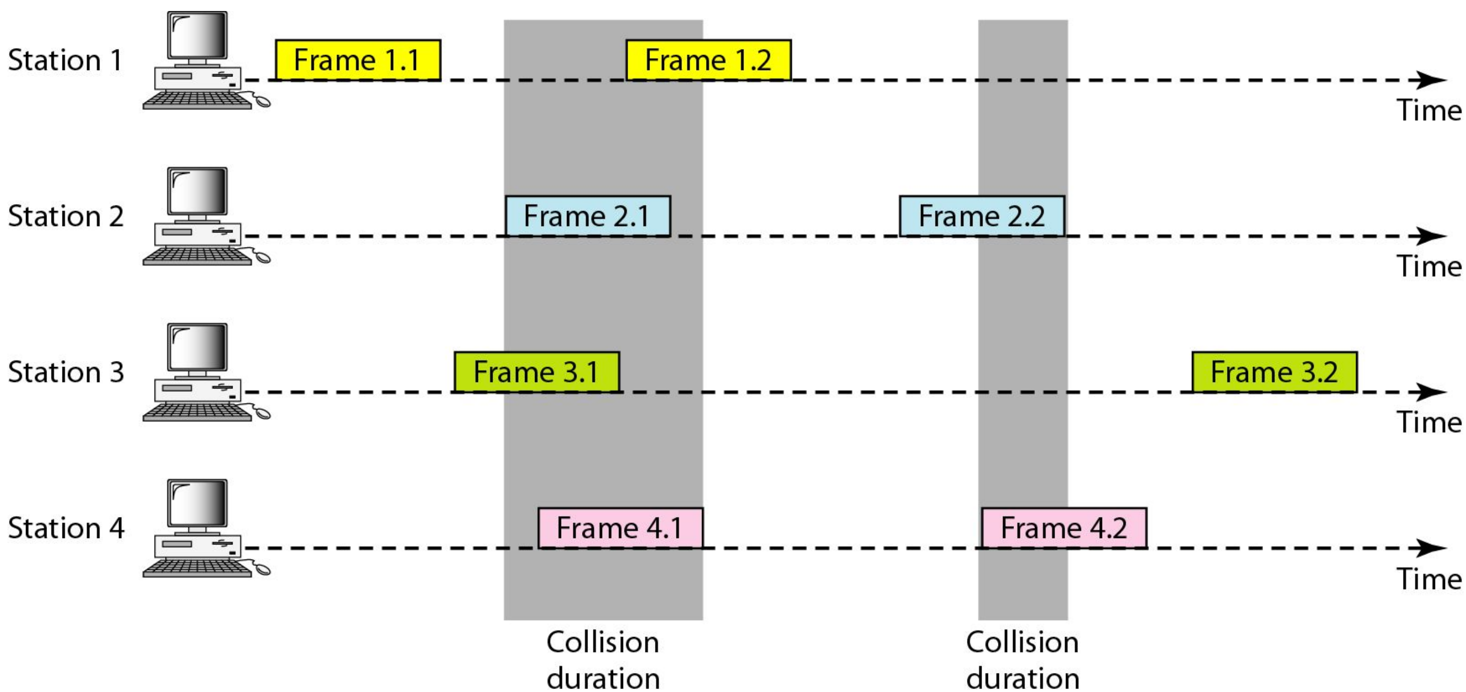
Medium Access Protocols



Reference: Ch12: Multiple Access, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 363

Pure ALOHA

- First random access method, developed at the **university of Hawaii** in 1970
- The idea is, each station **sends a frame** whenever it has a **data to send**
- High possibility of **collisions**



Reference: Ch12: Multiple Access, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 363

