2

Introduction to Industrial Data Networks & Protocols

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CONTENTS

Communication Topologies

- **Communication topology** means:

  (a) the way the communicating devices are inter-connected (or inter-linked), and

  (b) the way they communicate with each other.

- Basically, three communication topologies are used:

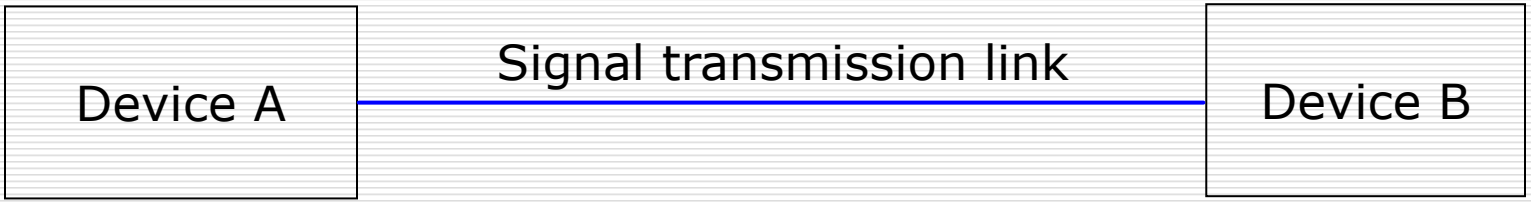
  A. Point-to-Point Communication

  B. Broadcasting

  C. Communication Network

A- Point-to-Point Communication

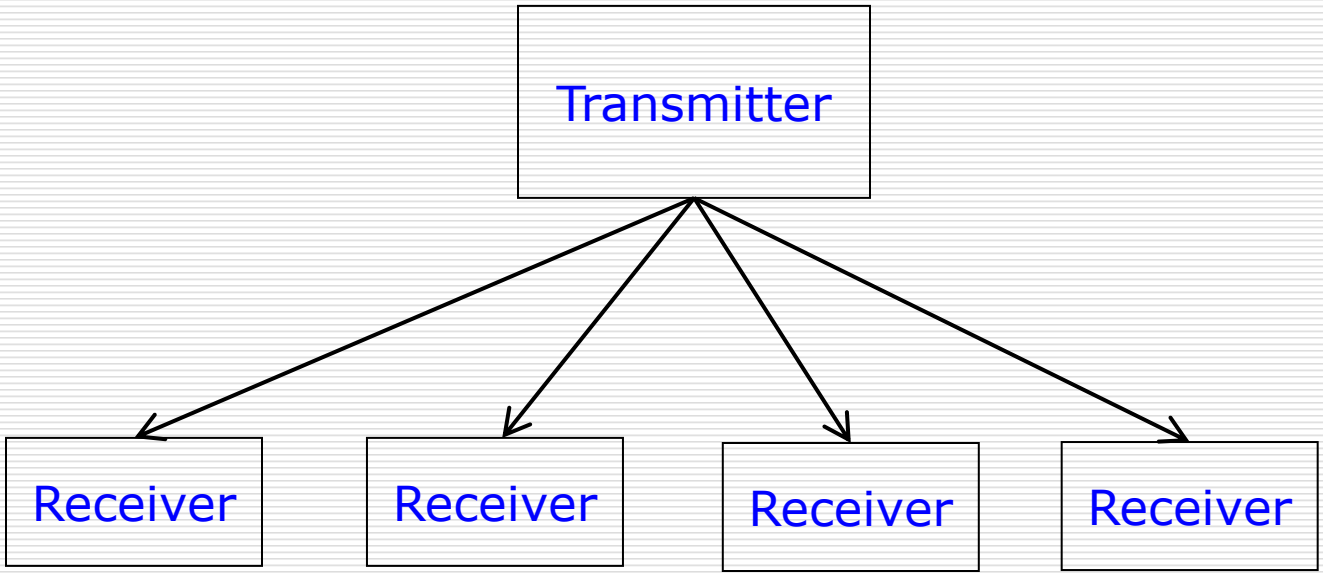
- It means communication between only two devices connected with each other through a ***signal transmission link***.
- A basic point-to-point communication system is shown below.



- Communication may take place in one of the following modes:
  - **a) Simplex mode:** Communication takes place from A to B only. So, device A should be a ***transmitter*** and device B a ***receiver***.
  - **b) Half-duplex mode:** Communication at any time can take place **either** from A to B **or** from B to A, but not in both directions at the same time. In former situation, device A should work as a transmitter and device B as receiver. For communication in the reverse direction, their roles will need to be reversed.
  - **c) Full-duplex mode:** Communication at any time can take place **simultaneously** from A to B and from B to A. Both devices should contain a transmitter as well as a receiver (i.e., a ***transceiver***).

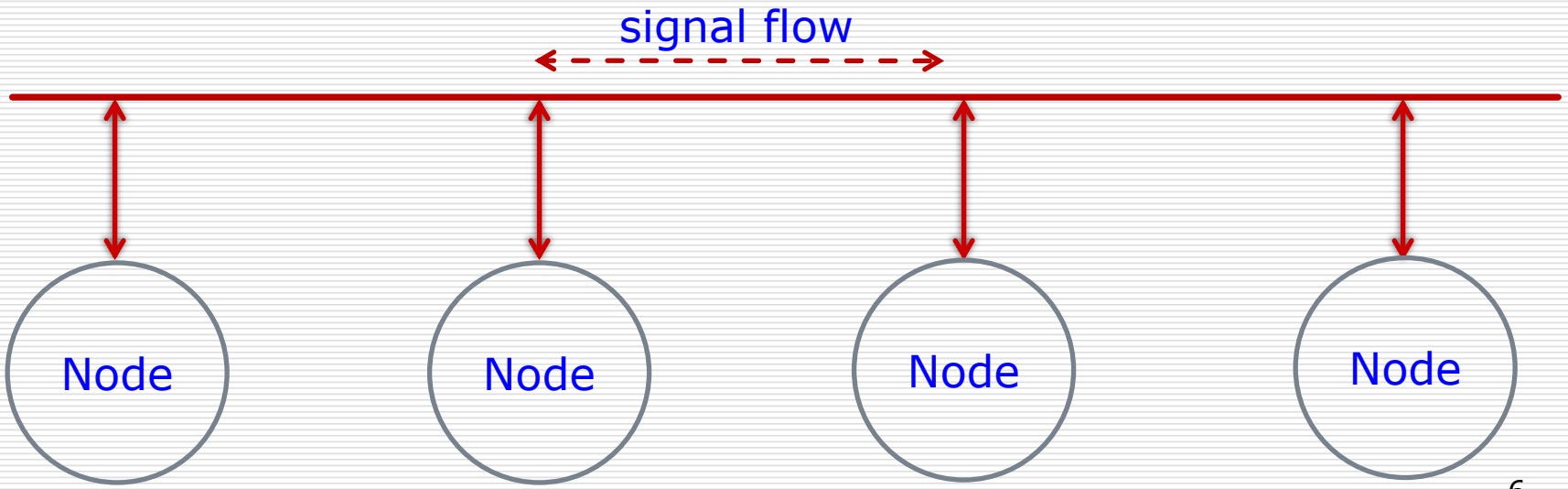
B- Broadcasting

- It means communication from one transmitting device (that is, transmitter) to several or all receiving devices (that is, receivers) to which the transmitting device is connected through signal transmission links.
- The communication is essentially one-way or simplex.
- A basic broadcasting system is shown below.



