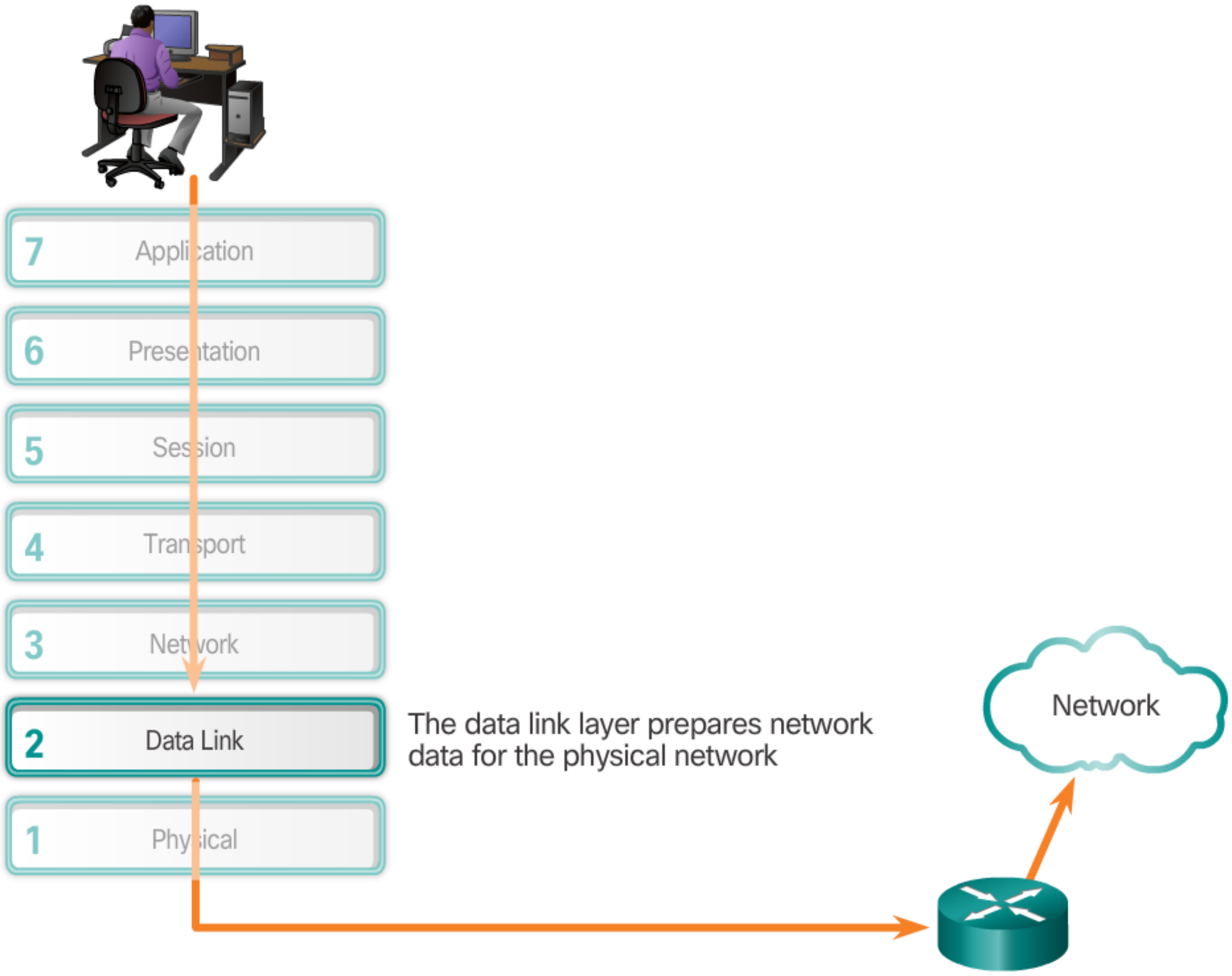
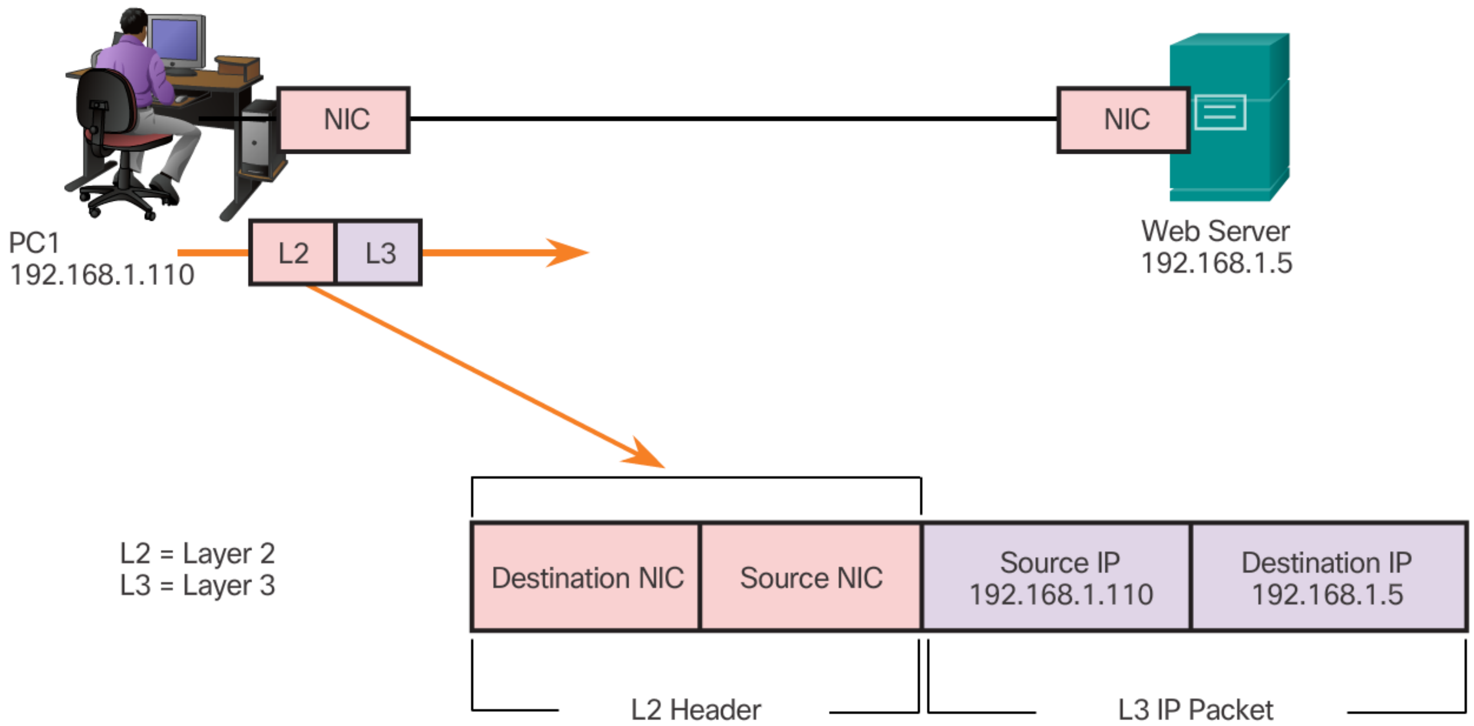
Data Link Layer



