CSE/PC/B/T/316
Computer Networks
Topic 1- Introduction

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Syllabus

- Introduction: Uses of Computer Networks, Types of Computer Networks, OSI Reference Model, TCP/IP model [4L]
- Review of Physical Layer [4L]
- Data Link Control and Protocols: Link Layer Services, Error detection and Correction Techniques, Multi Access Protocols, Link Layer Addressing, Ethernet, Hubs, Switches and Switches, Point to Point Protocol, Asynchronous Transfer Mode, Multiprotocol Label Switching [6L]
- Network Layer: Introduction, Virtual Circuit and Datagram Networks, IP Addressing, Subnetting, Routing Algorithms (Link State, Distance Vector, Hierarchical), Routing in the Internet (RIP, OSPF, BGP), Broadcast and Multicast Routing Algorithms, Routers, ICMP, IPv6 [8L]
- Transport Layer: Introduction to Transport Layer Services, Multiplexing and Demultiplexing, Connectionless Transport: UDP, Principles of Reliable Data Transfer, Connection Oriented Transport: TCP, Principles of Congestion Control, TCP Congestion Control, Sockets and Socket Programming, Quality of services (QOS) [8L]
- Application Layer: Web and HTTP, Domain Name Space (DNS), Electronic Mail (SMTP, MIME, IMAP, POP3), File Transfer Protocol, Cryptography [6L]
- Introduction to Wireless and Mobile Networks [4L]

COs of Theory

- CO1: Understand the layered architecture and explain the contemporary issues and importance of MAC sublayer of the Data Link Layer, network layer, transport layer and application layer of TCP-IP model, and how they can be used to assist in network design and implementation.
- CO2: Understand the protocols of MAC sublayer of the Data Link Layer and describe the IEEE standards for Ethernet (802.3) and wireless LAN (802.11).
- CO3: Understand internetworking principles and explain algorithms for multiple access, routing and different networking techniques and able to analyze the performance of these algorithms.
- CO4: Explain the protocols in Transport Layer and able to design network applications using these protocols.
- CO5: Explain the protocols in application layer and how they can be used to design popular internet applications.

COs of Lab

- CO1: Design and implement error detection techniques within a simulated network environment.
- CO2: Design and implement flow control mechanisms of Logical Link Control of Data Link Layer within a simulated network environment.
- CO3: Design and implement medium access control mechanisms within a simulated network environment using IEEE 802 standards.
- CO4: Design and implement network layer protocols within a simulated network environment or network tools using IEEE 802 standards.
- CO5: Design and implement various applications using Transport layer protocols and Application layer protocols for its implementation in client/server environment and analyze the performance.

Suggested Readings

1. Data Communications and Networking, Behrouz A Forouzan, McGraw Hill
2. Computer Networks, by Andrew S. Tanenbaum, Prentice Hall India
3. Computer Networking: A Top-Down Approach Featuring the Internet, by James F. Kurose and Keith W. Ross, Pearson Education

Slides are mainly prepared using online documents available of the above books and course materials of different institutes

REVIEW OF ERROR DETECTION IN DATA LINK LAYER

Computer Networks Lab

CO1: Design and implement error detection techniques within a simulated network environment.

Error Detection

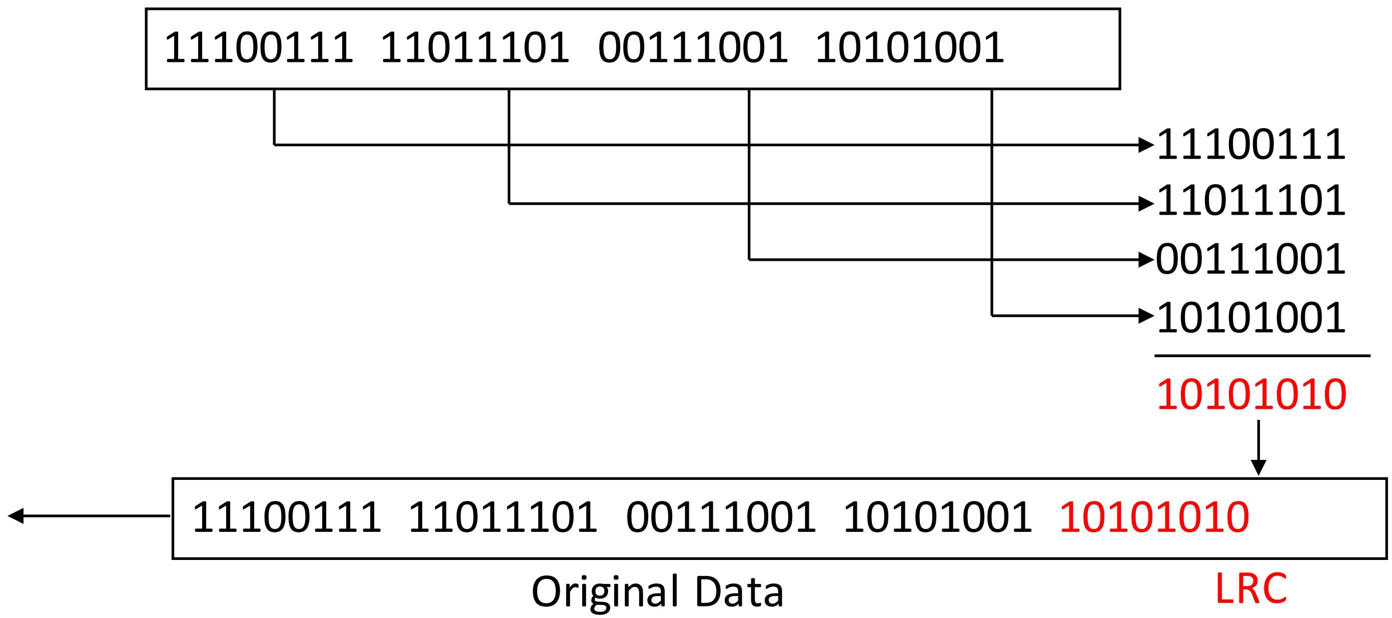
- Data transmission can contain errors
  - Single-bit
  - Burst errors of length n
    (n: distance between the first and last errors in data block)
- How to detect errors
  - If only data is transmitted, errors cannot be detected
    → Send more information with data that satisfies a special relationship
    → Add redundancy

Error Detection Methods

- **Vertical Redundancy Check (VRC)**
  - Append a single bit at the end of data block such that the number of ones is even
    → Even Parity (odd parity is similar)
    0110011 → 01100110
    0110001 → 01100011
  - VRC is also known as **Parity Check**
  - Performance:
    - Detects all odd-number errors in a data block

Error Detection Methods

- **Longitudinal Redundancy Check (LRC)**
  - Organize data into a table and create a parity for each column