C- Communication Network

- In this topology, communication is allowed among a number of devices interconnected by a network of signal transmission links.
- Any device in the communication network can communicate with any other device connected in the network.
- The communicating devices connected in the network are called as ***nodes***, which are basically transceivers.
- A communication network of ***bus topology*** is shown below. Other network topologies will be introduced later.



Introduction to Data Network

- A communication network may be either

  (a) **an analog communication network** , which uses analog communication, that is the information signal is an analog electrical signal, or

  (b) **a digital communication network**, which uses digital communication. The information signal is already in digital form or else has been converted into a digital signal for the purpose of communication.

- The digital information communicated on digital communication networks these days is mostly in the form of data, either generated by a digital device or stored in memory/storage device.

- Their communication networks are called as **Data Communication Networks** or simply as **Data Networks.**

Data Network Categorization

Depending on coverage area, ownership, user group and communication technology used, data networks may be categorized as under:

a) Local area network (LAN)
b) Personal area network (PAN)
c) Metropolitan area network (MAN)
d) Wide area network (WAN)
e) The Internet
f) Intranet

Local Area Network (LAN)

- Typically, the network is within a building or a campus
- Generally, it is privately owned
- Used by an organization or group of individuals
- **Works on a single communication technology**
- Acts as a building block of larger data networks, like WAN and Internet.

PAN and MAN

- Personal area network (PAN):
  - Special case (smaller version) of LAN
  - Typically, the network is within a room or hall of a building
  - It is always privately owned
  - Used by an individual
  - **Like LAN, it works on a single communication technology.**
- Metropolitan area network (MAN):
  - Special case (larger version) of LAN
  - Inter-connects devices in a town or city
  - It is either public or privately owned
  - Used by public or an organization
  - **Like LAN, it works on a single communication technology.**

Wide Area Network (WAN)

- Covers a wide area (a town, state or country)
- **Involves interconnection of two or more LANs**
- LANs in a WAN are in general privately owned
- The links used for interconnecting these LANs are often public communication lines
- User is generally the public
- **Involves several communication technologies.**

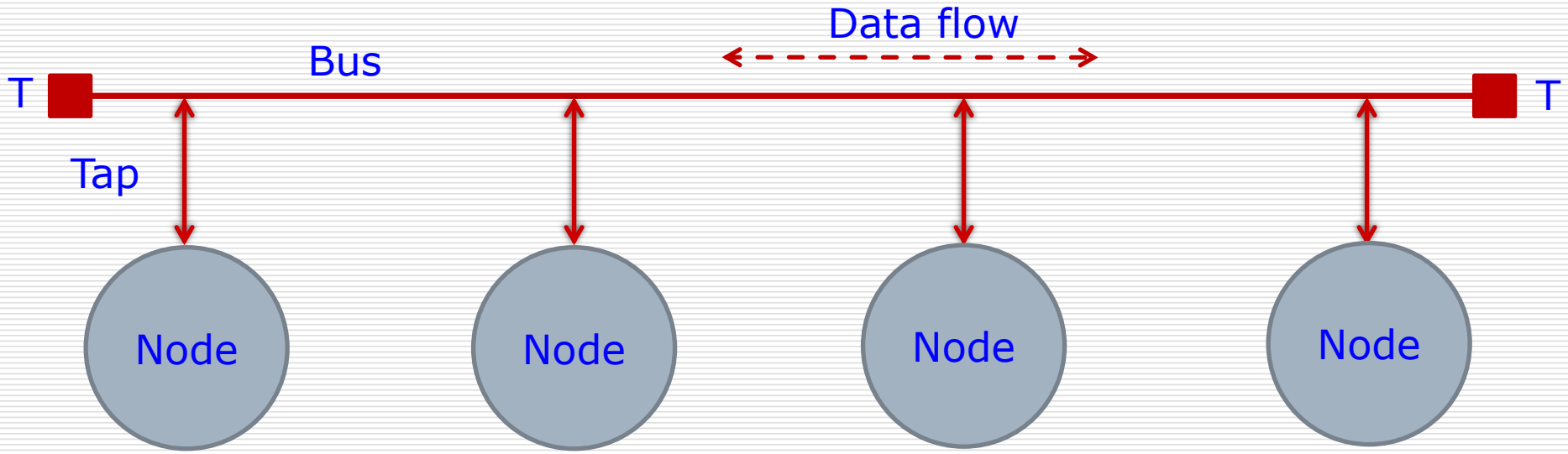
Internet and Intranet

- The Internet:
  - Popularly known as “the network of networks”
  - Involves interconnection of LANs and WANs
  - **Has global coverage for both private and public communications**
  - Services on Internet are provided through a hierarchy of local, regional, national and international **Internet Service Providers**
  - Communication across the Internet is defined by **TCP/IP protocol suite.**
- Intranet:
  - **Intranet is an implementation of the Internet technologies within an organization**
  - **Connected to the Internet**
  - **Privately owned by the organization**
  - **Covers and used by the organization.**