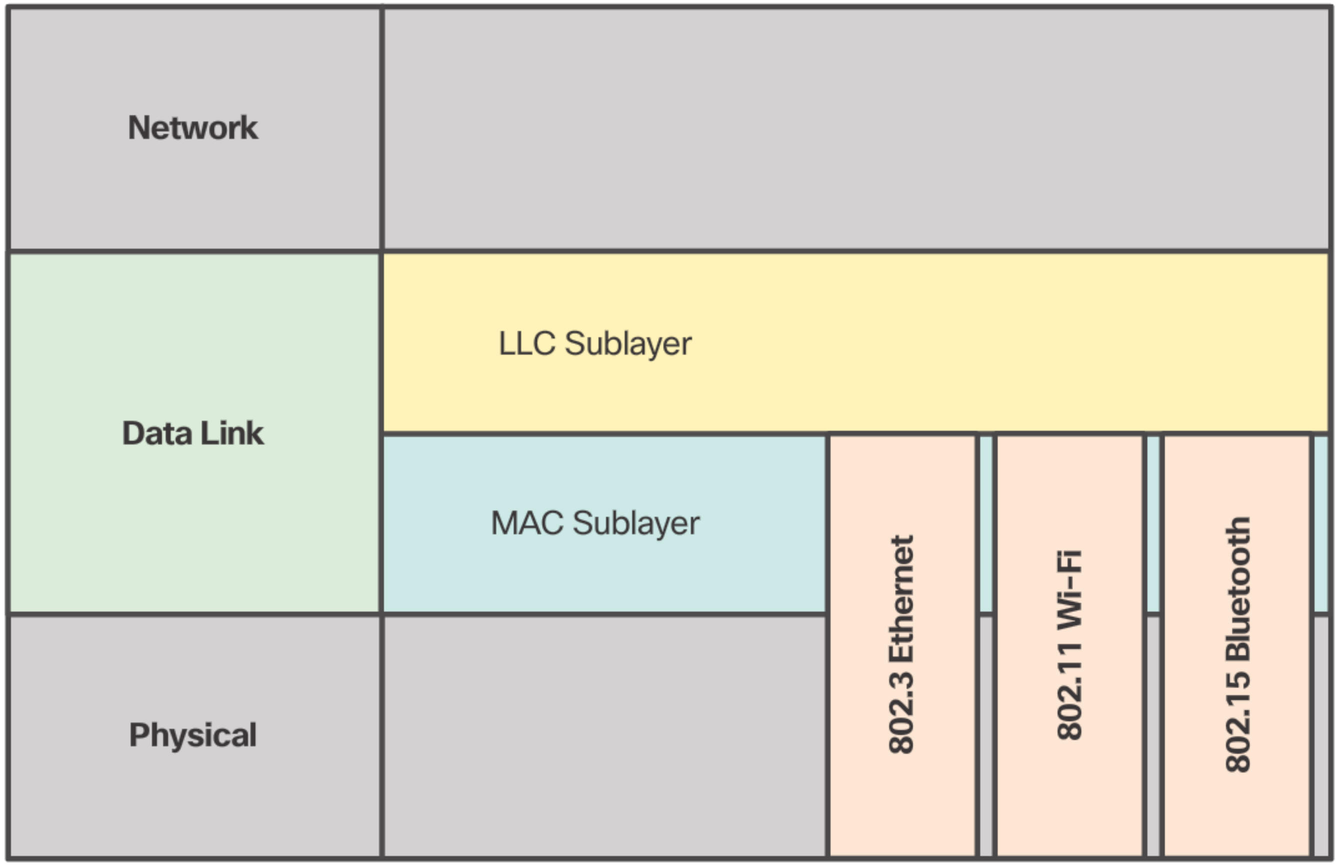
The data link layer of the OSI model (Layer 2), as shown in Figure, is responsible for:

- Allowing the upper layers to access the media
- Accepting Layer 3 packets and packaging them into frames
- Preparing network data for the physical network
- Controlling how data is placed and received on the media
- Exchanging frames between nodes over a physical network media, such as UTP or fiber-optic
- Receiving and directing packets to an upper layer protocol
- Performing error detection

Layer 2 Data Link Addresses



Data Link Sub Layer



- The data link layer is actually divided into two sublayers:
    - **Logical Link Control (LLC):** This upper sublayer defines the software processes that provide services to the network layer protocols. It places information in the frame that identifies which network layer protocol is being used for the frame. This information allows multiple Layer 3 protocols, such as IPv4 and IPv6, to utilize the same network interface and media.
    - **Media Access Control (MAC):** This lower sublayer defines the media access processes performed by the hardware. It provides data link layer addressing and delimiting of data according to the physical signaling requirements of the medium and the type of data link layer protocol in use.
- Separating the data link layer into sublayers allows for one type of frame defined by the upper layer to access different types of media defined by the lower layer. Such is the case in many LAN technologies, including Ethernet.