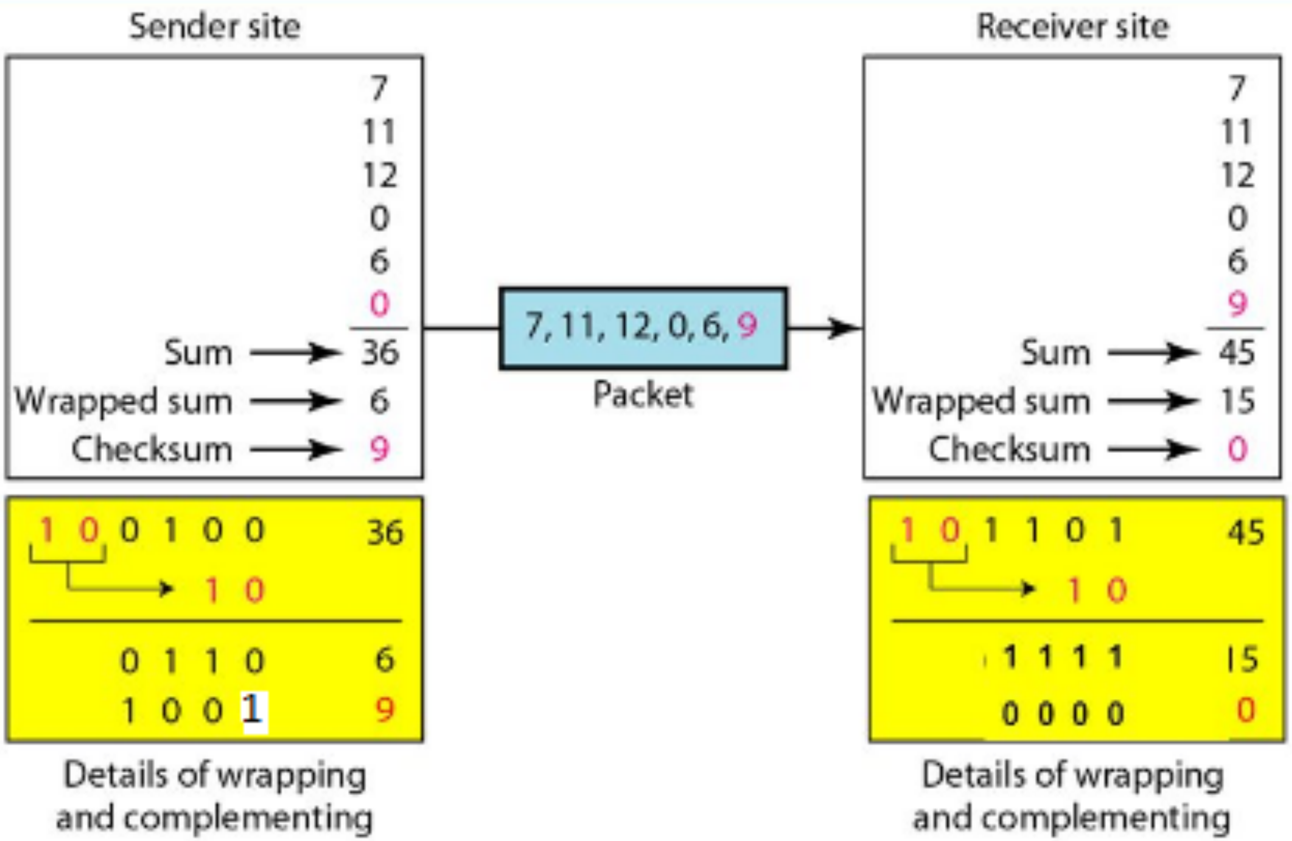
Error Detection Methods

- Performance:
  - Detects all burst errors up to length n (number of columns)
  - Misses burst errors of length n+1 if there are n-1 uninverted bits between the first and last bit
- **Checksum**
  - Used by upper layer protocols
  - Similar to LRC, uses one's complement arithmetic

Checksum

- Checksum is an error detection method
- The checksum is used in the Internet by several protocols although not at the data link layer.
- Suppose our data is a list of five 4-bit numbers that we want to send to a destination. In addition to sending these numbers, we send the sum of the numbers. For example, if the set of numbers is (7, 11, 12, 0, 6), we send (7, 11, 12, 0, 6, 36), where 36 is the sum of the original numbers. The receiver adds the five numbers and compares the result with the sum. If the two are the same, the receiver assumes no error, accepts the five numbers, and discards the sum. Otherwise, there is an error somewhere and the data are not accepted.
- We can make the job of the receiver easier if we send the negative (complement) of the sum, called the checksum. In this case, we send (7, 11, 12, 0, 6, −36). The receiver can add all the numbers received (including the checksum). If the result is 0, it assumes no error; otherwise, there is an error.

Example



Sender site
7
11
12
0
6
0
Sum → 36
Wrapped sum → 6
Checksum → 9
1 0 0 1 0 0 36
1 0
0 1 1 0 6
1 0 0 1 9
Details of wrapping and complementing
7, 11, 12, 0, 6, 9
Packet
Receiver site
7
11
12
0
6
9
Sum → 45
Wrapped sum → 15
Checksum → 0
1 0 1 1 0 1 45
1 0
1 1 1 1 15
0 0 0 0 0
Details of wrapping and complementing

Sender site:

1. The message is divided into 16-bit words.
2. The value of the checksum word is set to 0.
3. All words including the checksum are added using one's complement addition.
4. The sum is complemented and becomes the checksum.
5. The checksum is sent with the data.

Receiver Site:

1. The message (including checksum) is divided into 16-bit words.
2. All words are added using one's complement addition.
3. The sum is complemented and becomes the new checksum.
4. If the value of checksum is 0, the message is accepted; otherwise, it is rejected

Cyclic Redundancy Check

- Powerful error detection scheme
- Rather than addition, binary division is used → Finite Algebra Theory (Galois Fields)
- Can be easily implemented with small amount of hardware
  - Shift registers
  - XOR (for addition and subtraction)

Cyclic Redundancy Check

- Let us assume *k* message bits and *n* bits of redundancy

$$\left.\underbrace{xxxxxxxxxx}_{\text{k bits}}\ \underbrace{yyyy}_{\text{n bits}}\right\}\ \text{Block of length k+n}$$

- Associate bits with coefficients of a polynomial
  1 0 1 1 0 1 1
  $1x^6+0x^5+1x^4+1x^3+0x^2+1x+1$
  $= x^6+x^4+x^3+x+1$

Example

- Send
  - $M(x) = 110011 \rightarrow x^5+x^4+x+1$ (6 bits)
  - $P(x) = 11001 \rightarrow x^4+x^3+1$ (5 bits, n = 4)
    → 4 bits of redundancy
  - Form $x^nM(x) \rightarrow$ 110011 0000
    → $x^9+x^8+x^5+x^4$
  - Divide $x^nM(x)$ by $P(x)$ to find $C(x)$

```
             100001
      ____________
11001 ) 1100110000
        11001
        -----
             10000
             11001
             -----
              1001  = C(x)
```

Send the block 110011 1001

- Receive

```
        __________
11001 ) 1100111001
        11001
        -----
             11001
             11001
             -----
             00000
               |
               v
       No remainder
       → Accept
```

Cyclic Redundancy Check

- Let M(x) be the **message polynomial**
- Let P(x) be the **generator polynomial**
  - P(x) is fixed for a given CRC scheme
  - P(x) is known both by sender and receiver
- Create a block polynomial F(x) based on M(x) and P(x) such that F(x) is divisible by P(x)

$$\frac{F(x)}{P(x)} = Q(x) + \frac{0}{P(x)}$$

Cyclic Redundancy Check

- Sending
  1. Multiply $M(x)$ by x^n
  2. Divide $x^nM(x)$ by $P(x)$
  3. Ignore the quotient and keep the reminder $C(x)$
  4. Form and send $F(x) = x^nM(x)+C(x)$

- Receiving
  1. Receive $F'(x)$
  2. Divide $F'(x)$ by $P(x)$
  3. Accept if remainder is 0, reject otherwise

Assignment 1: Design and implement an error detection module.
Due on: 2-6 August 2021 (in your respective lab classes)

- Design and implement an error detection module which has four schemes namely LRC, VRC, Checksum and CRC. Please note that you may need to use these schemes separately for other applications (assignments). You can write the program in any language. The program should accept the name of a test file (contains a sequence of frames) from the command line and then print the input data frame, signature block and the output data frame on console standard output. Next, test the same program to produce a PASS/FAIL result for following cases.

  (a) Error is detected by all four schemes. Use a suitable CRC polynomial (list is given in next page).

  (b) Error is detected by checksum but not by CRC.

  (c) Error is detected by VRC but not by CRC.

  [Note: Inject error in random positions in the input data frame. Write a separate method for that]

- Please note that your design and implementation of these schemes can help you to make your assignment different from your classmates. Write the code by yourself and protect your code. The assignment is simple, but we encourage you to do improvisation with this.