LAN Topologies

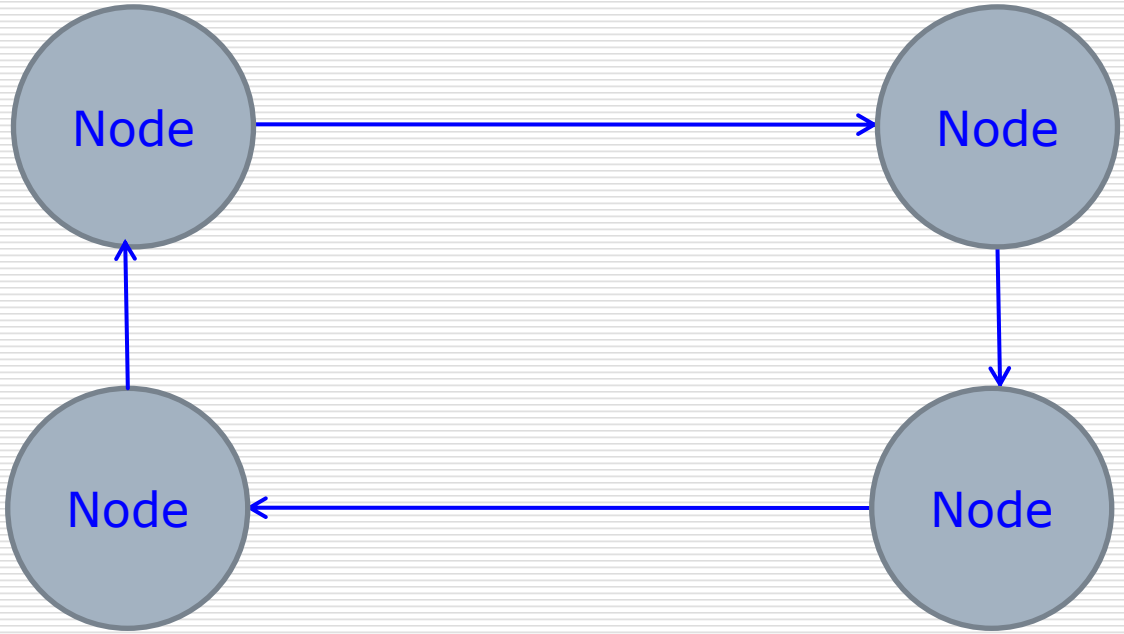
- **Network topology** means:
  (a) the way the communicating devices (nodes) are inter-connected or inter-linked, and
  (b) the way they communicate with each other.
- LAN topology is important in determining the structure of any data network because:
  (a) LAN is the basis of other single-technology data networks, like PAN and MAN
  (b) LAN is the building block for wider area networks, like WAN, Internet and intranet
- Five basic LAN topologies are:
  1. Bus
  2. Ring
  3. Star
  4. Tree
  5. Mesh

Bus (or Multi-drop) Topology



- Bus is a linear transmission medium
- Nodes are connected to the bus through taps
- **Data flow is bidirectional**
- Terminator (T) absorbs signal, thus avoids echo.

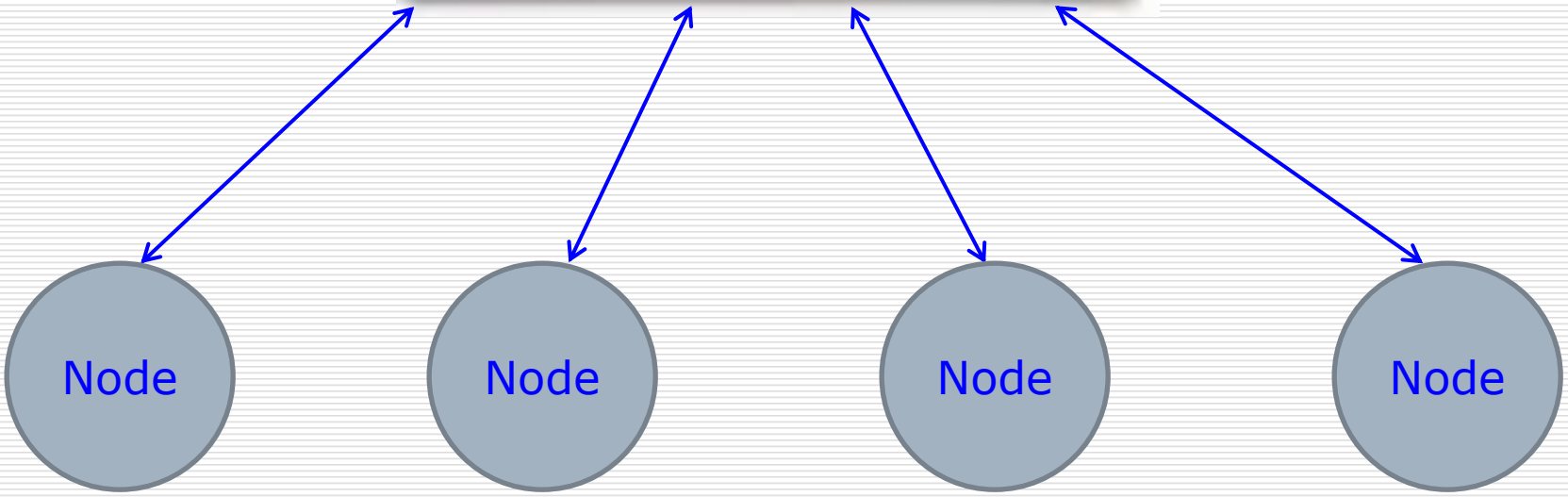
Ring (or Loop) Topology



- Nodes are connected in tandem (series) to form closed loop
- **Data flow is unidirectional**
- Data flows through nodes
- **Each node acts as a repeater : It receives data on one link and transmits bit-by-bit to the next node on the other link.**