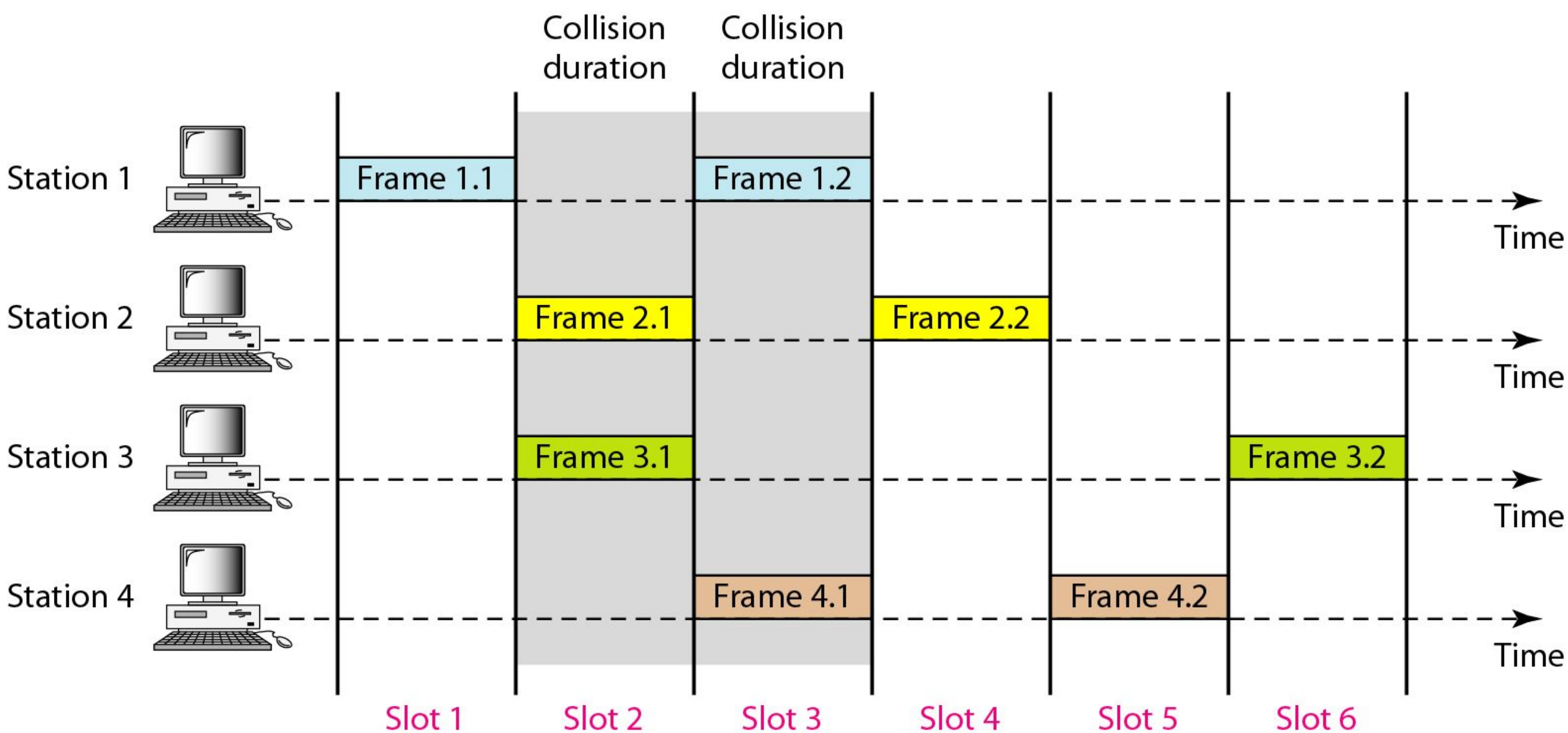
Pure ALOHA

- When the **frames collide**, they are **destroyed**
- Receiver sends **ACK's** for the **lost frames**
- If sender does **not** receive an **ACK** for sent frame then he assumes **loss of frame** and resends the same
- Now the **chances** of this stations **colliding** together while resending are **even high**
- Pure ALOHA solves this problem by making each station **wait a random amount** of time before resending its frame
- This random time is called **"back-off time"**
- Another method to reduce congestion is, it **sets limit on** maximum number of **retransmission attempts** K_{max}
- If **K_{max}** is **reached** a station must **give up** and try later

Reference: Ch12: Multiple Access, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 363

Slotted ALOHA

- **Improves** the **efficiency** of pure ALOHA
- Here the **time** is **divided** into slots
- Each station is forced to **send only** at the beginning of the **time slot**



Slotted ALOHA

Advantages:

- Because the stations are allowed to send only at the beginning of the time slot, **collisions** are **reduced**
- The **throughput** of slotted ALOHA (37%) is double of the Pure ALOHA (18%)

Pure ALOHA	Slotted ALOHA
Each station sends a frame whenever it has a data to send	Each station is forced to send only at the beginning of the time slot
Collision rate is very high.	Collision rate is comparatively less
Collision Domain= 2× Frame time	Collision Domain= Frame time
Efficiency is 18%	Efficiency is 37%

Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

Lecture 18

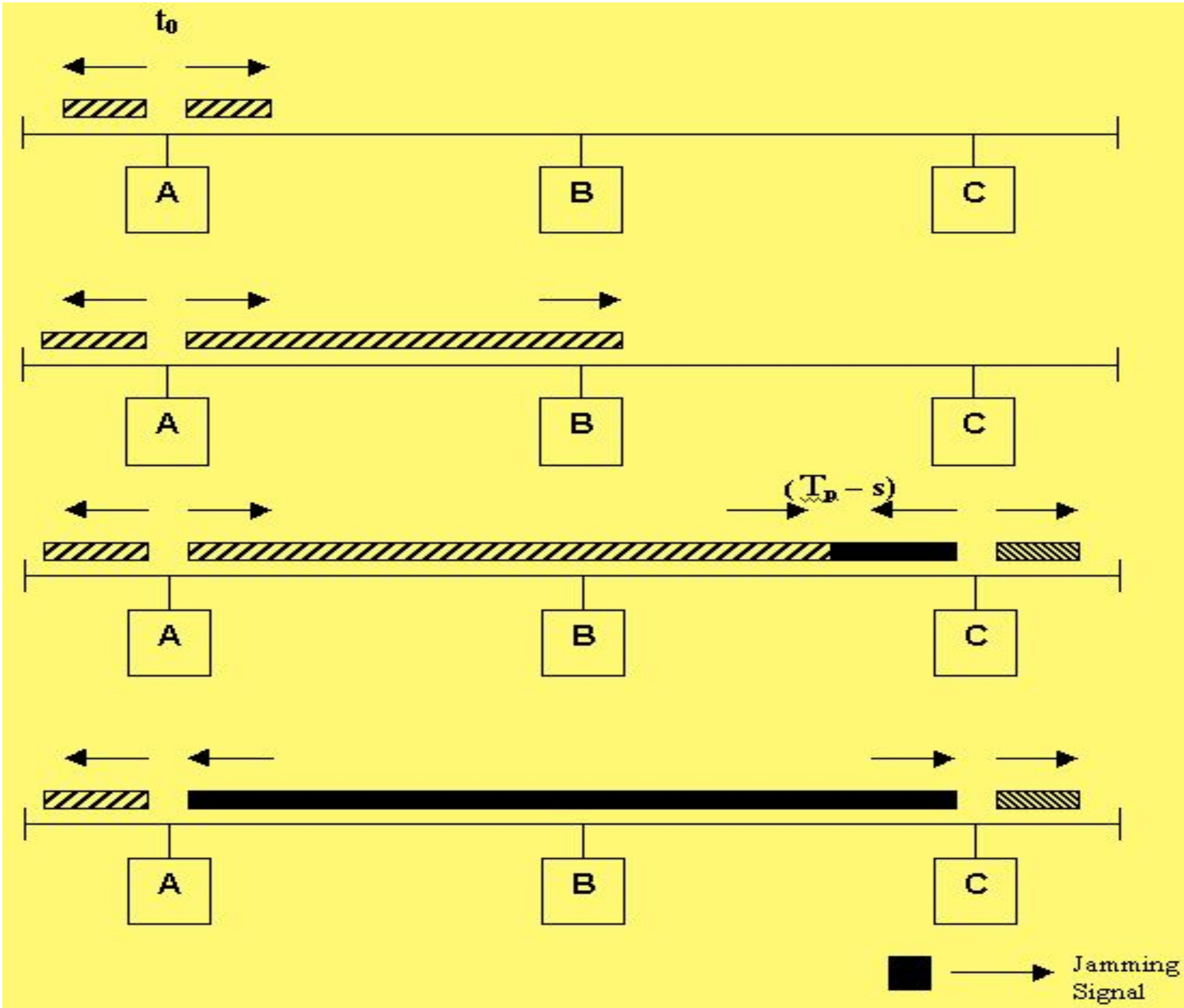
Carrier Sense Multiple Access

- The chance of collision is reduced if a **station senses** the medium **before** trying to **use** it
- CSMA forces each **station** first to **listen** to the **medium** before sending data ← **(carrier sense)**
- Carrier sense methods:
  - Non Persistent CSMA
  - 1-Persistent CSMA
  - P-Persistent CSMA
- The collisions still exists, if two stations transmit at the same time
- Two types:
  - With Collision Detection **(CD)**
  - With Collision Avoidance **(CA)**

CSMA/CD (CSMA with Collision Detection)

- CSMA does not specify procedure after collision
- Therefore stations continue transmitting even though a collision occur
- In CSMA/CD, a station monitors the medium after it sends a frame to see if the transmission was successful
- If there is a collision, the **jamming signal** is sent to indicate collision

CSMA/CD (CSMA with Collision Detection)



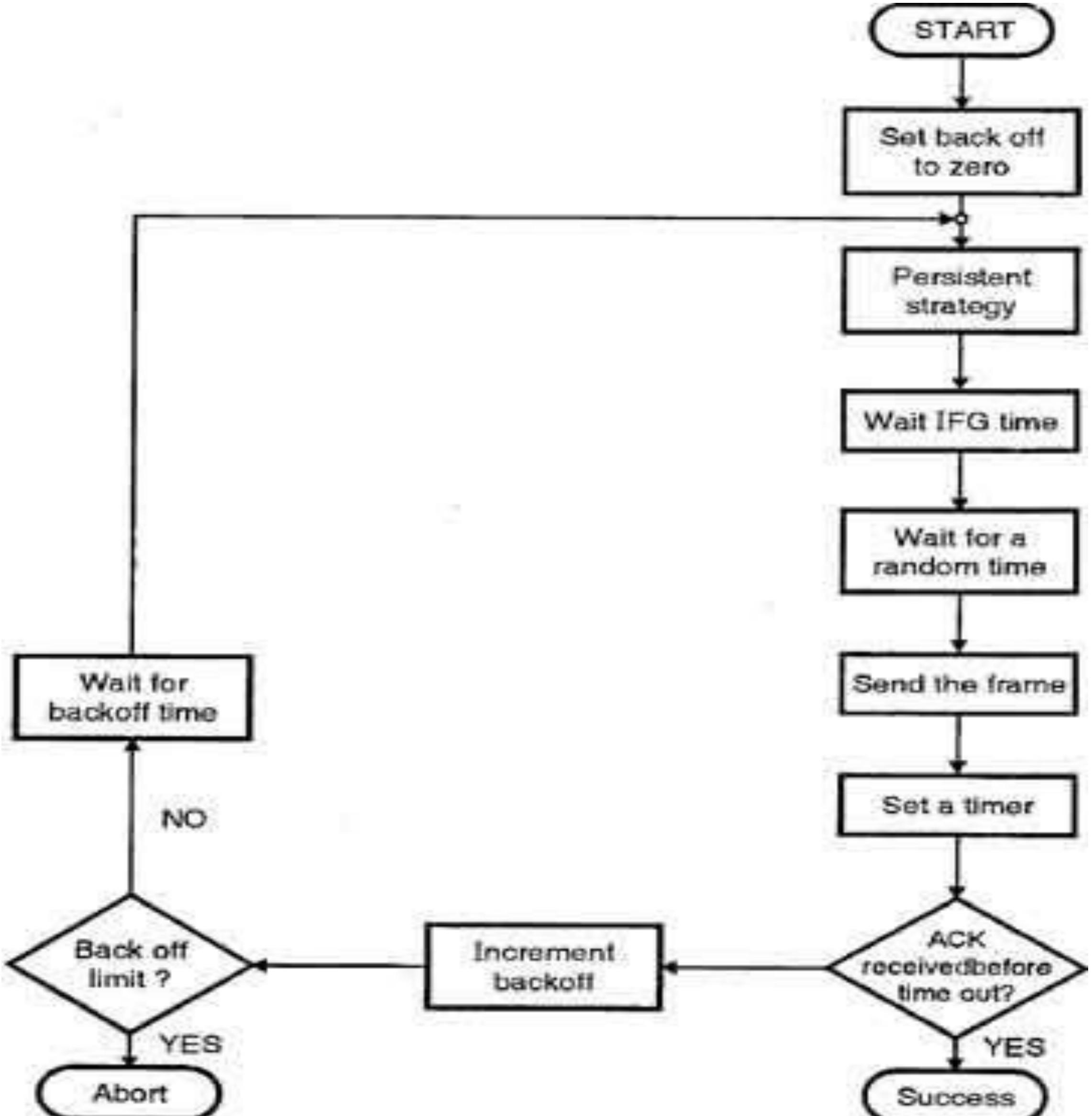
Reference: Ch12: Multiple Access, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 363