Polynomial Name	Polynomial	Use
CRC-1	$x + 1$	Parity
CRC-4-ITU	$x^4 + x + 1$	ITU G.704
CRC-5-ITU	$x^5 + x^4 + x^2 + 1$	ITU G.704
CRC-5-USB	$x^5 + x^2 + 1$	USB
CRC-6-ITU	$x^6 + x + 1$	ITU G.704
CRC-7	$x^7 + x^3 + 1$	Telecom systems, MMC
CRC-8-ATM	$x^8 + x^2 + x + 1$	ATM HEC
CRC-8-CCITT	$x^8 + x^7 + x^3 + x^2 + 1$	1-Wire bus
CRC-8-Maxim	$x^8 + x^5 + x^4 + 1$	1-Wire bus
CRC-8	$x^8 + x^7 + x^6 + x^4 + x^2 + 1$	General
CRC-8-SAE	$x^8 + x^4 + x^3 + x^2 + 1$	SAE J1850
CRC-10	$x^{10} + x^9 + x^5 + x^4 + x + 1$	General
CRC-12	$x^{12} + x^{11} + x^3 + x^2 + x + 1$	Telecom systems
CRC-15-CAN	$x^{15} + x^{14} + x^{10} + x^8 + x^7 + x^4 + x^3 + 1$	CAN
CRC-16-CCITT	$x^{16} + x^{12} + x^5 + 1$	XMODEM,X.25, V.41, Bluetooth, PPP, IrDA, CRC-CCITT
CRC-16	$x^{16} + x^{15} + x^2 + 1$	USB
CRC-24-Radix64	$x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^7 + x^6 + x^5 + x^4 + x^3 + x + 1$	General
CRC-32-IEEE802.3	$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$	Ethernet, MPEG2
CRC-32C	$x^{32} + x^{28} + x^{27} + x^{26} + x^{25} + x^{23} + x^{22} + x^{20} + x^{19} + x^{18} + x^{14} + x^{13} + x^{11} + x^{10} + x^9 + x^8 + x^6 + 1$	General
CRC-32K	$x^{32} + x^{30} + x^{29} + x^{28} + x^{26} + x^{20} + x^{19} + x^{17} + x^{16} + x^{15} + x^{11} + x^{10} + x^7 + x^6 + x^4 + x^2 + x + 1$	General
CRC-64-ISO	$x^{64} + x^4 + x^3 + x + 1$	ISO 3309
CRC-64-ECMA	$x^{64} + x^{62} + x^{57} + x^{55} + x^{54} + x^{53} + x^{52} + x^{47} + x^{46} + x^{45} + x^{40} + x^{39} + x^{38} + x^{37} + x^{35} + x^{33} + x^{32} + x^{31} + x^{29} + x^{27} + x^{24} + x^{23} + x^{22} + x^{21} + x^{19} + x^{17} + x^{13} + x^{12} + x^{10} + x^9 + x^7 + x^4 + x + 1$	ECMA-182

Report

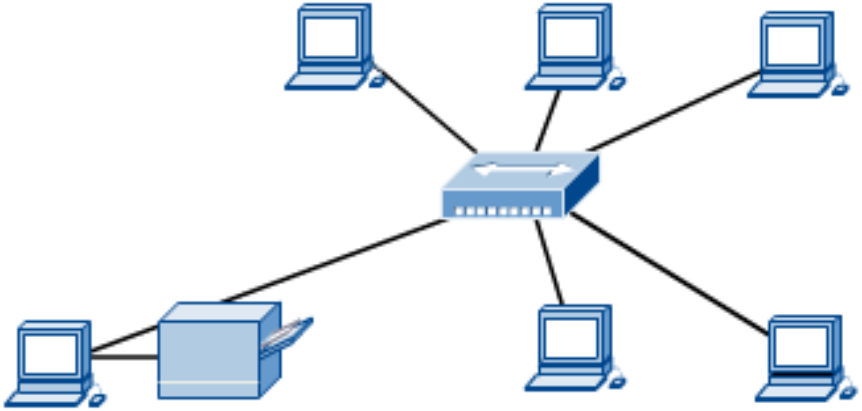
- Title: (Basic information like name, class, group, assignment number, problem statement and date (deadline and submission)).
- Design: (short paragraph describing the purpose of the program, draw a structure diagram to reflect the procedural organization of the program as you have designed it in the previous step, input and output format)
- Implementation: (code snippet, method description, interfaces etc.)
- Test cases: (Describe the tests you will perform to verify the correctness of your program. This should be a *thorough* and *exhaustive* list of test cases designed to show that your program does everything it is supposed to do. The combined tests should exercise every line of code in your program. For each test case, give sample test data and state what you are checking.
- Results: (Figures or graphs, tables)
- Analysis: (discussion on results considering different test cases, error, correctness, known bugs, possible improvements)
- Comments: Evaluate the lab assignment. What did you learn from it? Was it too hard? (explain why?) Too easy? (explain why?) Suggest improvements if you can.

Networks

- Network is a set of devices (often referred to as nodes) connected by communication links.
- A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network. A link can be a cable, air, optical fiber, or any *medium* which can transport a signal carrying information.

Computer Networks

- Computer network connects two or more autonomous computers.

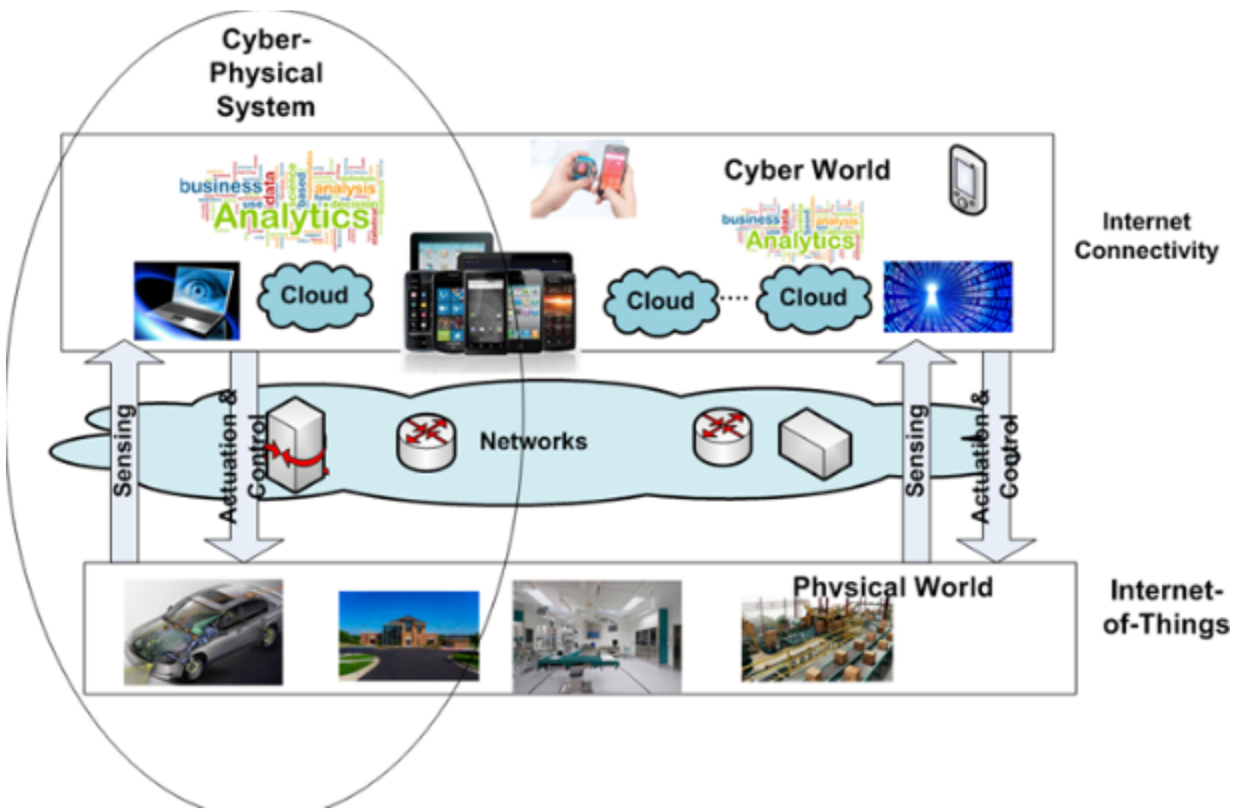


- The computers can be geographically located anywhere.

Applications of Networks

- **Resource Sharing**
  - Hardware (computing resources, disks, printers)
  - Software (application software)
- **Information Sharing**
  - Easy accessibility from anywhere (files, databases)
  - Search Capability (WWW)
- **Communication**
  - Email
  - Message broadcast
- **Remote computing**
- **Distributed processing (Cloud Computing)**

Some terms..CPS, IoT, Cloud



Network Components

- **Physical Media**
- **Interconnecting Devices**
- **Computers**
- **Networking Software**
- **Applications**

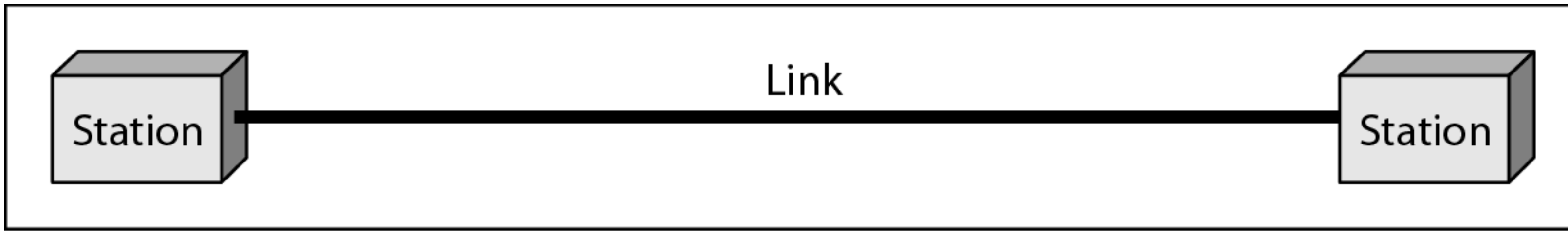
Network Criteria

- Performance
  - Depends on Network Elements
  - Measured in terms of Delay and Throughput
- Reliability
  - Failure rate of network components
  - Measured in terms of availability/robustness
- Security
  - Data protection against corruption/loss of data due to:
    - Errors
    - Malicious users