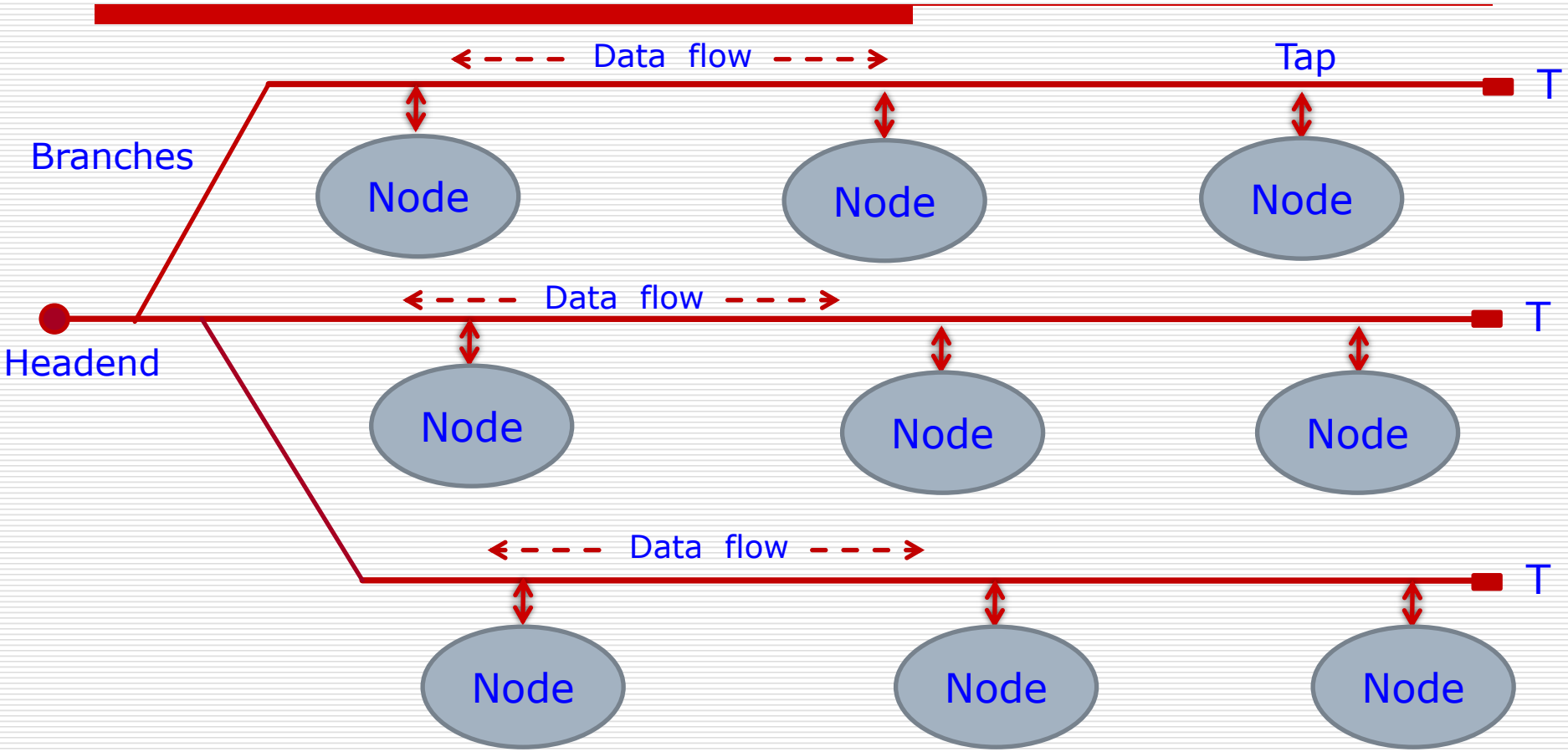
Star Topology

Central node



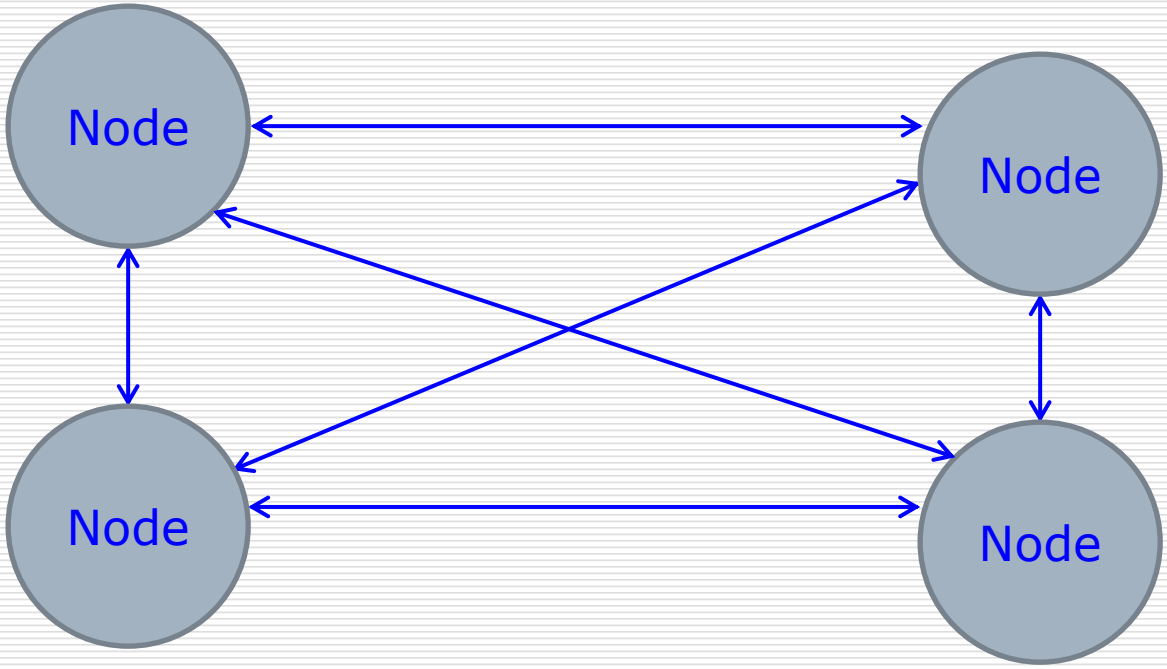
- Network is comprised of point-to-point circuits
- Central node: Hub or switch
- Hub: Operates in broadcasting mode
- Switch: Operates as a frame-switching device

Tree Topology



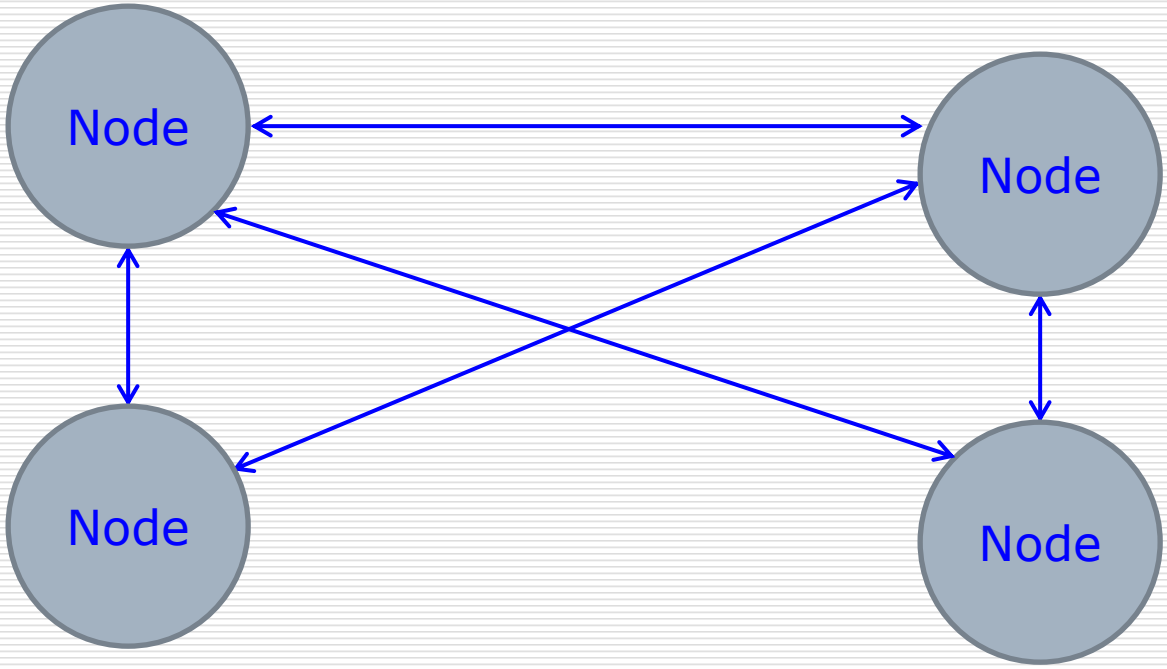
- **Generalization of bus topology**
- Each branch may have further branches, which may be called as sub-branches.