CSMA/CA (CSMA with Collision Avoidance)

- Used for wireless mediums
- The sender sense the medium. If medium is free, the sender transmits immediately
- If medium is not free, a **random back-off** algorithm is used to decide when the sender should sense the medium again

Reference: Ch12: Multiple Access, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 363

CSMA/CA random backoff algorithm



Computer Network & Network Design

Module 2

Physical Layer & Data Link Layer

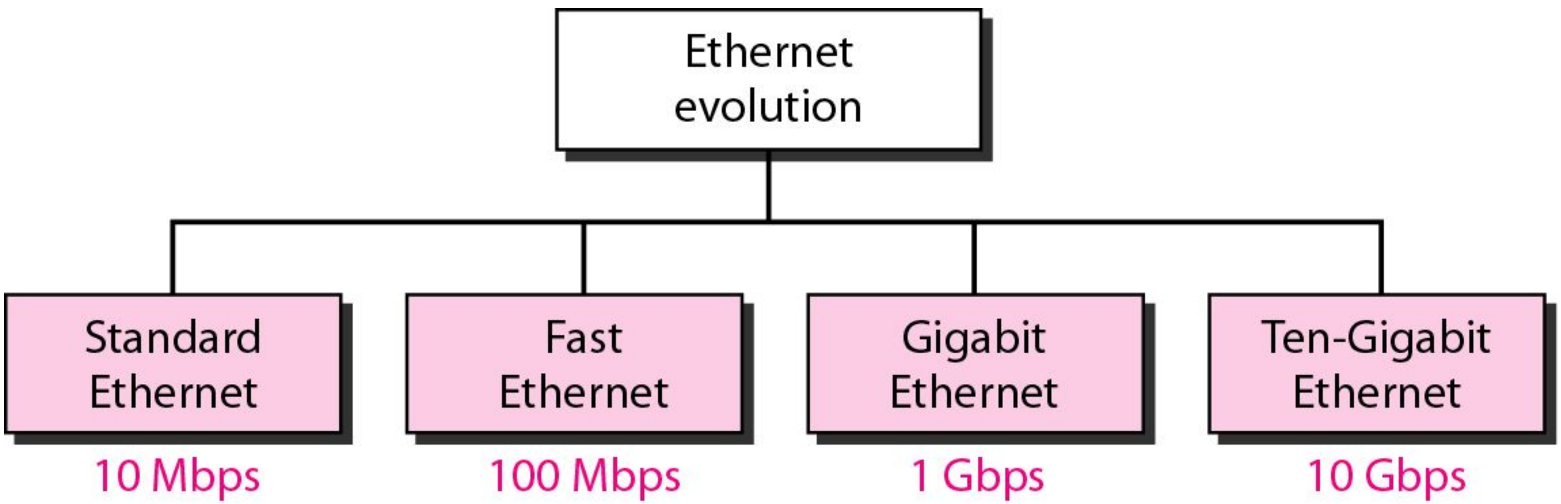
Lecture 19

ETHERNET - IEEE standard 802.3

- A standard for **wired LANs**
- Defined by **IEEE's project 802**
- **Project 802 :**
  - defines and regulates manufacturing and interconnectivity between LANs
  - defines several technologies such as Ethernet(802.3), Token Ring(802.5), Token Bus(802.4) etc
- Ethernet is a **dominant technology** among all
- The original Ethernet was created in 1976 at Xerox's Palo Alto Research Center (PARC)
- Since then, it has gone through **four generations**

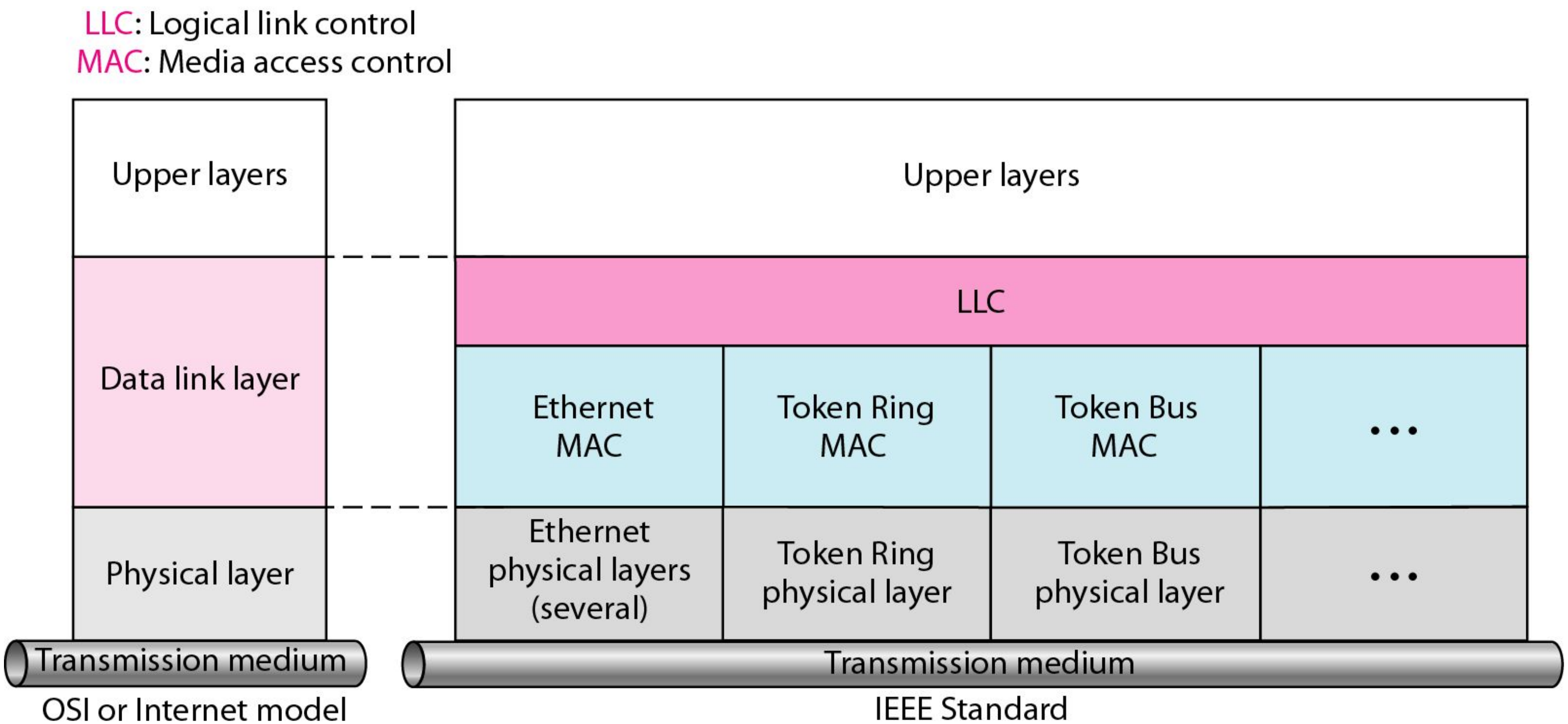
Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Ethernet evolution through four generations