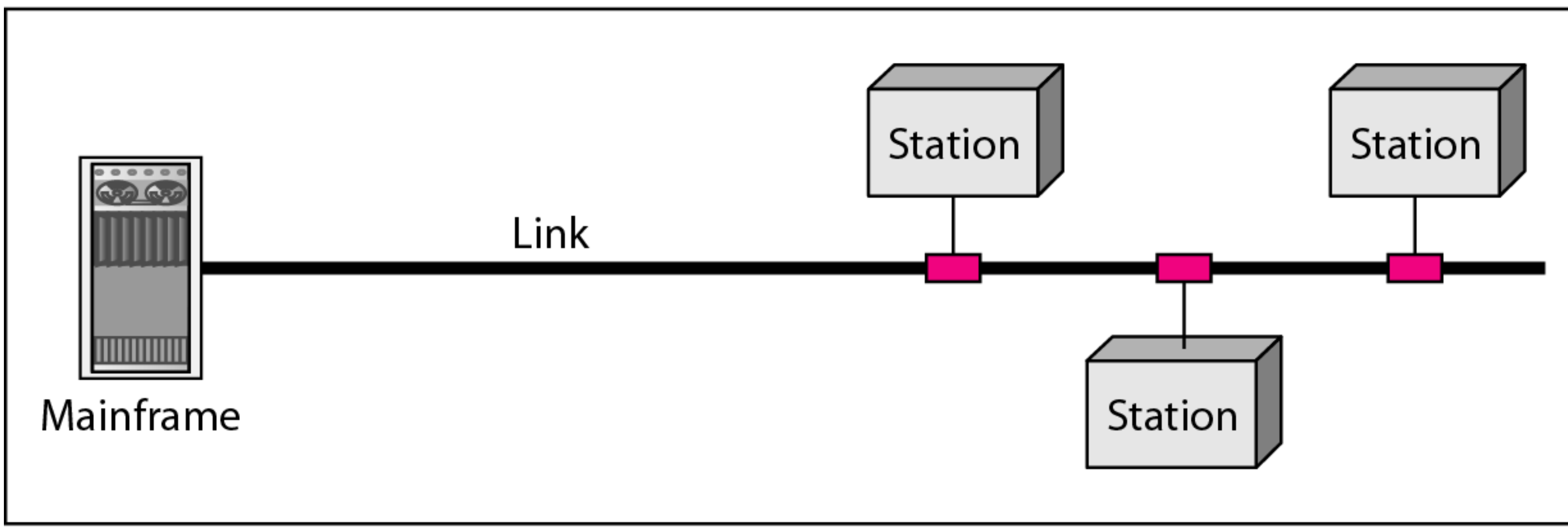
Physical Structures

- Type of Connection
  - Point to Point - single transmitter and receiver
  - Multipoint - multiple recipients of single transmission
- Physical Topology
  - Connection of devices
  - Type of transmission - unicast, mulitcast, broadcast