Mesh Topology : Fully-Connected Mesh



- Each node is connected to **every other node** in the network
- **Each connecting link is bidirectional**
- Total number of links = n(n-1)/2 for ‘n’ nodes
- Number of I/O ports on each node = (n-1)
- Highest reliability

Mesh Topology : Partially-Connected Mesh



- Each node is connected to **some, but not all**, of the other nodes, in the network
- **Each connecting link is bidirectional**
- Total number of links is **less than** n(n-1)/2 for 'n' nodes
- Number of I/O ports on some or all of nodes is **less than** (n-1)
- High reliability, but not as high as that of fully-connected mesh.

Wired and Wireless LANs

- Depending on the signal transmission medium (STM) used in LAN, it may be:
  - Wired LAN (referred to simply as LAN)
  - Wireless LAN (referred to as WLAN)
- Wired LANs use either copper wires or optical fibre as STM.
- WLANs use radio frequency transmissions and do not require any physical medium, like copper wires or optical fibre, for these transmissions.

WLAN

- In most cases, an **ISM frequency band** is used in the WLAN to avoid radio-frequency licensing issues
- Advantages of WLAN:
  - Easy and fast deployment
  - Nomadic and mobile access
  - Connecting field devices in inaccessible locations, in case of field networks in industry.
- Major issues with WLAN:
  - Noise & interference
  - Interception & eavesdropping
  - Jamming
- Share of WLANs in LAN-market is increasing fast for two reasons:
  - Because of their above-stated advantages, and
  - Because the above-stated issues have been largely resolved.

Industrial Communications

- Based on the application areas, communications are divided into two groups:
  a) General-purpose or business communications
  b) Industrial communications
- Industrial communications are the communications carried out in industry for two broad purposes:
  a) Remote measurement and monitoring of variables in an industrial plant
  b) Remote control of an industrial process or plant
- In industrial communications, digital/data communication techniques are now used much more widely than analog communication techniques for following reasons:
  a) Better performance
  b) Higher reliability
  c) Cost competitiveness
  d) Wider use of computers, digital controllers and digital field devices (instruments, sensors, actuators etc.) in industry.

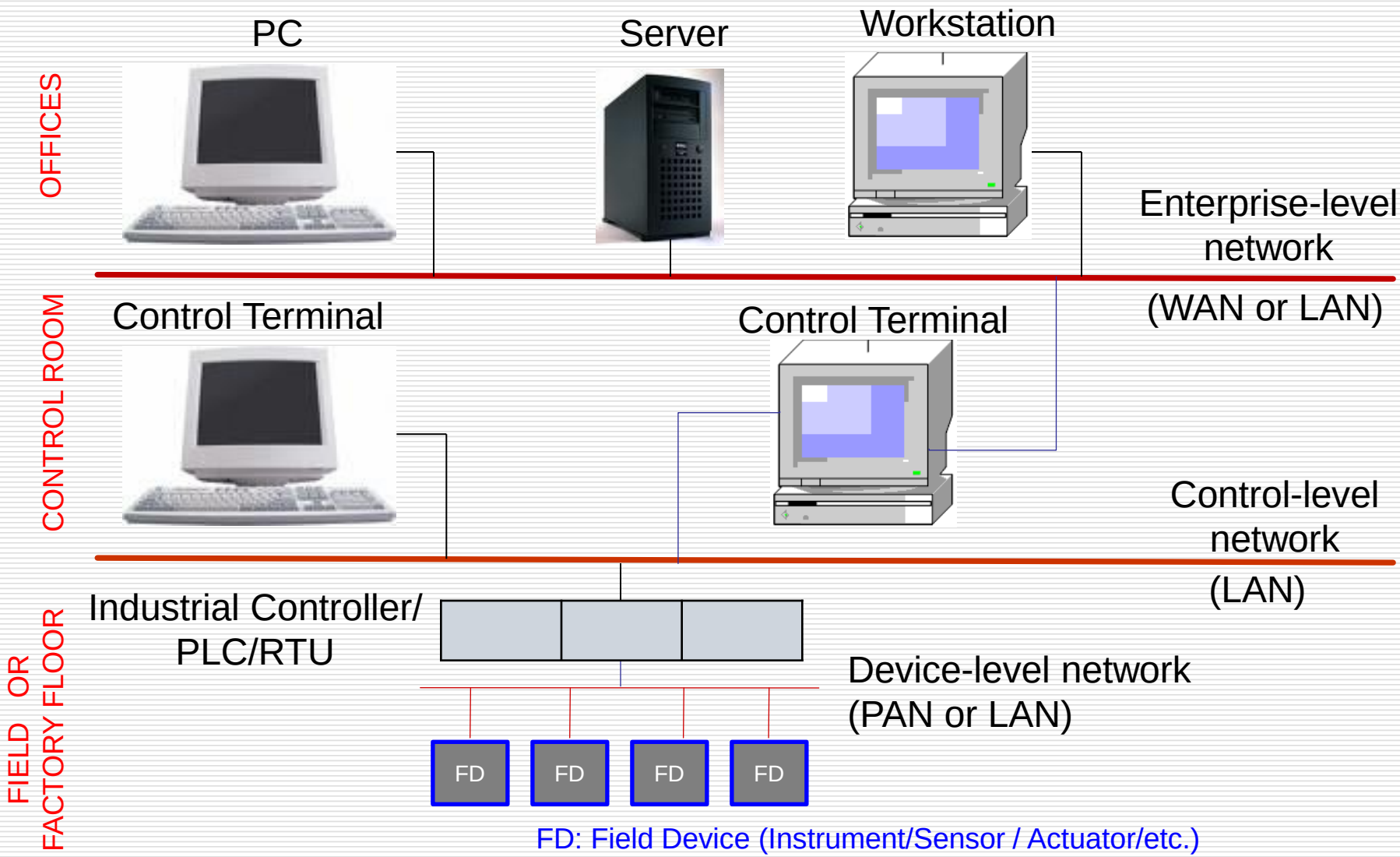
Industrial Communication Scenarios

1. Communication among computers/ servers/ work-stations.
2. Communication between a computer and its peripherals.
3. Communication between a computer and intelligent instruments.
4. Communication between a controller and its field devices (instruments, sensors, actuators etc.).
5. Communication among field devices (instruments, sensors, actuators etc.).