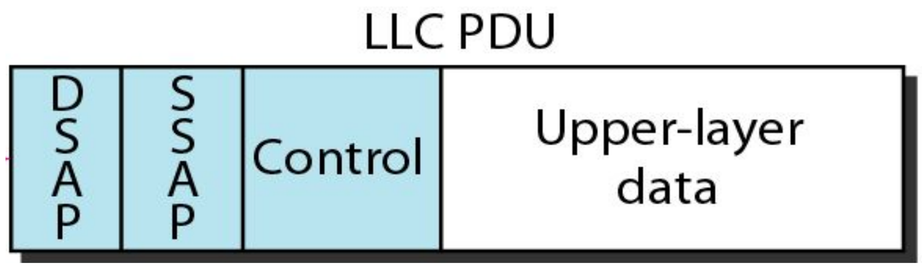
What Ethernet defines?

- Defines rules for Data link and Physical layer
- Divides DLL in two parts:
  - D/LLC (Data/Logical Link Control)- commonly defined for project 802
  - MAC (Medium Access Control)- varies with standard



Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

LLC framing



- **DSAP** - destination service access point & **SSAP** - source service access point defines the **upper layer protocols** using services of LLC
- **Control:** used for **error** control and **flow control**
- **Data:** hold data from upper layer

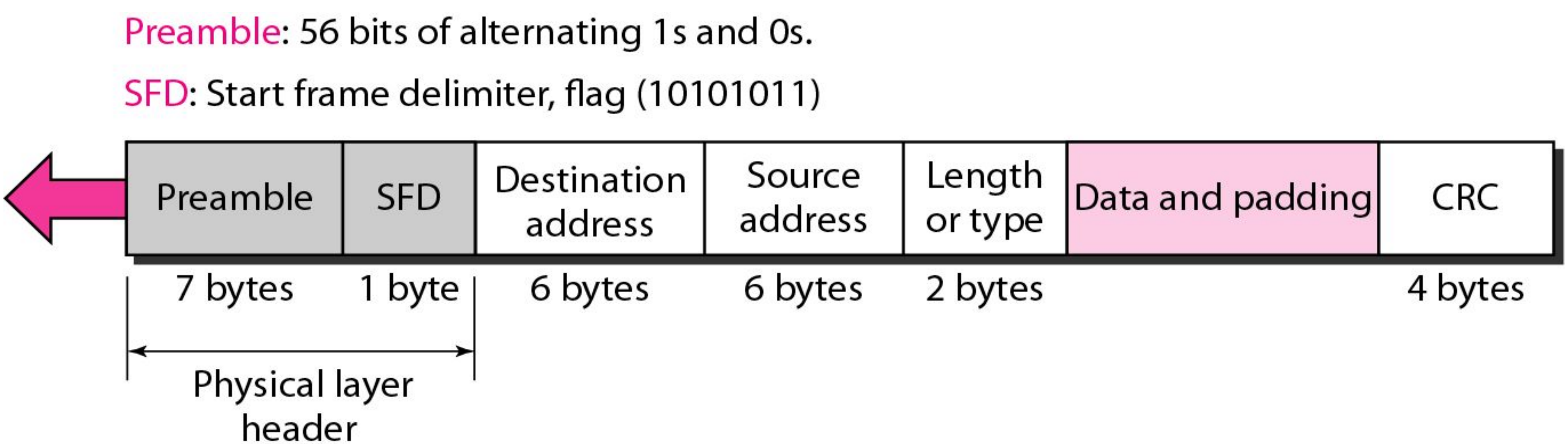
Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Standard Ethernet- MAC sublayer

- MAC sublayer governs the operation of access method
- Frames the data received from the upper layer and passes it to the physical layer

Frame Format:

- Contains seven fields
- Dose not provide ACK frame. It is left to higher layers