Types of Connections

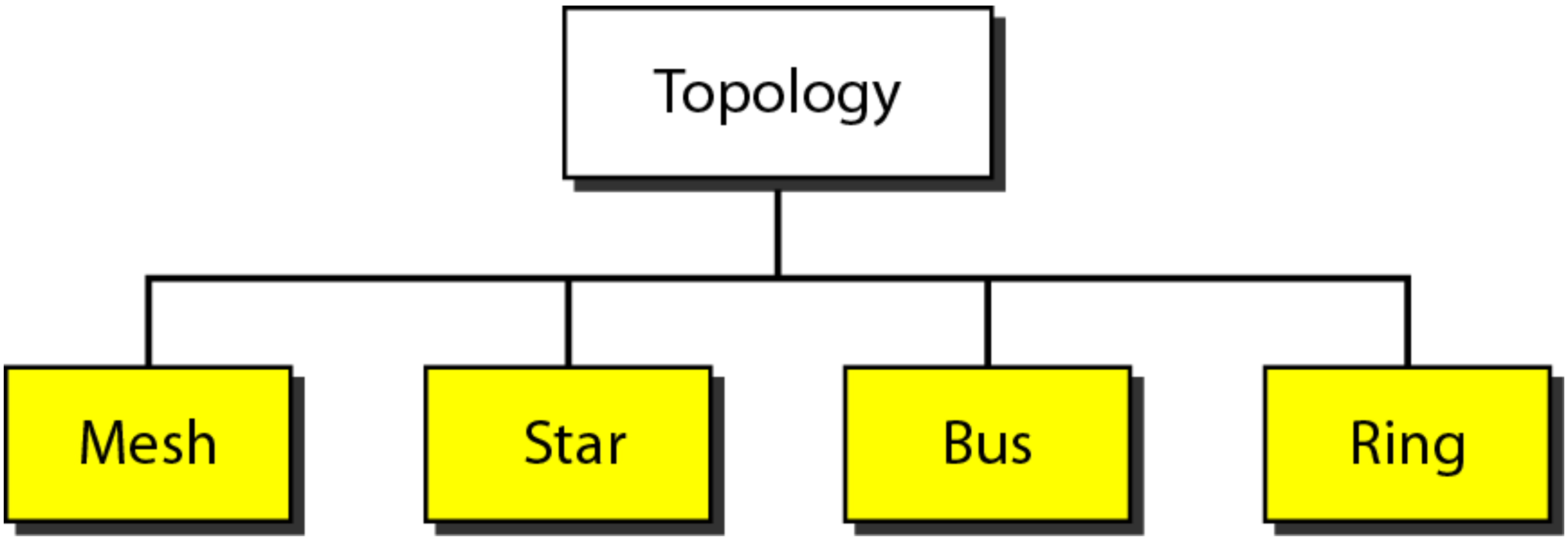


a. Point-to-point



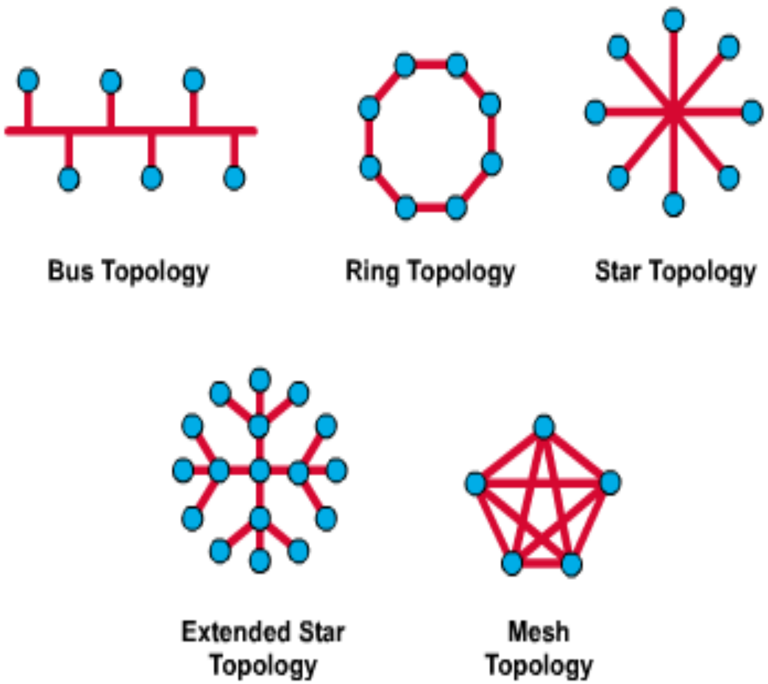
b. Multipoint

Categories of Topology

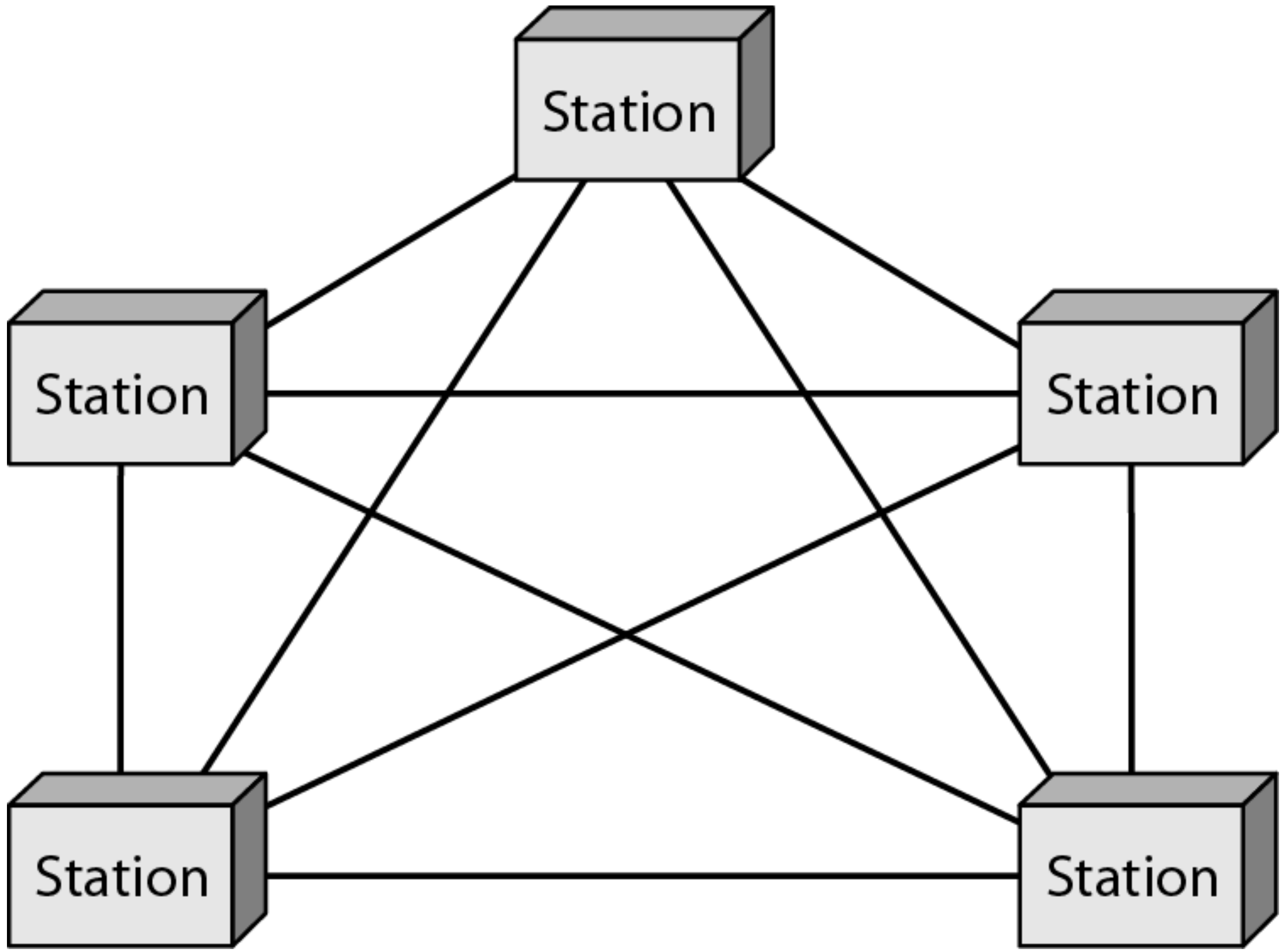


Network Topology

- The network topology defines the way in which computers, printers, and other devices are connected. A network topology describes the layout of the wire and devices as well as the paths used by data transmissions.

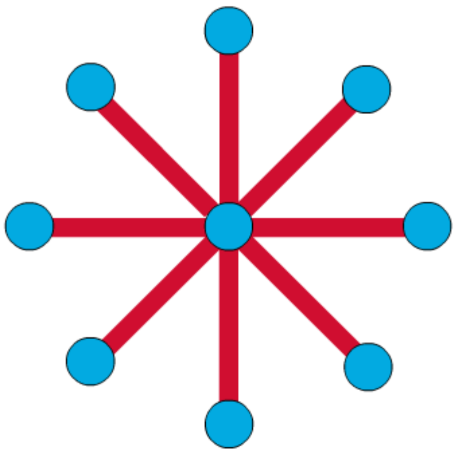


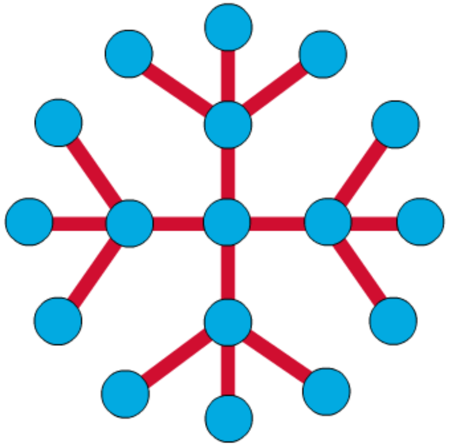
A fully connected mesh topology (five devices)



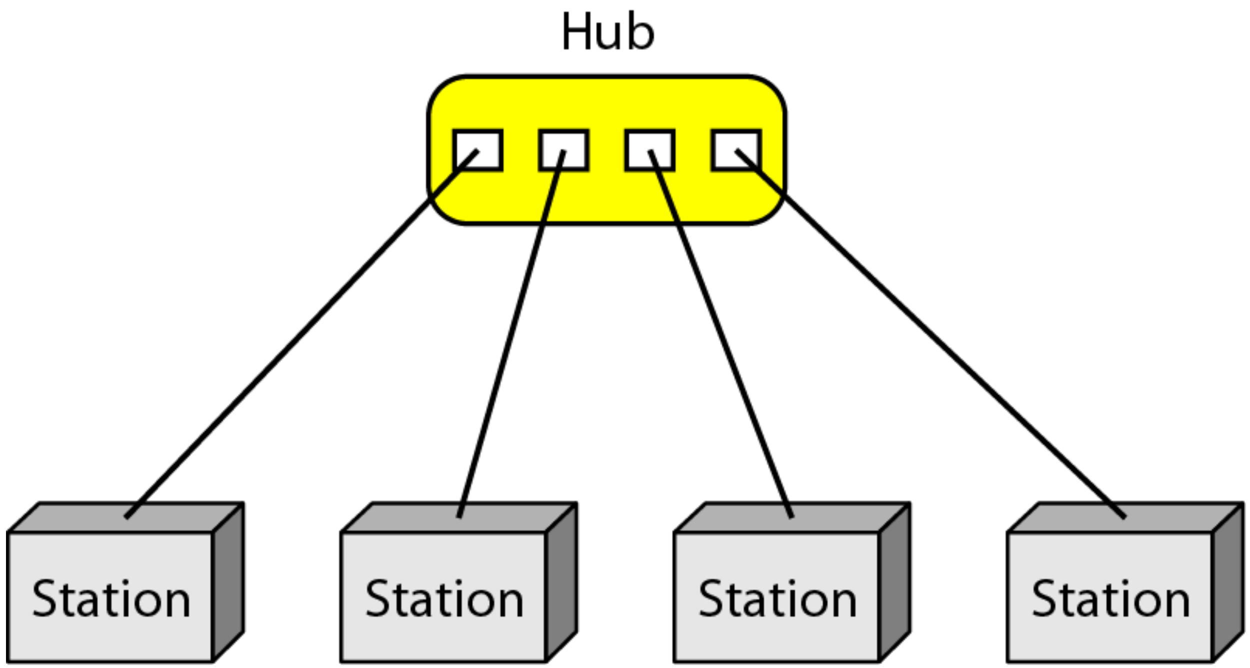
Star Topology

- The star topology is the most commonly used architecture in Ethernet LANs.
- Larger networks use the extended star topology also called tree topology. When used with network devices that filter frames or packets, like bridges, switches, and routers, this topology significantly reduces the traffic on the wires by sending packets only to the wires of the destination host.