Introduction to Industrial Data Network

- Broadly speaking, data networks are used for two types of applications:
  (a) General purpose or business applications
  (b) Industrial applications
- Examples of general-purpose or business applications are: e-mail, Internet browsing, net-banking, e-commerce, and so on.
- In case a data network is used in an industrial application, it is referred to as ***Industrial Data Network.***
- Industrial data networks are used in industry for two broad purposes:
  a) Remote measurement or monitoring of industrial variables
  b) Control of an industrial process or plant
- The communicating devices (nodes) in a business data network are generally computers and servers.
- The communicating devices (nodes) in an industrial data network are computers, servers, work-stations, control terminals, digital controllers and field devices (instruments, sensors and actuators).

Hierarchy of Industrial Data Networks



Hierarchy of Industrial Data Networks

- Enterprise-Level Network

  Network of the PCs, workstations and servers located in various offices of the enterprise and the control terminals located in the control room.

- Control-Level Network

  a) Network of the control-terminals and master-controller, all located in the control room, or

  b) Network of the control-terminals in the control room and industrial controllers/ programmable logic controllers (PLCs)/ remote terminal units (RTUs) located in the field or on factory floor.

- Device-Level Network

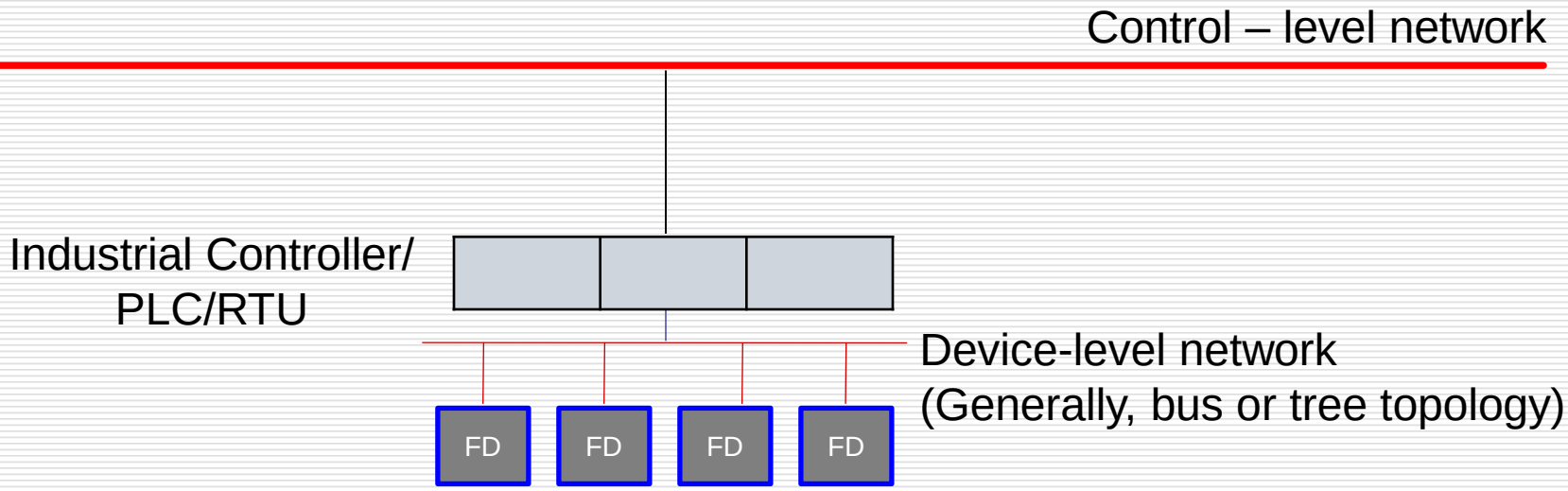
  a) Network of an industrial controller/PLC/RTU and its associated field devices (instruments, sensors, actuators, etc.) located in the field or on factory floor, or

  b) Network of field devices located in the field or on factory floor.