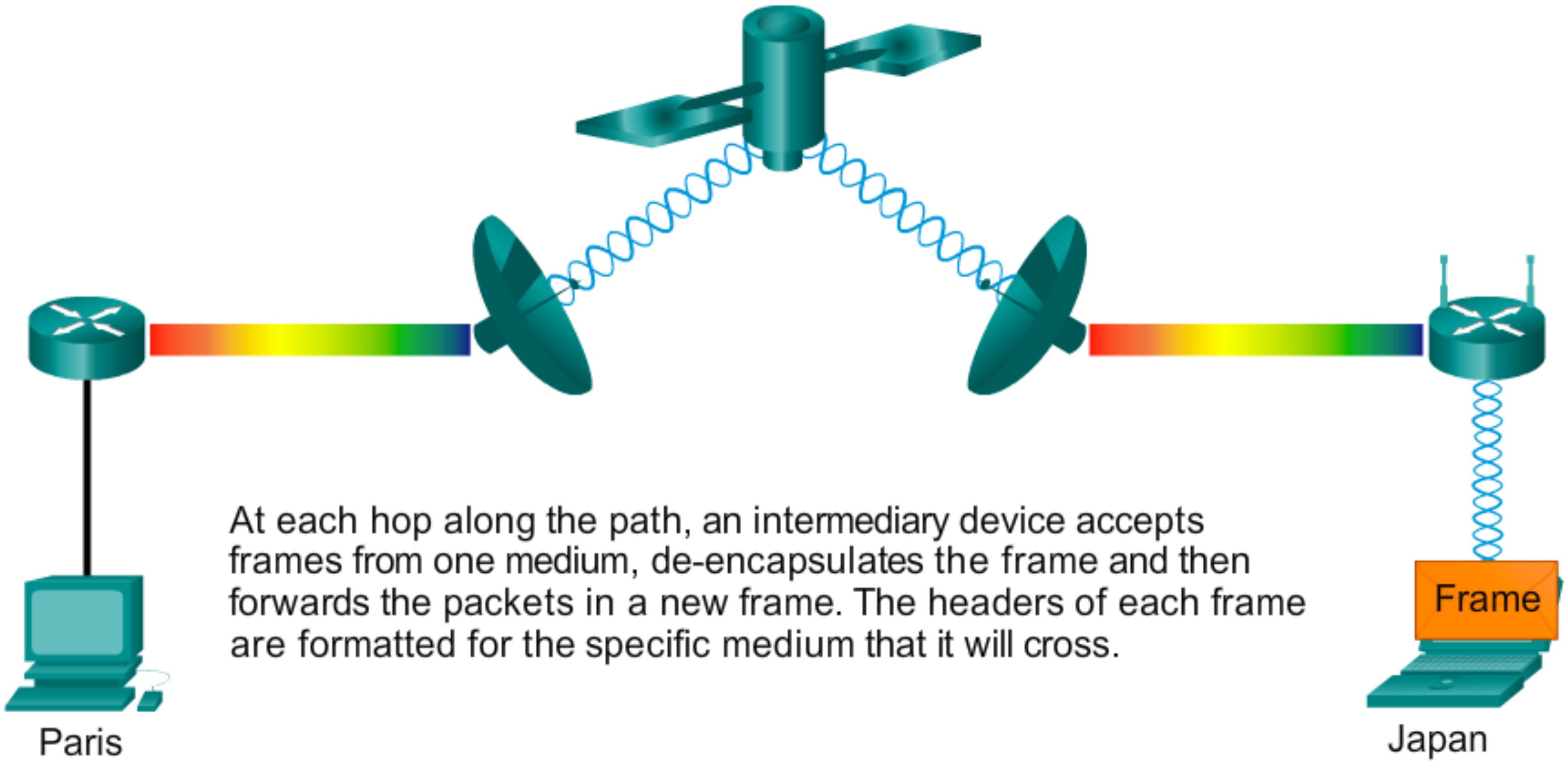
Media Access Control

- Layer 2 protocols specify the encapsulation of a packet into a frame and the techniques for getting the encapsulated packet on and off each medium. The technique used for getting the frame on and off media is called the media access control method.
- As packets travel from source host to destination host, they typically traverse over different physical networks. These physical networks can consist of different types of physical media such as copper wires, optical fibers, and wireless consisting of electromagnetic signals, radio and microwave frequencies, and satellite links.
- The packets do not have a way to directly access these different media. It is the role of the OSI data link layer to prepare network layer packets for transmission and to control access to the physical media. The media access control methods described by the data link layer protocols define the processes by which network devices can access the network media and transmit frames in diverse network environments.
- Without the data link layer, network layer protocols such as IP, would have to make provisions for connecting to every type of media that could exist along a delivery path. Moreover, IP would have to adapt every time a new network technology or medium was developed. This process would hamper protocol and network media innovation and development. This is a key reason for using a layered approach to networking.

The Data Link Layer

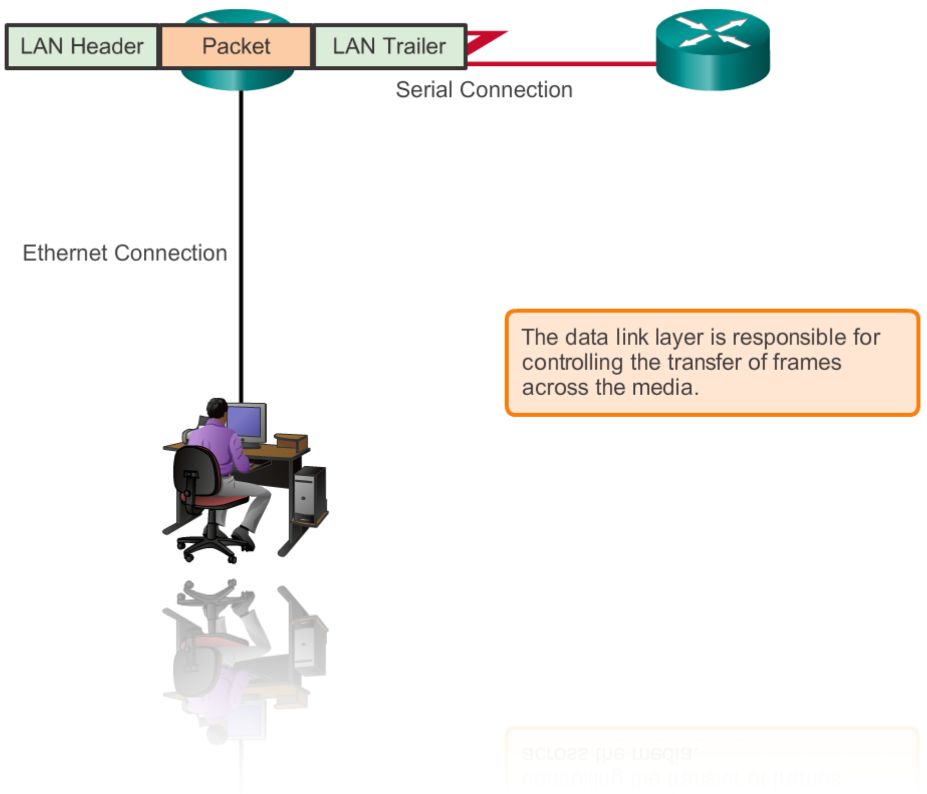
Data link layer protocols govern how to format a frame for use on different media.

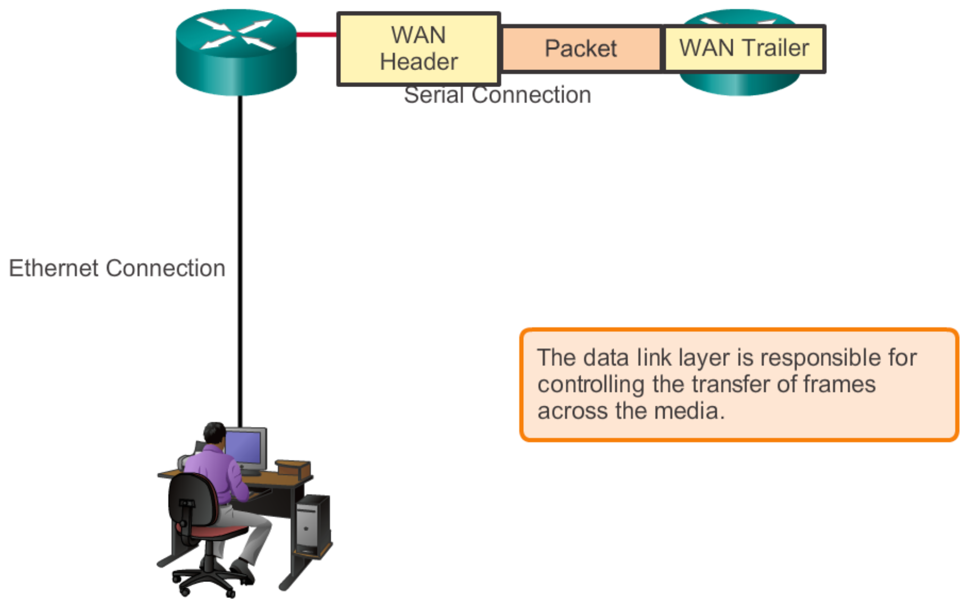
Different protocols may be in use for different media.