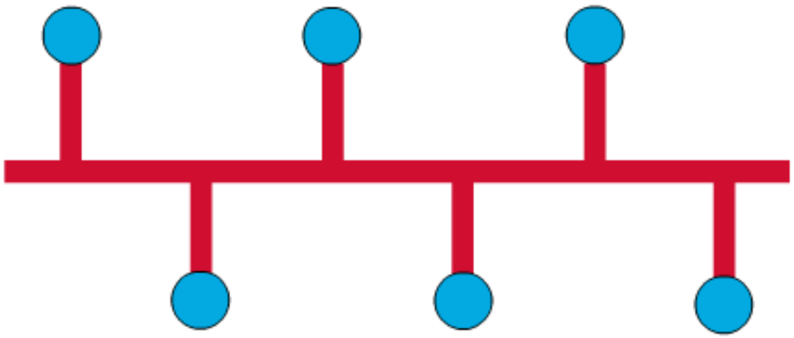


A star topology connecting four stations

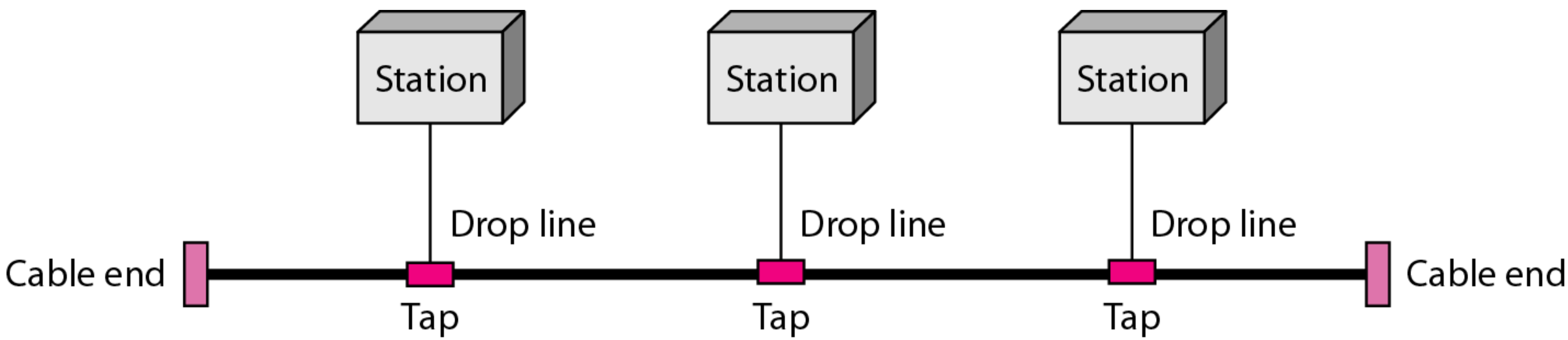


Bus Topology

- Commonly referred to as a linear bus, all the devices on a bus topology are connected by one single cable.

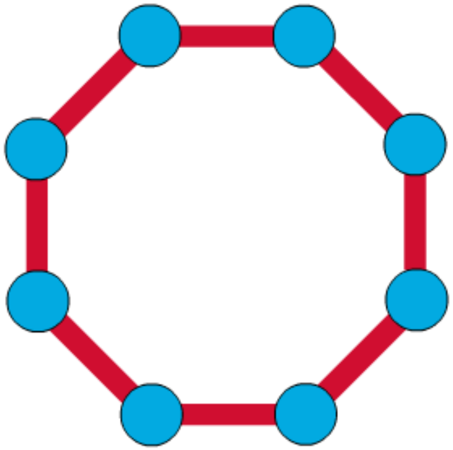


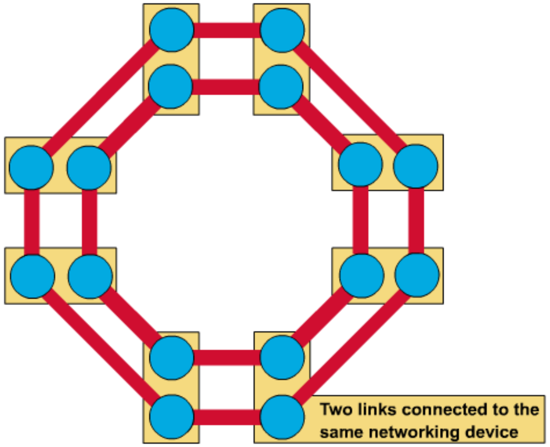
A bus topology connecting three stations



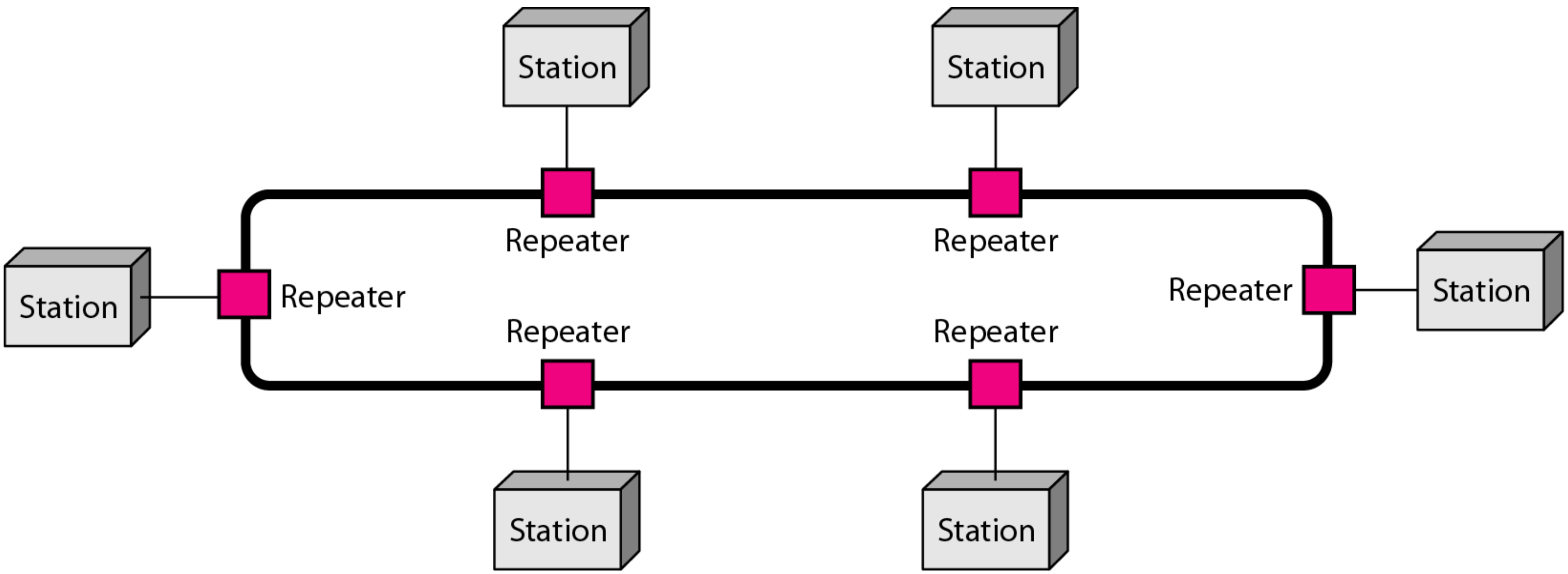
Ring Topology

- A frame travels around the ring, stopping at each node. If a node wants to transmit data, it adds the data as well as the destination address to the frame.
- The frame then continues around the ring until it finds the destination node, which takes the data out of the frame.
  - Single ring – All the devices on the network share a single cable
  - Dual ring – The dual ring topology allows data to be sent in both directions.