Device-Level Network

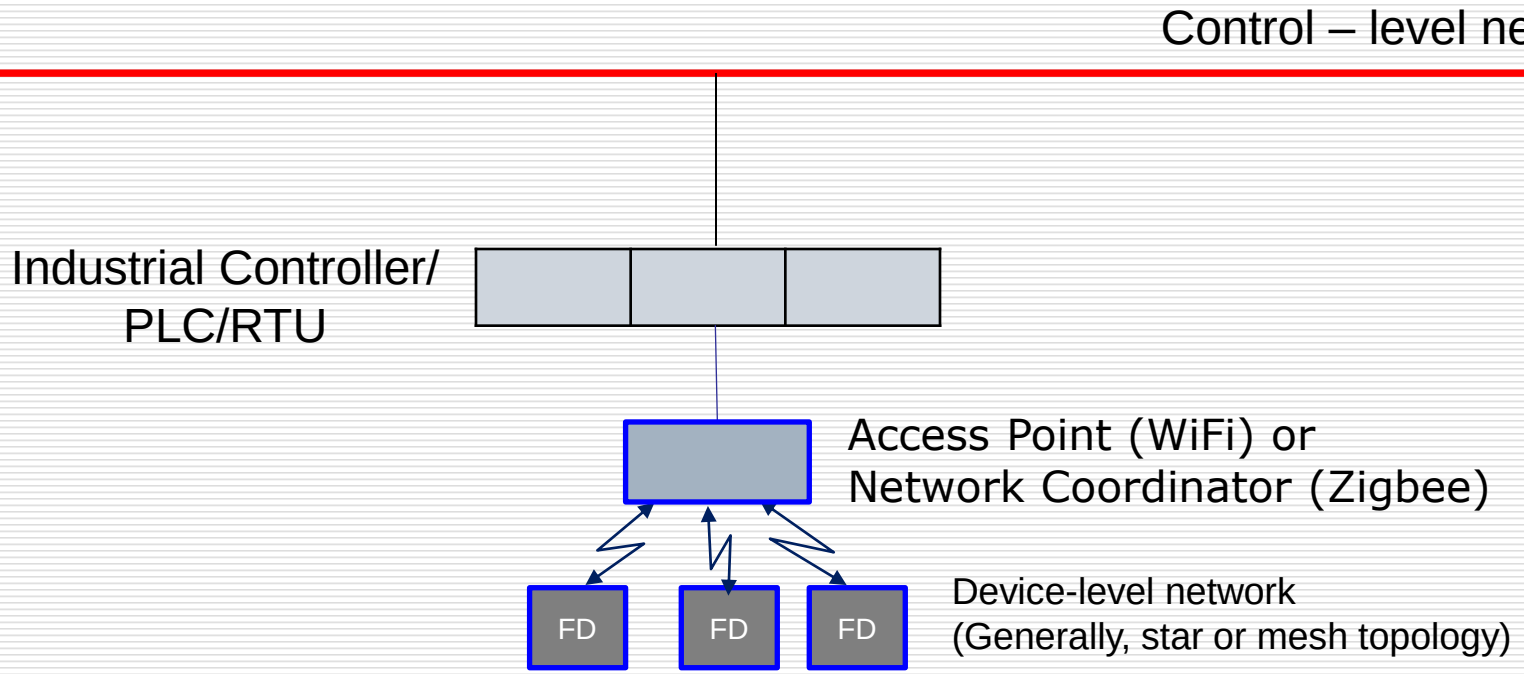
- Depending on application scenario, this network may be called as:
  - Device-level network, or
  - Field-device network, or
  - Factory-floor network.
- Depending on the type of field devices, it may be called as:
  - Sensor network, or
  - Transducer network, or
  - Sensor and actuator network.
- Depending on wired or wireless signal transmission, the device-level network may be either
  - Wired device-level network, or
  - Wireless device-level network.

Wired Device–Level Network



FD: Field Device (Instrument/ Sensor/ Actuator/etc.)

Wireless Device–Level Network



FD: Field Device (Instrument/ Sensor/ Actuator/etc.)

Special Requirements of Device Level Networks

- Low latency or small end-to-end delay
- Low bandwidth or data rate will be good enough
- High data security
- High network security
- Low power consumption or long battery life in case of wireless sensor networks (WSNs).

What is Network Protocol? (1)

- The word protocol in general means a ***formal system or set of rules defined*** for conducting an activity successfully and smoothly.
- Some well-known examples from our daily life are: 'official protocol', 'diplomatic protocol', 'police protocol', 'medical protocol' and 'treatment protocol'.
- So is the case of 'communication protocol'.
- ***'Communication protocol'*** may be defined as the ***formats and sequence of messages*** required to be exchanged between two communicating devices ***for a reliable and efficient communication*** between them.

What is Network Protocol? (2)

- Let us extend the definition of communication protocol to networking or network protocol.
- '***Networking or network protocol***' may be defined as the ***formats and sequence of messages*** required to be exchanged between the two nodes communicating with each other on a data communication network, along with the rules to select the path or ***route of data flow and control transmission-medium access etc., for an overall reliable and efficient data communication on the network.***
- Communication on a network can be very complex and, therefore, the related network protocols too will be very complex.
- ***Network reference models*** are available to help explain, understand and apply such complex network protocols.

What is Network Standard?

- Generally speaking, technical standards are the ***'technical specifications, prescriptions and rules'*** that ***must be adhered to*** in (a) designing and manufacturing products and/or (b) providing services, so that they are ***consistent*** regardless of the product manufacturer and the service provider.
- Let us extend this definition to networking or network standards.
- '***Networking or network standards'*** may be defined as the technical specifications, prescriptions and rules that must be adhered to in:
  (a) designing and manufacturing components of data networks.
  (b) setting up new data networks, and
  (c) providing services on data networks.
- These standards must be followed by designers and manufacturers of network components and network-services providers.
- These standards are also expected to be adhered to while setting up new data networks.

Important Protocols for Industrial Wired-Networks

1. RS-422
2. RS-485
3. Modbus
4. Foundation Fieldbus
5. DNP (Distributed Network Protocol)
6. Ethernet
7. Ethernet/IP
8. HART (Highway Addressable Remote Transmitter)
9. CAN Bus (Controller Area Network)
10. Profibus (Process Field Bus)
11. LON (Local Operation Network)
12. BAC-Net (Building Automation Control Network)