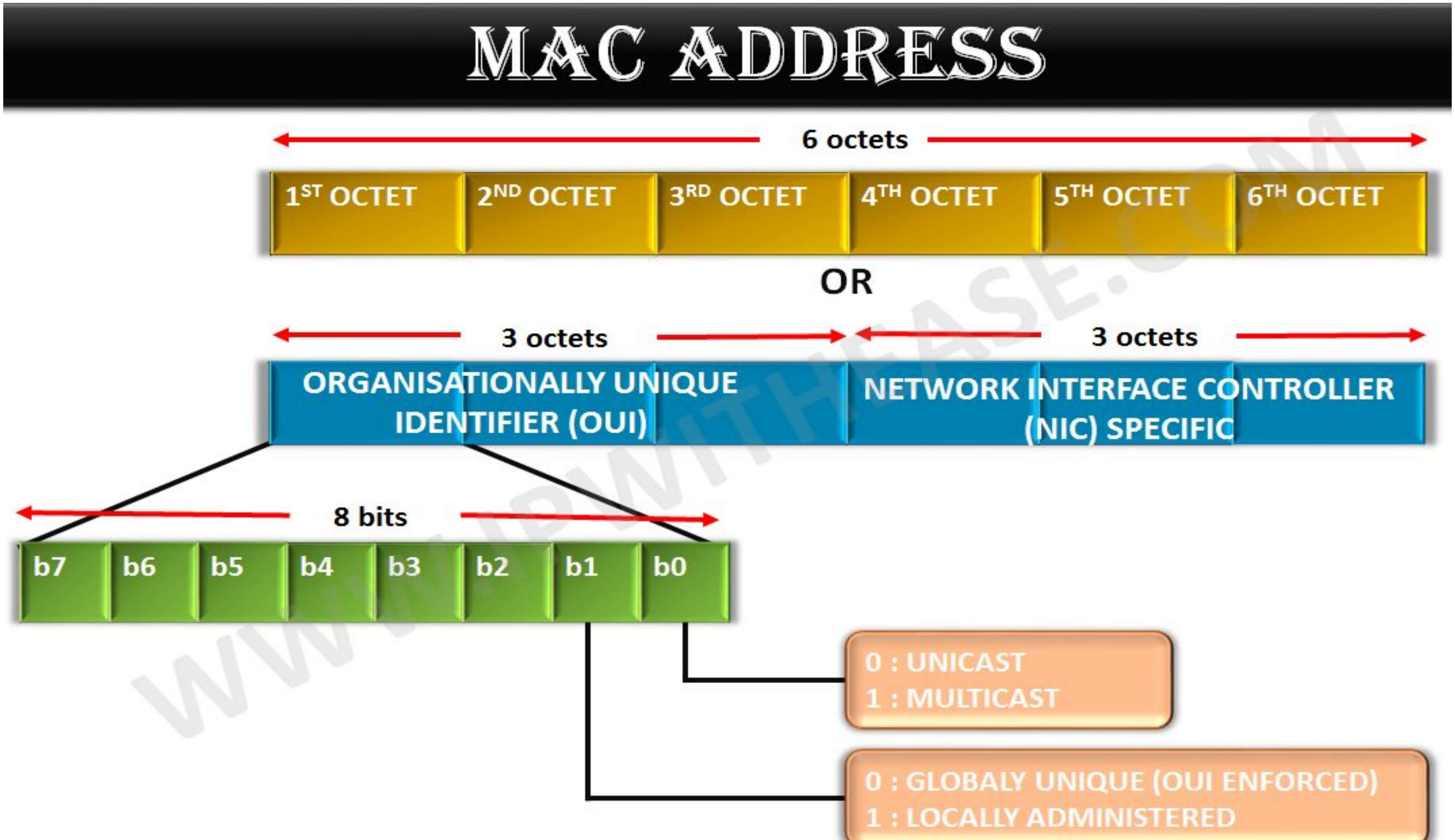
Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Standard Ethernet- MAC sublayer

- **Preamble:** contains **7 bytes** of **alternating 0s and 1s**. Provides an **alert** and a timing pulse
- **SFD:** 1byte- **10101011** signals beginning of the frame. Warns for last chance of synchronization. Last 2 bits 11 alerts receiver about the next field as destination address
- **DA:** 6 byte field contains physical address of destination station
- **SA:** 6 byte field contains physical address of source station
- **Length or type:** defines number of bytes in the data field.
- **Data:** carries encapsulated data from upper layers. Minimum of 46 and maximum of 1500 bytes.
- **CRC:** contains error detection information. CRC-32 is used.

Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Standard Ethernet- MAC sublayer defines MAC address



CSMA-CD in Ethernet

- Data is transmitted in the form of **packets**
- **Sense channel** prior to actual packet transmission
- **Transmit packet** only if channel is sensed **idle**; else, **defer** the transmission until channel becomes idle
- After packet transmission is started, the **node monitors its own transmission** to see if the packet has experienced a collision
- If packet is observed to be undergoing a **collision**, **transmission is aborted** and packet is retransmitted after a random interval of time according to **Binary Exponential Back-off algorithm**

Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Computer Network & Network Design