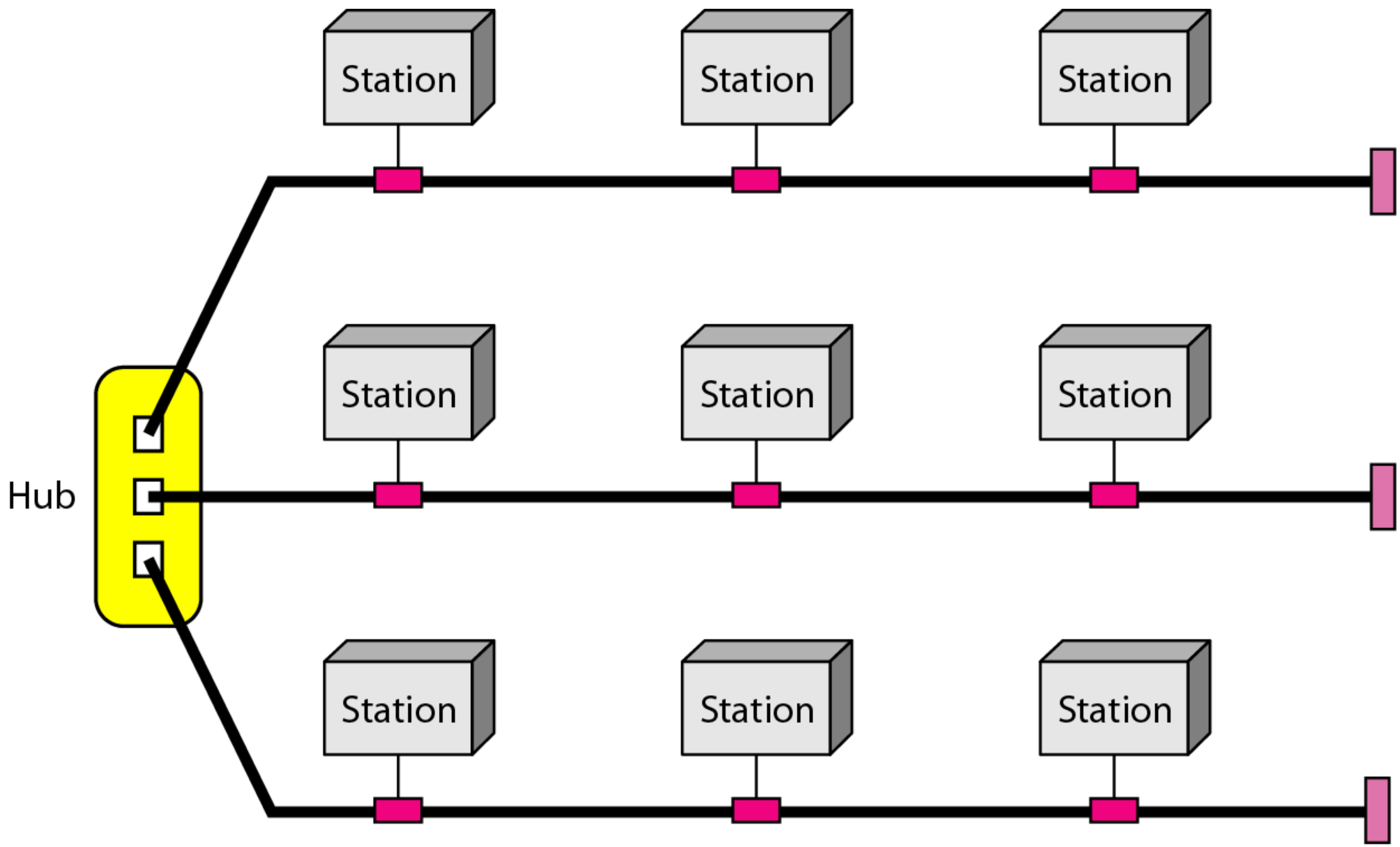




A ring topology connecting six stations

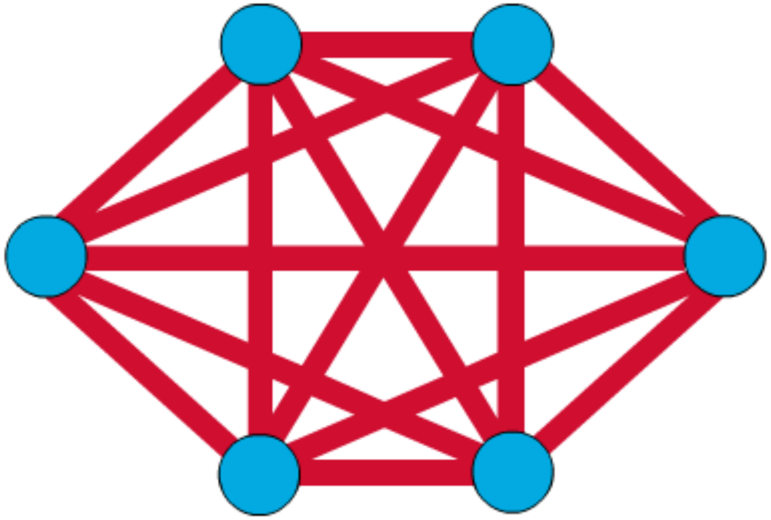


A hybrid topology: a star backbone with three bus networks



Mesh Topology

- The mesh topology connects all devices (nodes) to each other for redundancy and fault tolerance.
- It is used in WANs to interconnect LANs and for mission critical networks like those used by banks and financial institutions.
- Implementing the mesh topology is expensive and difficult.



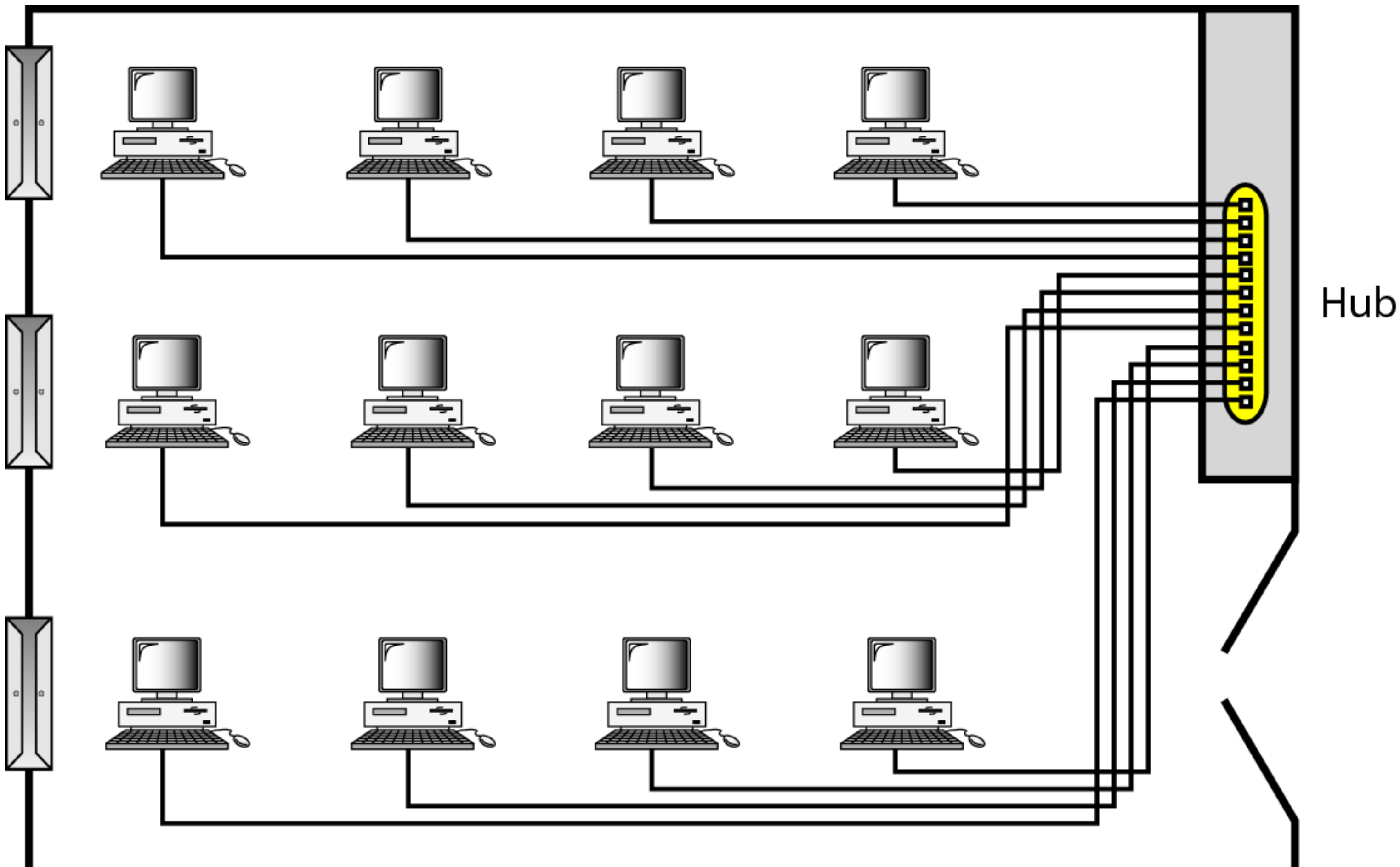
Categories of Networks

- Local Area Networks (LANs)
  - Short distances
  - Designed to provide local interconnectivity
- Wide Area Networks (WANs)
  - Long distances
  - Provide connectivity over large areas
- Metropolitan Area Networks (MANs)
  - Provide connectivity over areas such as a city, a campus