At each hop along the path, an intermediary device accepts frames from one medium, de-encapsulates the frame and then forwards the packets in a new frame. The headers of each frame are formatted for the specific medium that it will cross.

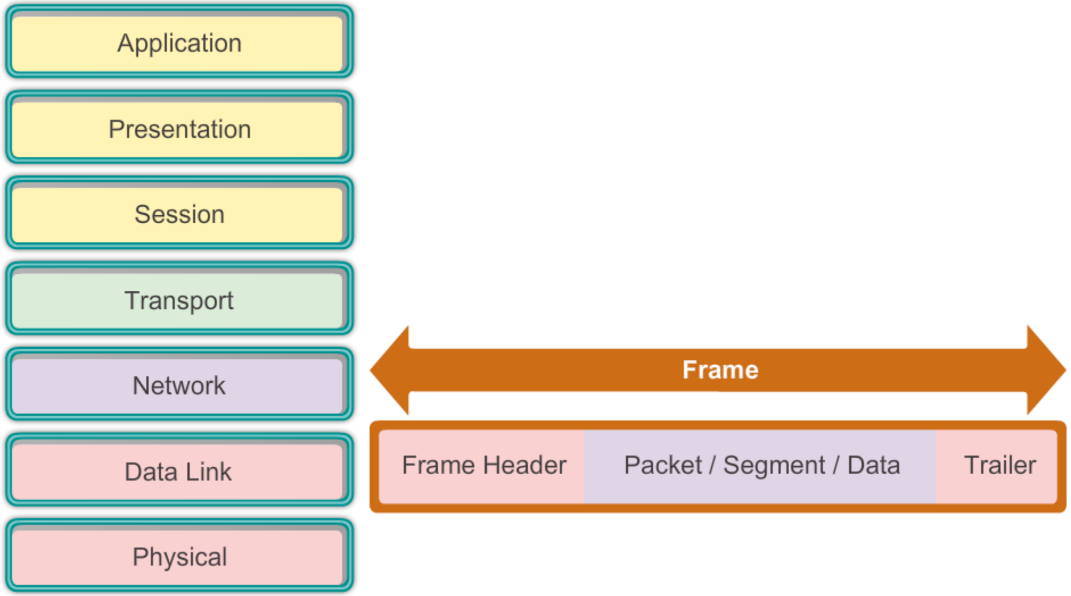
Transfer of Frames





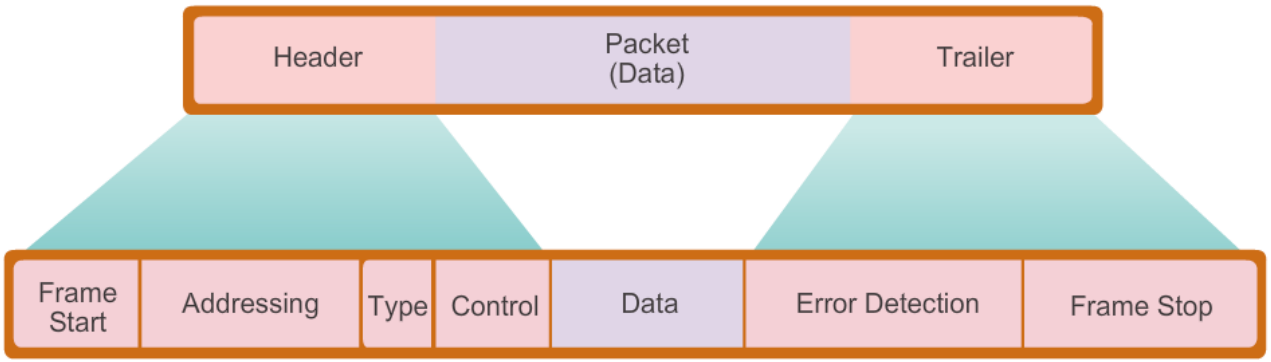
Layer 2 Frame Structure

- the data link layer frame includes:
  - Header: Contains control information, such as addressing, and is located at the beginning of the PDU.
  - Data: Contains the IP header, transport layer header, and application data.
  - Trailer: Contains control information for error detection added to the end of the PDU.



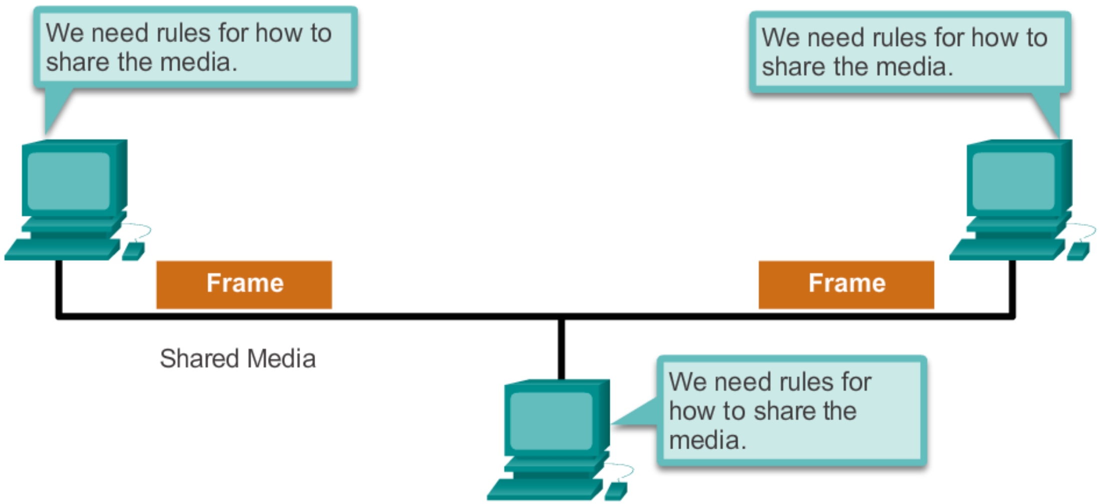
Creating a Frame

- When data travels on the media, it is converted into a stream of bits, or 1s and 0s. If a node is receiving long streams of bits, how does it determine where a frame starts and stops or which bits represent the address?
- Framing breaks the stream into decipherable groupings, with control information inserted in the header and trailer as values in different fields. This format gives the physical signals a structure that can be received by nodes and decoded into packets at the destination.
- As shown in the figure, generic frame field types include:
    - Frame start and stop indicator flags: Used by the MAC sublayer to identify the beginning and end limits of the frame.
    - Addressing: Used by the MAC sublayer to identify the source and destination nodes.
    - Type: Used by the LLC to identify the Layer 3 protocol.
    - Control: Identifies special flow control services.
    - Data: Contains the frame payload (i.e., packet header, segment header, and the data).
    - Error Detection: Included after the data to form the trailer, these frame fields are used for error detection.