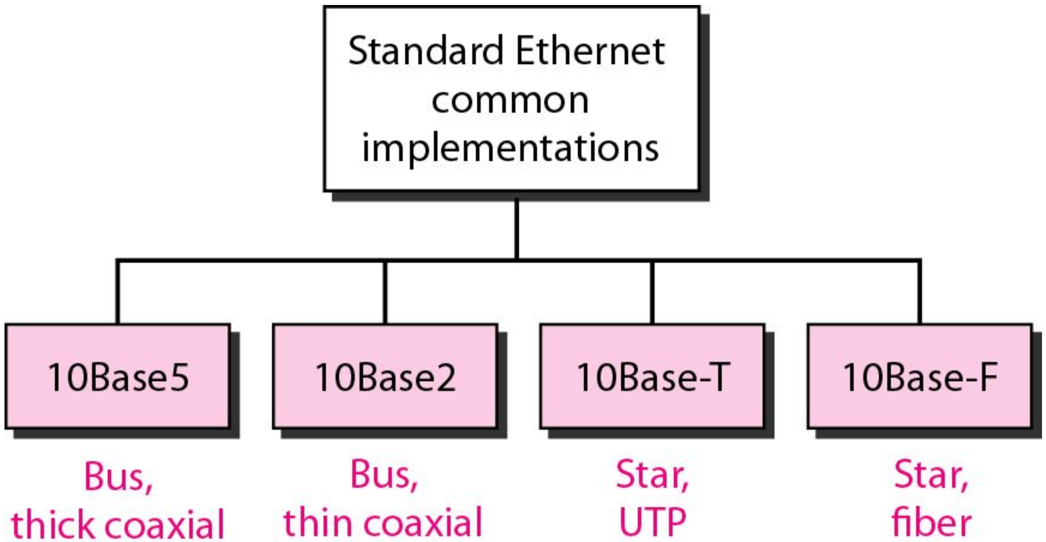
Module 2

Physical Layer & Data Link Layer

Lecture 20

Standard Ethernet- Physical Layer

- Defines four physical layer implementations



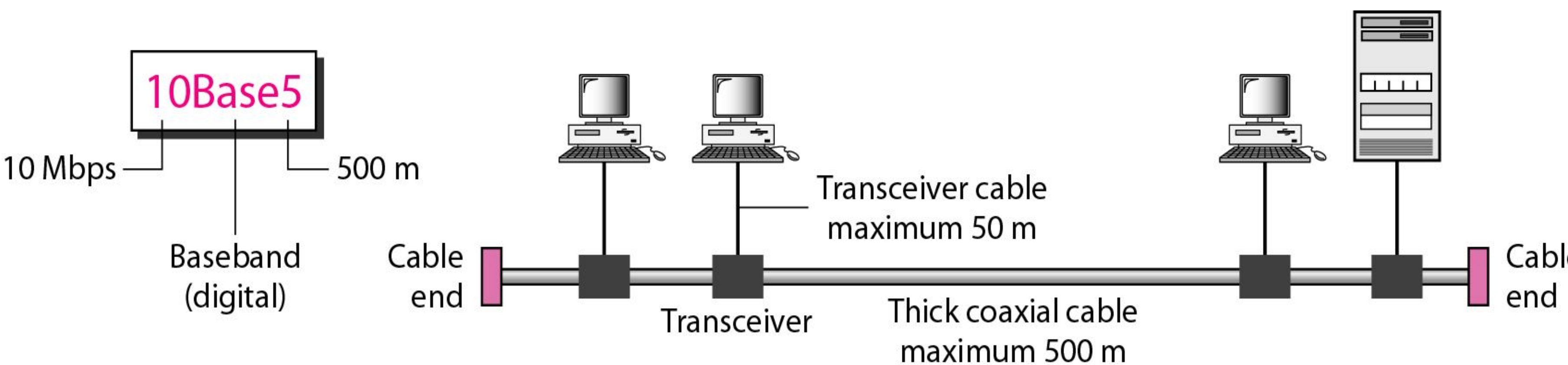
Encoding and Decoding

- Use digital signaling (baseband) at 10 Mbps
- Coding used is Manchester scheme

Standard Ethernet- Physical Layer

10Base5: Thick Ethernet

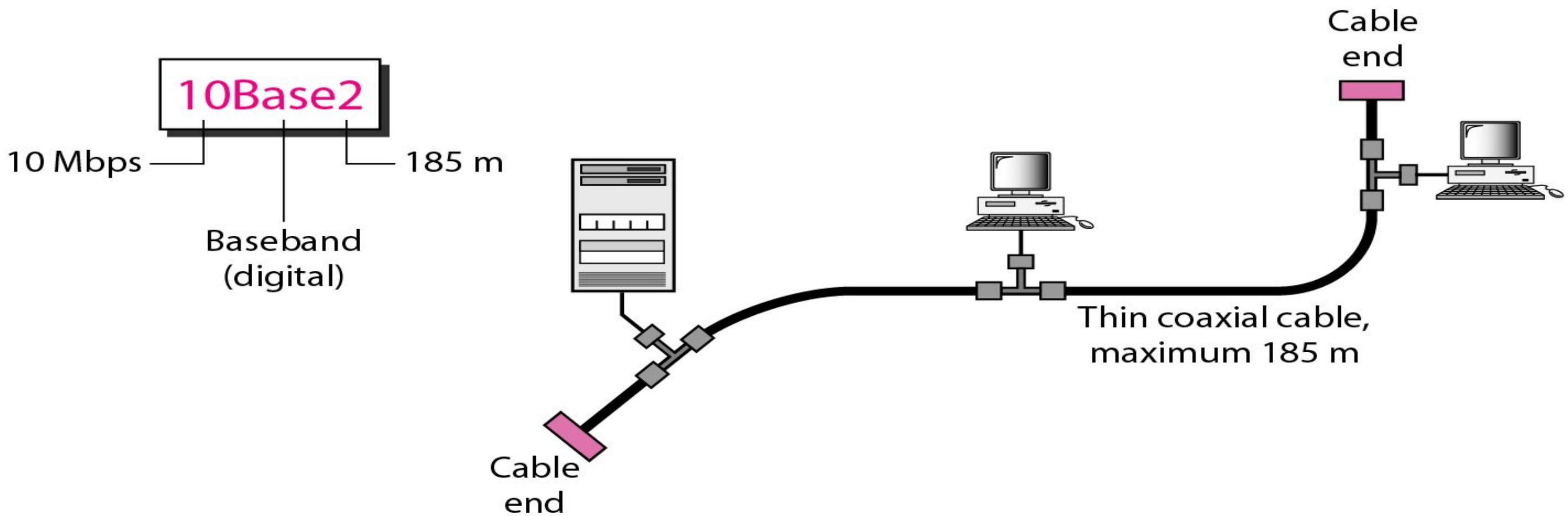
- Name derives from the size of the cable, which is of the size of a garden hose and too stiff to bend
- Use bus topology, with external transceiver connected via a tap
- Transceiver is responsible for transmitting, receiving and detecting collisions
- The maximum length of coaxial cable is 500m