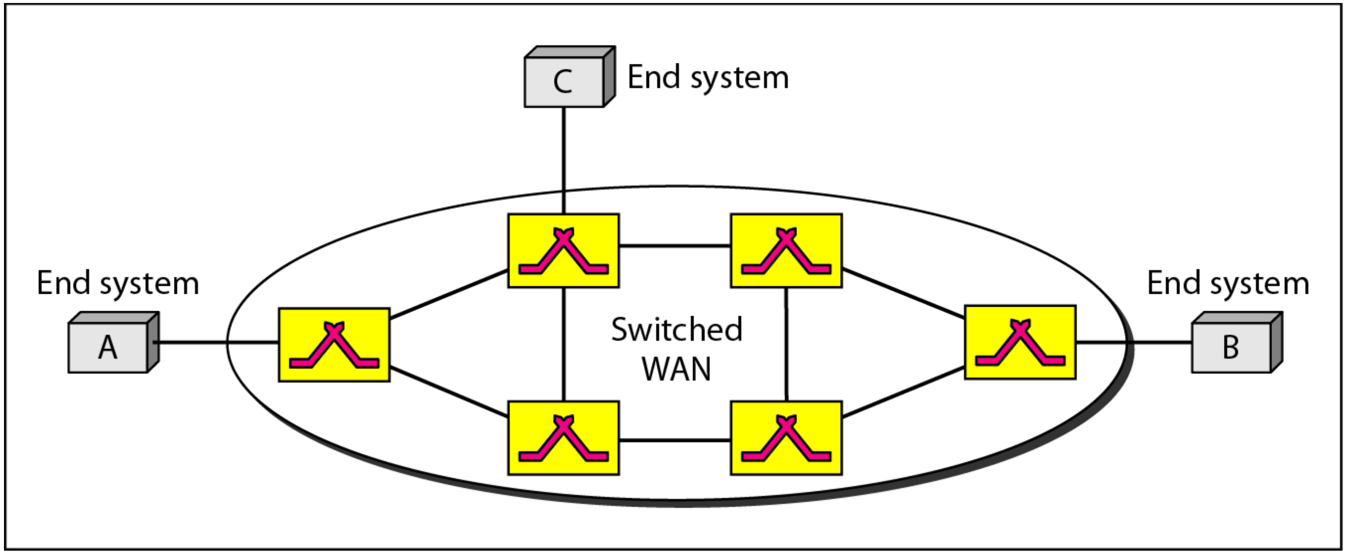
LAN, MAN and WAN

- Network in small geographical Area (Room, Building or a Campus) is called LAN (Local Area Network)
- Network in a City is call MAN (Metropolitan Area Network)
- Network spread geographically (Country or across Globe) is called WAN (Wide Area Network)

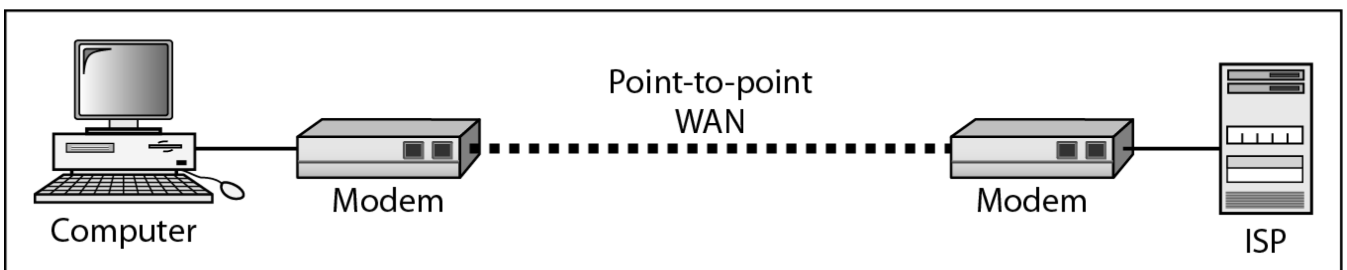
LAN



WANs: a switched WAN and a point-to-point WAN



a. Switched WAN



b. Point-to-point WAN

WAN technologies

- There are two types of long distance communication technologies that are used for WANs.
  - Dedicated connection
    - A dedicated line is a full-time point-to-point connection provided by a communication carrier that lasts for the length of the lease period.
  - Switched connection
    - There are several types of switched connections: circuit switched, packet switched, and cell switched

Circuit Switching

- In circuit switching, circuits are established prior to the transmission of data and torn down at the end of the transmission.
- During transmission of data, all of the packets take the same path.
- The Public Switch Telephone Network (PSTN) is an example of a circuit switch system.
  - A call is placed and a circuit established when the other end of the circuit is answered.
  - Modems that operate between computer systems are a specific example.

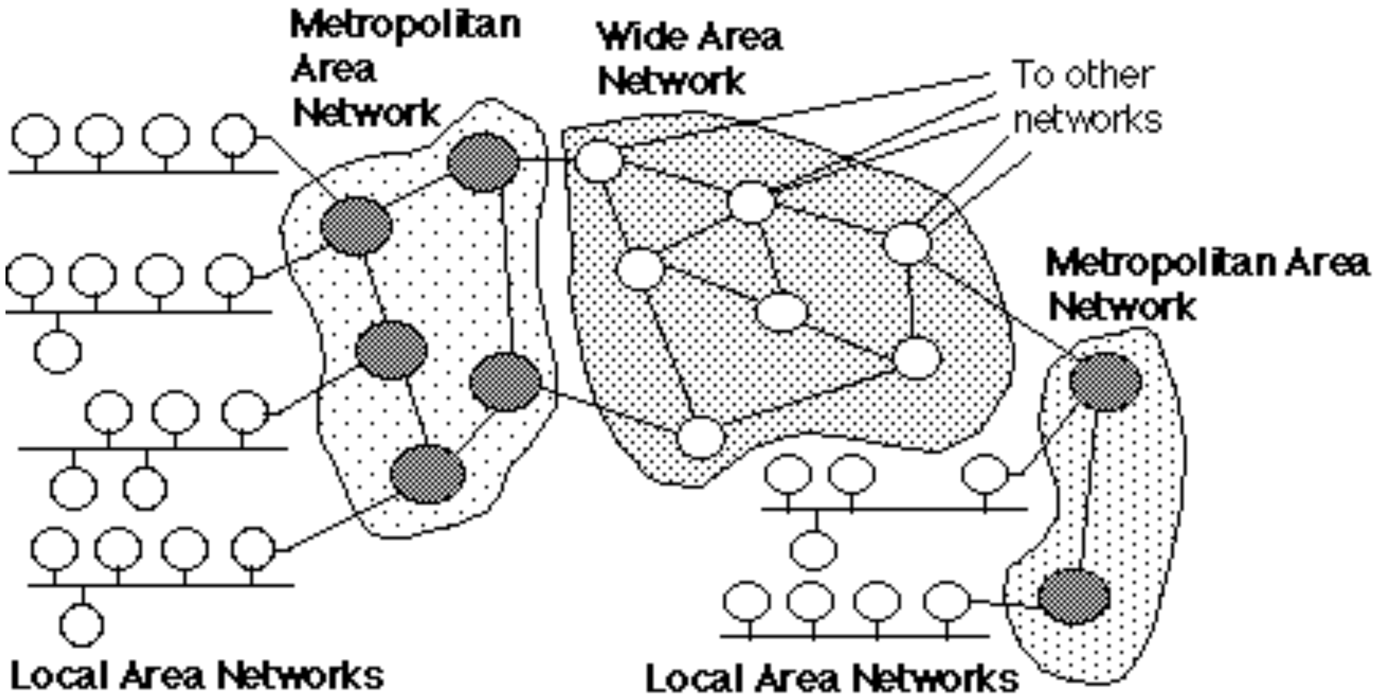
Packet Switching

- In packet switching, circuits may be selected on a packet-by-packet basis.
- The Internet widely uses packet switch networks, for individual packets in the same transmission may take different routes through the network to the same destination.
- Upper layers of the OSI model place the packets into the correct order.

Cell Switching

- **Cell switching** is associated with Asynchronous Transmission Mode (ATM) which is considered to be a high speed switching technology that attempted to overcome the speed problems faced by the shared media like Ethernet.
- Cell switching uses a connection-oriented packet-switched network.
  - It is called cell switching because this methodology uses a fixed length of packets of 53 bytes out of which 5 bytes are reserved for header.
  - Unlike cell technology, packet switching technology uses variable length packets.
  - Even though cell switching closely resembles packet switching because cell switching also breaks the information into smaller packets of fixed length.

LAN→MAN→ WAN


Metropolitan Area Network
Wide Area Network
To other networks
Metropolitan Area Network
Local Area Networks
Local Area Networks