Media Access Control

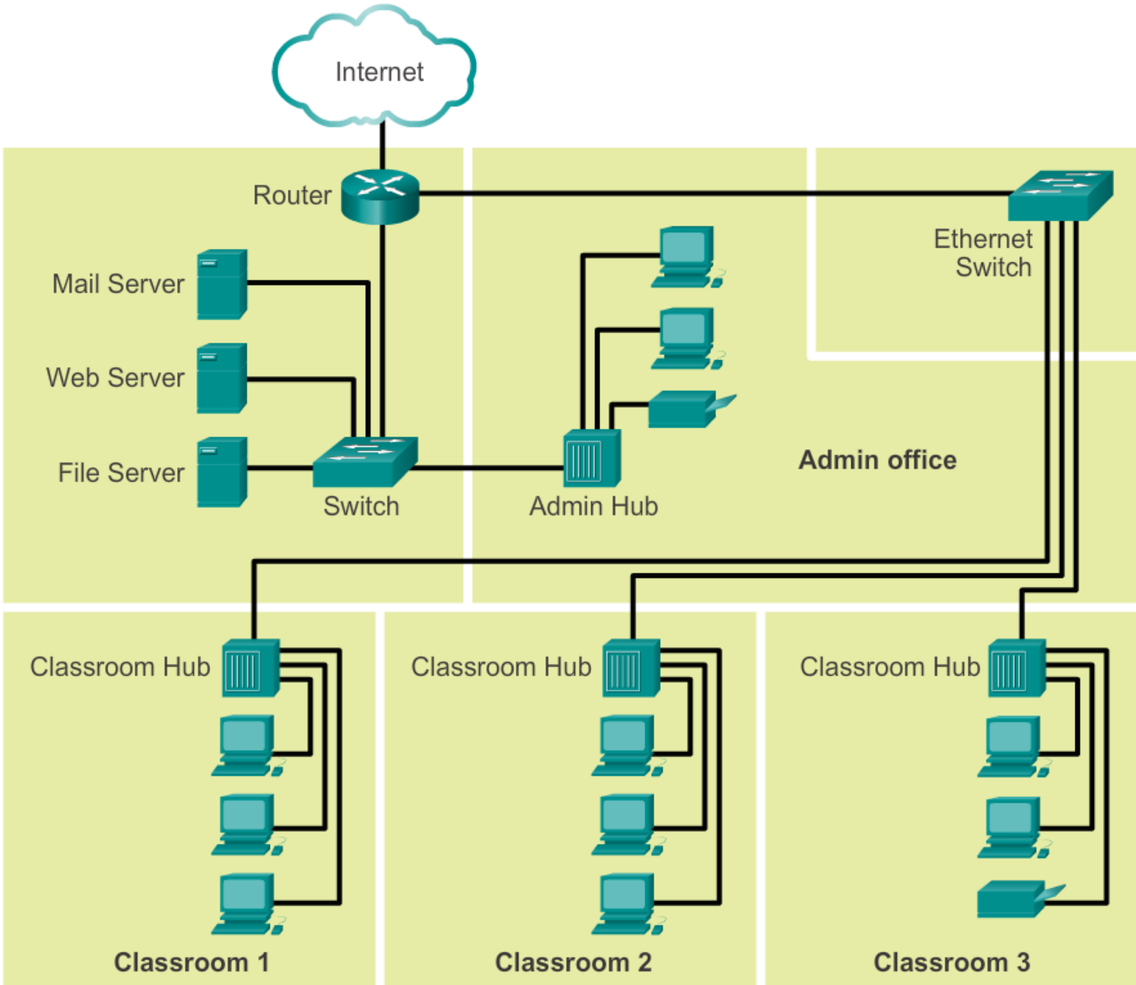
- Regulating the placement of data frames onto the media is controlled by the media access control sublayer.
- The actual media access control method used depends on:
    - **Topology:** How the connection between the nodes appears to the data link layer.
    - **Media sharing:** How the nodes share the media. The media sharing can be point-to-point such as in WAN connections or shared such as in LAN networks.