Standard Ethernet- Physical Layer

10Base2: Thin Ethernet

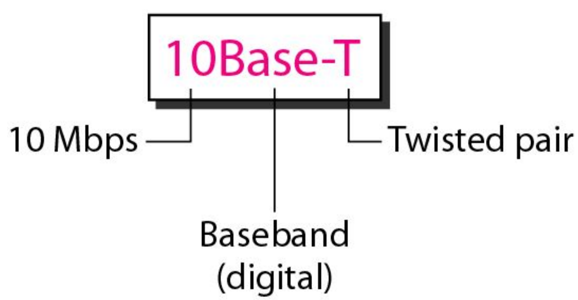
- Cable is much thinner and more flexible
- Also use bus topology
- The transceiver is normally a part of the network interface card (NIC), which is installed inside the station
- More cost effective and simple to install
- Length of each segment can not exceed 185 m(close to 200m)

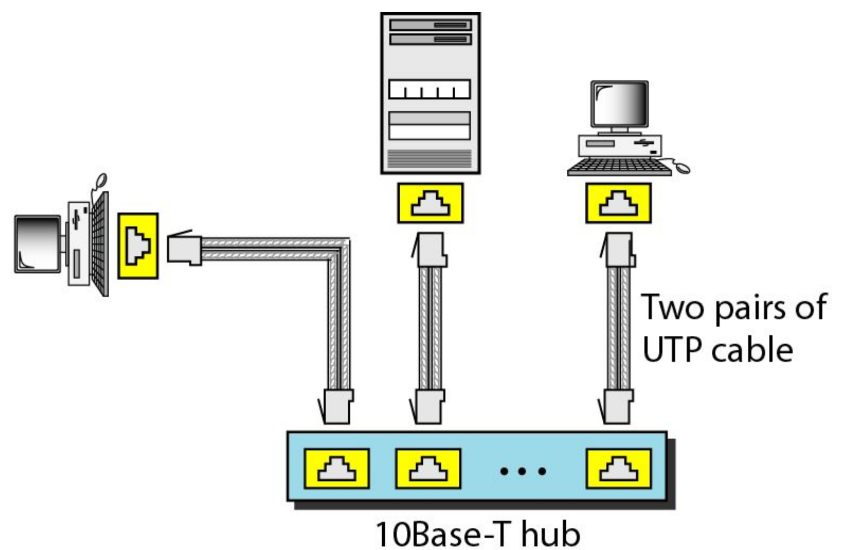


Standard Ethernet- Physical Layer

10Base-T: Twisted-Pair Ethernet

- Uses star topology
- The stations are connected to a hub via two pairs of twisted cable
- A pair of twisted cable create two paths between the station and the hub
- The maximum length of the twisted cable here is 100m



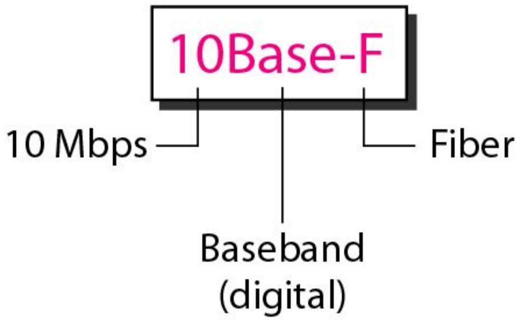


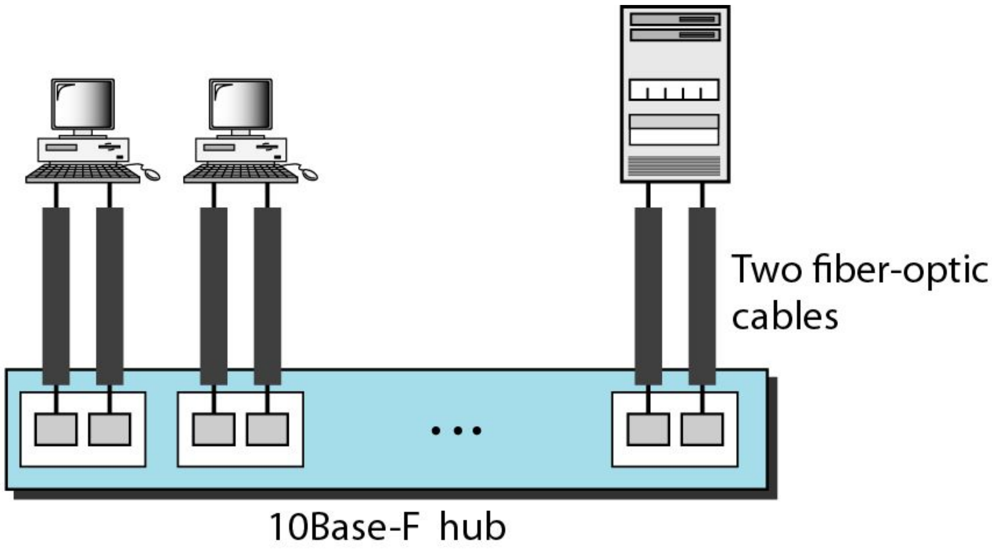
Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Standard Ethernet- Physical Layer

10Base-F: Fiber Ethernet

- Uses star topology to connect stations to a hub
- The stations are connected to a hub via two pairs of fiber-optic cable





Summary of Standard Ethernet implementations

Characteristics	*10Base5*	*10Base2*	*10Base-T*	*10Base-F*
Media	Thick coaxial cable	Thin coaxial cable	2 UTP	2 Fiber
Maximum length	500 m	185 m	100 m	2000 m
Line encoding	Manchester	Manchester	Manchester	Manchester

Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395

Standard Ethernet- variations

Fast Ethernet

- Can transmit data at a rate of 100 Mbps.

Gigabit Ethernet

- Data rate is 1000 Mbps.

Ten-Gigabit Ethernet

- Data rate is 10Gbps

Reference: Ch13: Wired LANs: Ethernet, Behrouz A. Forouzan, Data Communications and Networking, 4th Edition, Mc Graw Hill education, page 395