Important Protocols for Industrial Wireless-Networks

1. Zigbee
   (conforming to IEEE 802.15.4 standard)

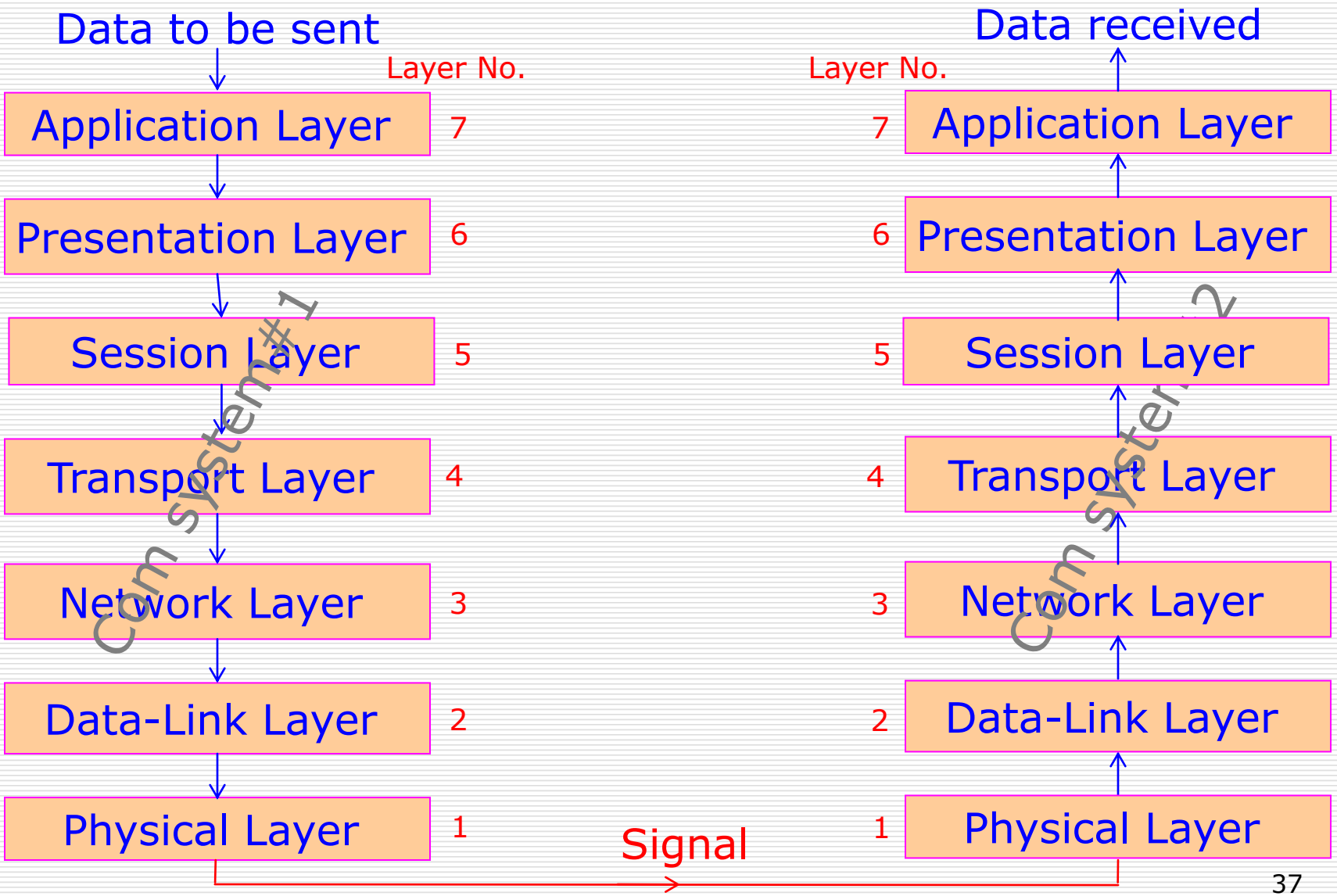
2. WiFi
   (conforming to IEEE 802.11 standard)

3. Bluetooth
   (conforming to IEEE 802.15.1 standard)

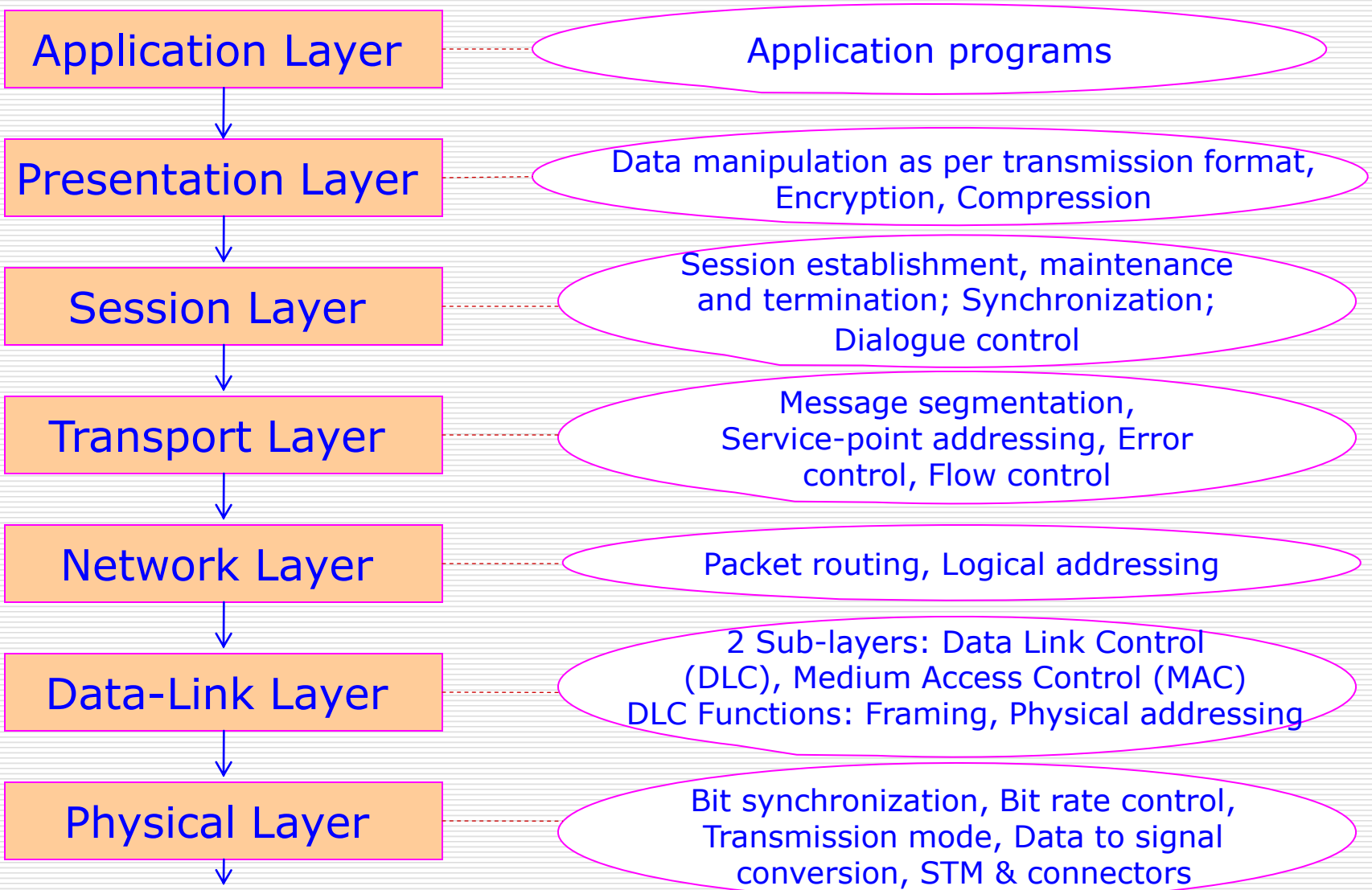
7-Layer OSI Model of Communication System

- Model was developed and issued by International Standards Organization (ISO)
- OSI: Open System Interconnection
- Reference model of communication systems (including data networks)
- Defines 7 functional layers in a generalized communication system
- For use as reference “to identify and classify the different functions of a given communication system”
- Not a standard or set of prescriptions for a communication system to adhere to
- A communication system may not have all the 7 layers
- Depending on the application, some layers may be absent
- A communication protocol or standard may not define or specify all the seven layers.

Data Transfer Between Systems



Functions of 7 Layers at Transmitting End



Functions of 7 Layers at Receiving End