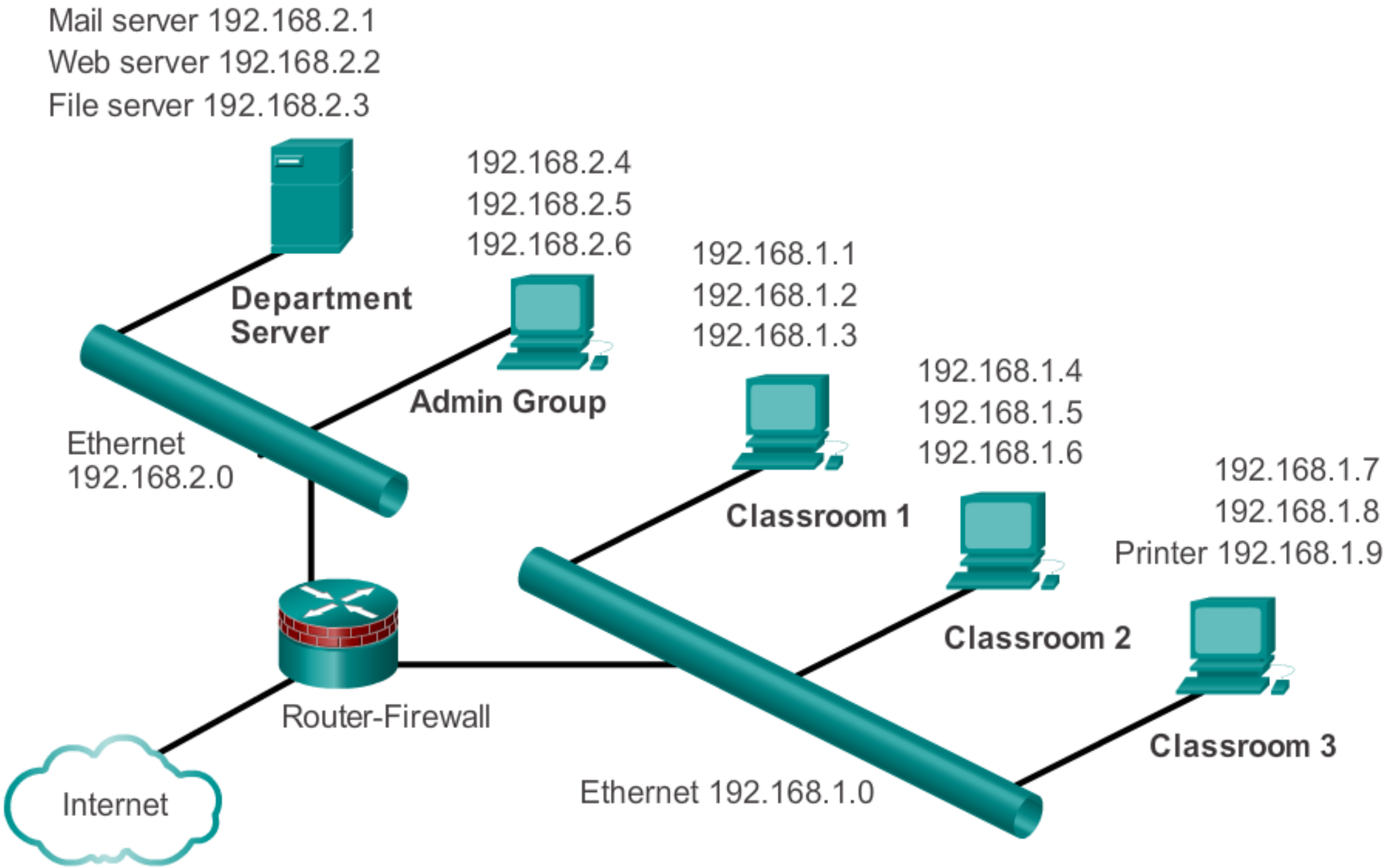
Topologies

- The topology of a network is the arrangement or relationship of the network devices and the interconnections between them. LAN and WAN topologies can be viewed in two ways:
    - **Physical topology:** Refers to the physical connections and identifies how end devices and infrastructure devices such as routers, switches, and wireless access points are interconnected. Physical topologies are usually point-to-point or star. See Figure 1.
    - **Logical topology:** Refers to the way a network transfers frames from one node to the next. This arrangement consists of virtual connections between the nodes of a network. These logical signal paths are defined by data link layer protocols. The logical topology of point-to-point links is relatively simple while shared media offers deterministic and a non-deterministic media access control methods. See Figure 2.

Physical Topology

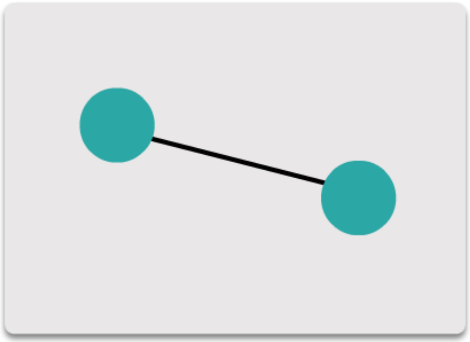


Logical Topology

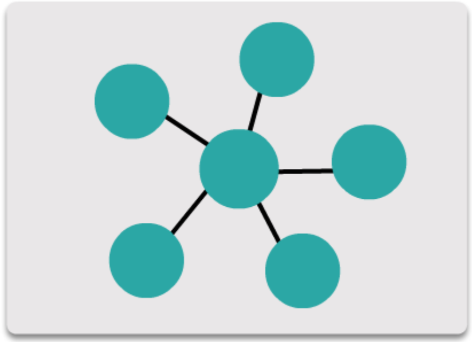


Common Physical WAN Topologies

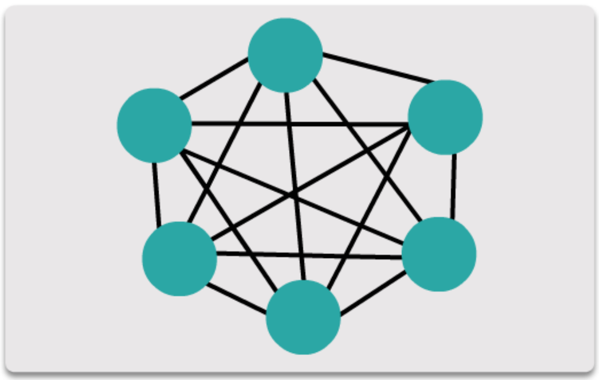
- WANs are commonly interconnected using the following physical topologies:
  - **Point-to-Point:** This is the simplest topology which consists of a permanent link between two endpoints. For this reason, this is a very popular WAN topology.
  - **Hub and Spoke:** A WAN version of the star topology in which a central site interconnects branch sites using point-to-point links.
  - **Mesh**: This topology provides high availability, but requires that every end system be interconnected to every other system. Therefore the administrative and physical costs can be significant. Each link is essentially a point-to-point link to the other node. Variations of this topology include a partial mesh where some but not all of end devices are interconnected.



Point-to-point topology



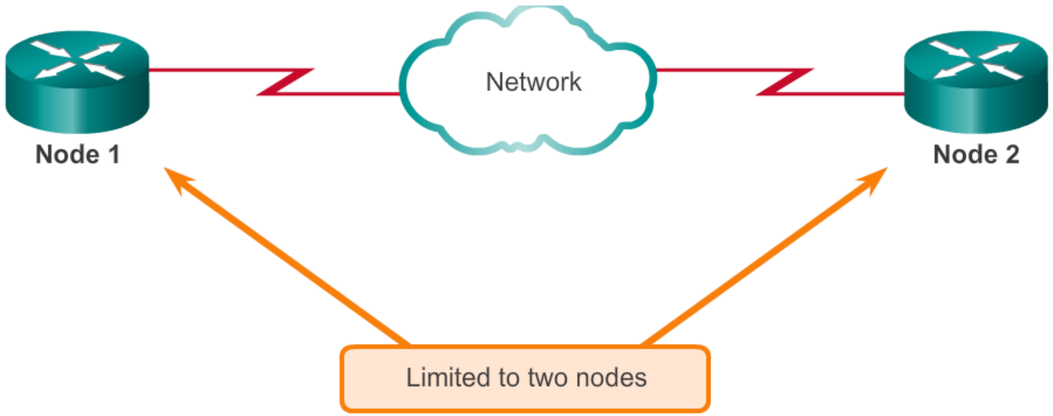
Hub and spoke topology



Full mesh topology

Physical Point to Point Topology

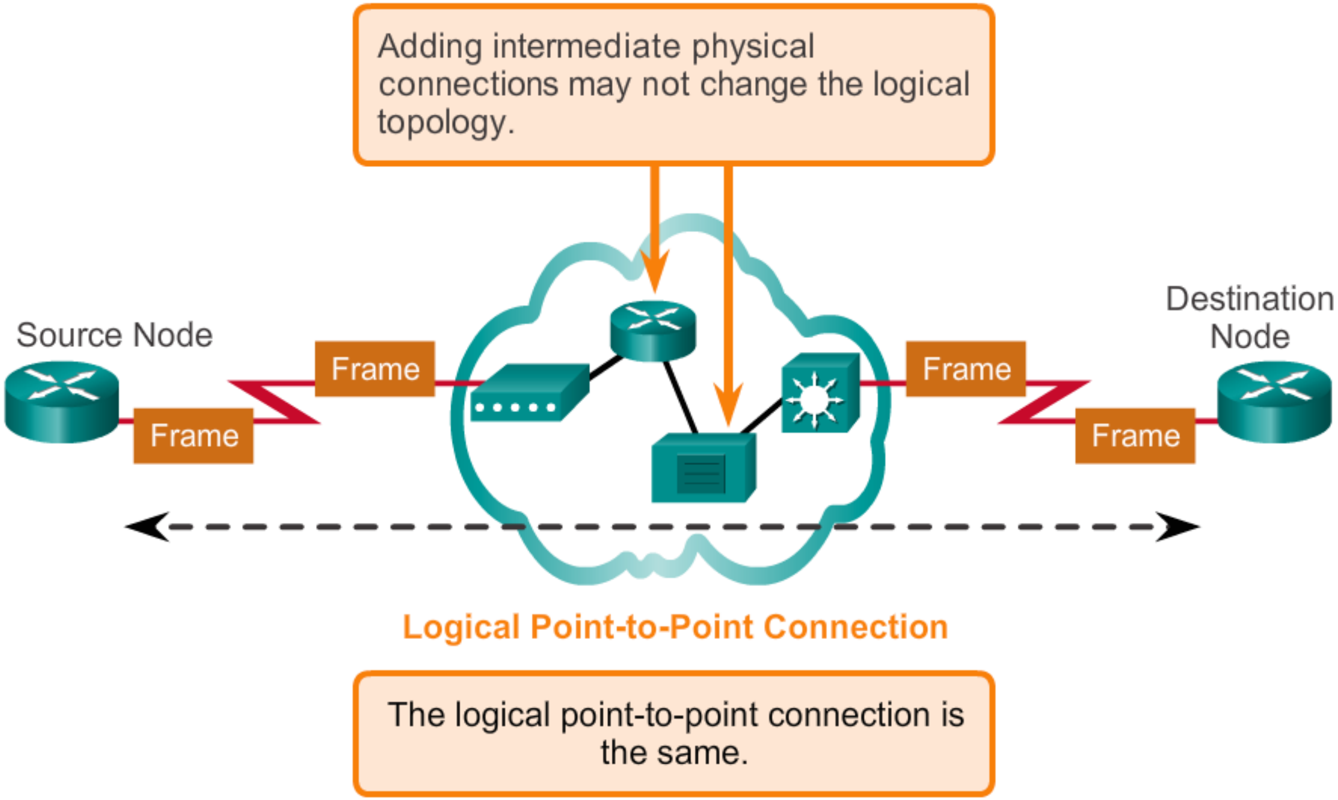
- Physical point-to-point topologies directly connect two nodes as shown in the figure.
- In this arrangement, two nodes do not have to share the media with other hosts. Additionally, a node does not have to make any determination about whether an incoming frame is destined for it or another node. Therefore, the logical data link protocols can be very simple as all frames on the media can only travel to or from the two nodes. The frames are placed on the media by the node at one end and taken off the media by the node at the other end of the point-to-point circuit.
- Data link layer protocols could provide more sophisticated media access control processes for logical point-to-point topologies, but this would only add unnecessary protocol overhead.



Logical Point to Point Topology

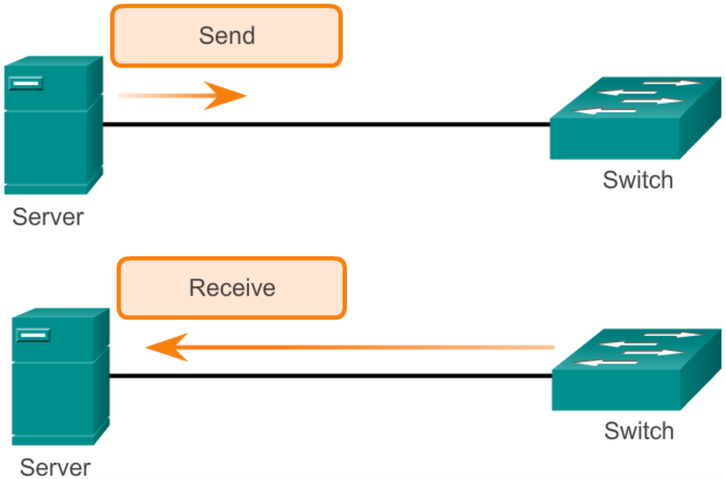
- The end nodes communicating in a point-to-point network can be physically connected via a number of intermediate devices. However, the use of physical devices in the network does not affect the logical topology.
- As shown in Figure 1, the source and destination node may be indirectly connected to each other over some geographical distance. In some cases, the logical connection between nodes forms what is called a virtual circuit. A virtual circuit is a logical connection created within a network between two network devices. The two nodes on either end of the virtual circuit exchange the frames with each other. This occurs even if the frames are directed through intermediary devices. Virtual circuits are important logical communication constructs used by some Layer 2 technologies.
- The media access method used by the data link protocol is determined by the logical point-to-point topology, not the physical topology. This means that the logical point-to-point connection between two nodes may not necessarily be between two physical nodes at each end of a single physical link.

Logical Point to Point Topology

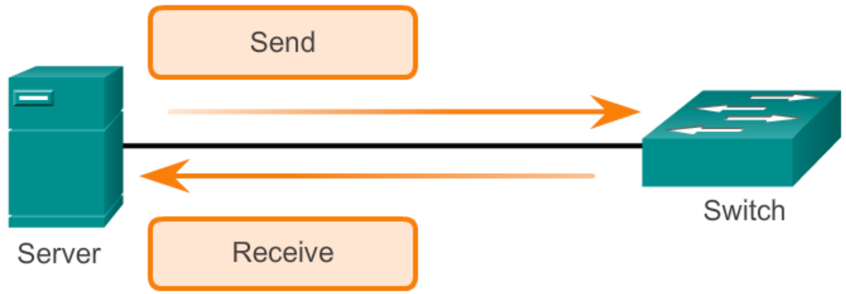


Half and Full Duplex

- In point-to-point networks, data can flow in one of two ways:
  - **Half-duplex communication:** Both devices can both transmit and receive on the media but cannot do so simultaneously. Ethernet has established arbitration rules for resolving conflicts arising from instances when more than one station attempts to transmit at the same time. Figure 2 shows half-duplex communication.
  - **Full-duplex communication:** Both devices can transmit and receive on the media at the same time. The data link layer assumes that the media is available for transmission for both nodes at any time. Therefore, there is no media arbitration necessary in the data link layer. Figure 3 shows full-duplex communication.



Half-Duplex Commmunication

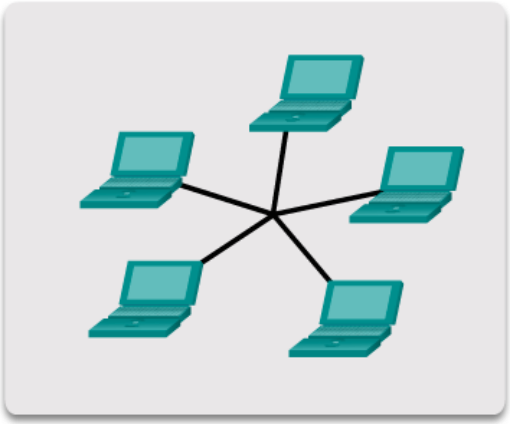


Full-Duplex Commmunication

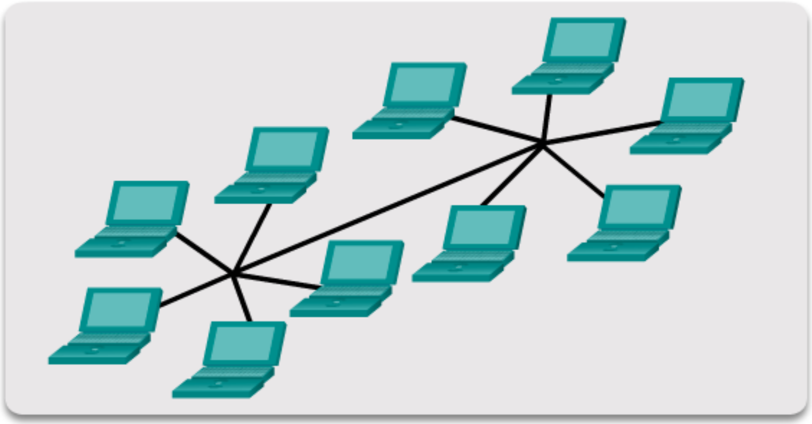
LAN Topologies

- Physical topology defines how the end systems are physically interconnected. In shared media LANs, end devices can be interconnected using the following physical topologies:
    - **Star**: End devices are connected to a central intermediate device. Early star topologies interconnected end devices using hubs. However, star topologies now use switches. The star topology is the most common physical LAN topology primarily because it is easy to install, very scalable (easy to add and remove end devices), and easy to troubleshoot.
    - **Extended star or hybrid**: In an extended star topology, central intermediate devices interconnect other star topologies. In a hybrid topology, the star networks may interconnect using a bus topology.
    - **Bus**: All end systems are chained to each other and terminated in some form on each end. Infrastructure devices such as switches are not required to interconnect the end devices. Bus topologies were used in legacy Ethernet networks because it was inexpensive to use and easy to set up.
    - **Ring:** End systems are connected to their respective neighbor forming a ring. Unlike the bus topology, the ring does not need to be terminated. Ring topologies were used in legacy Fiber Distributed Data Interface (FDDI) networks. Specifically, FDDI networks employ a second ring for fault tolerance or performance enhancements.
- The figure illustrates how end devices are interconnected on LANs.

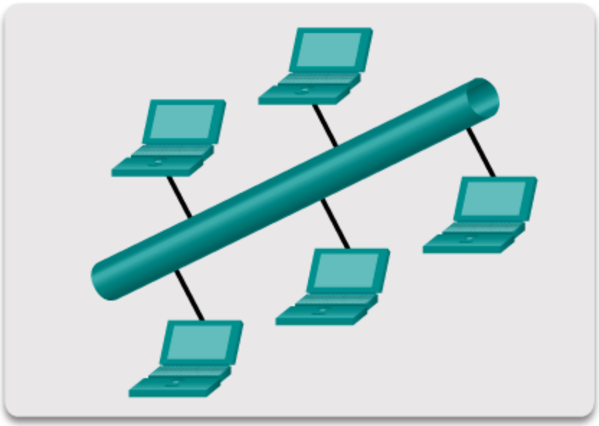
Physical Topology



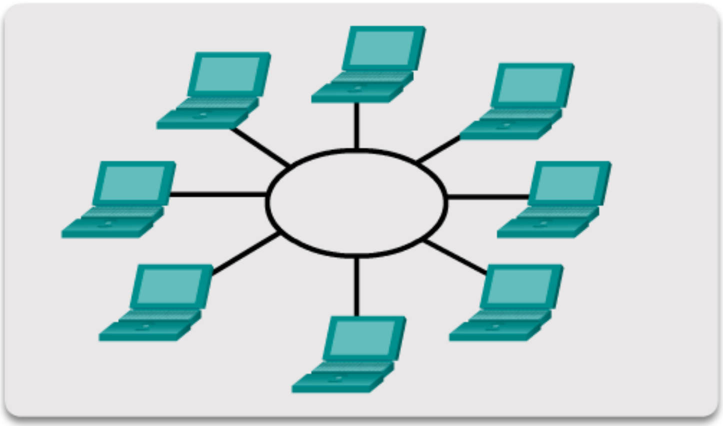
Star topology



Extended star topology



Bus topology

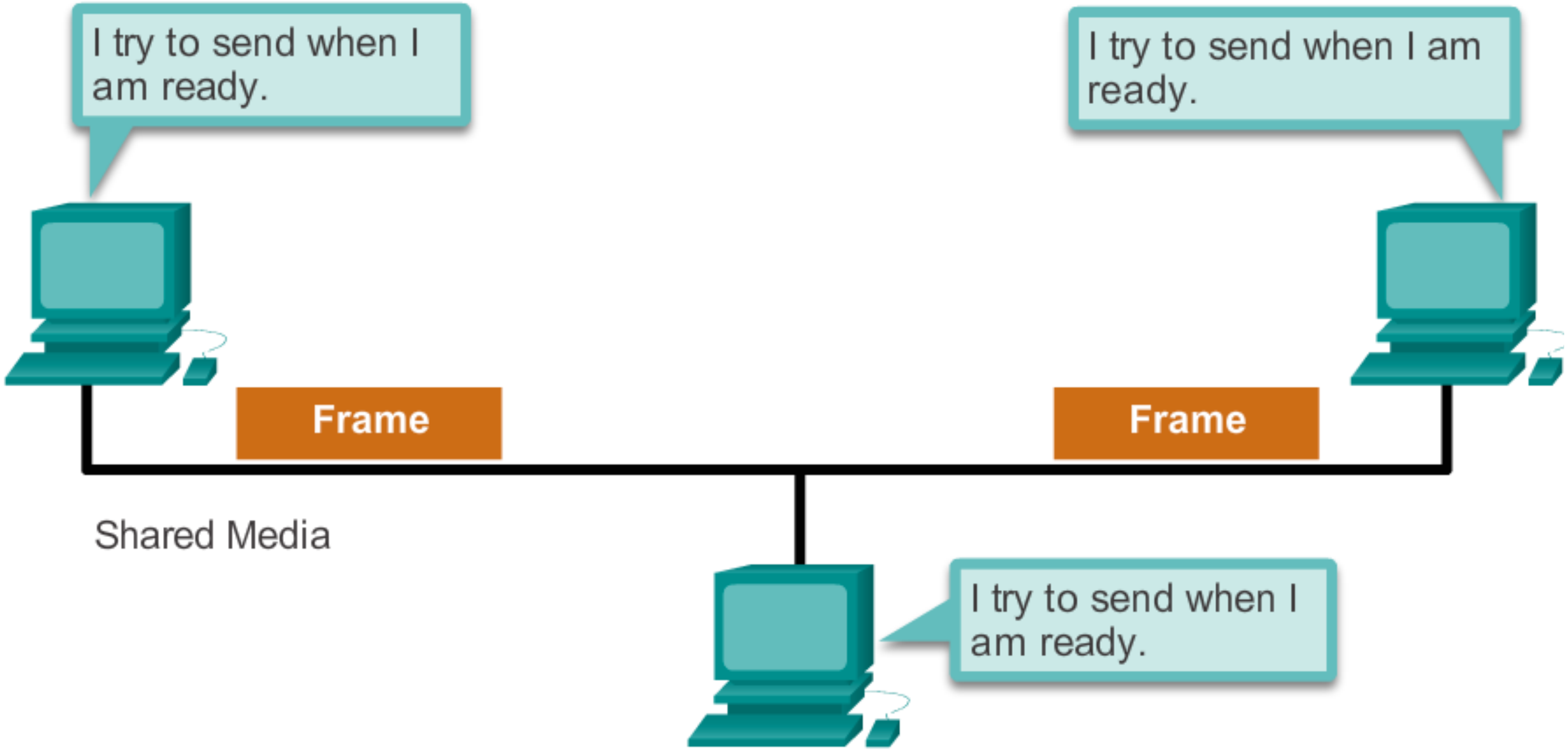


Ring topology

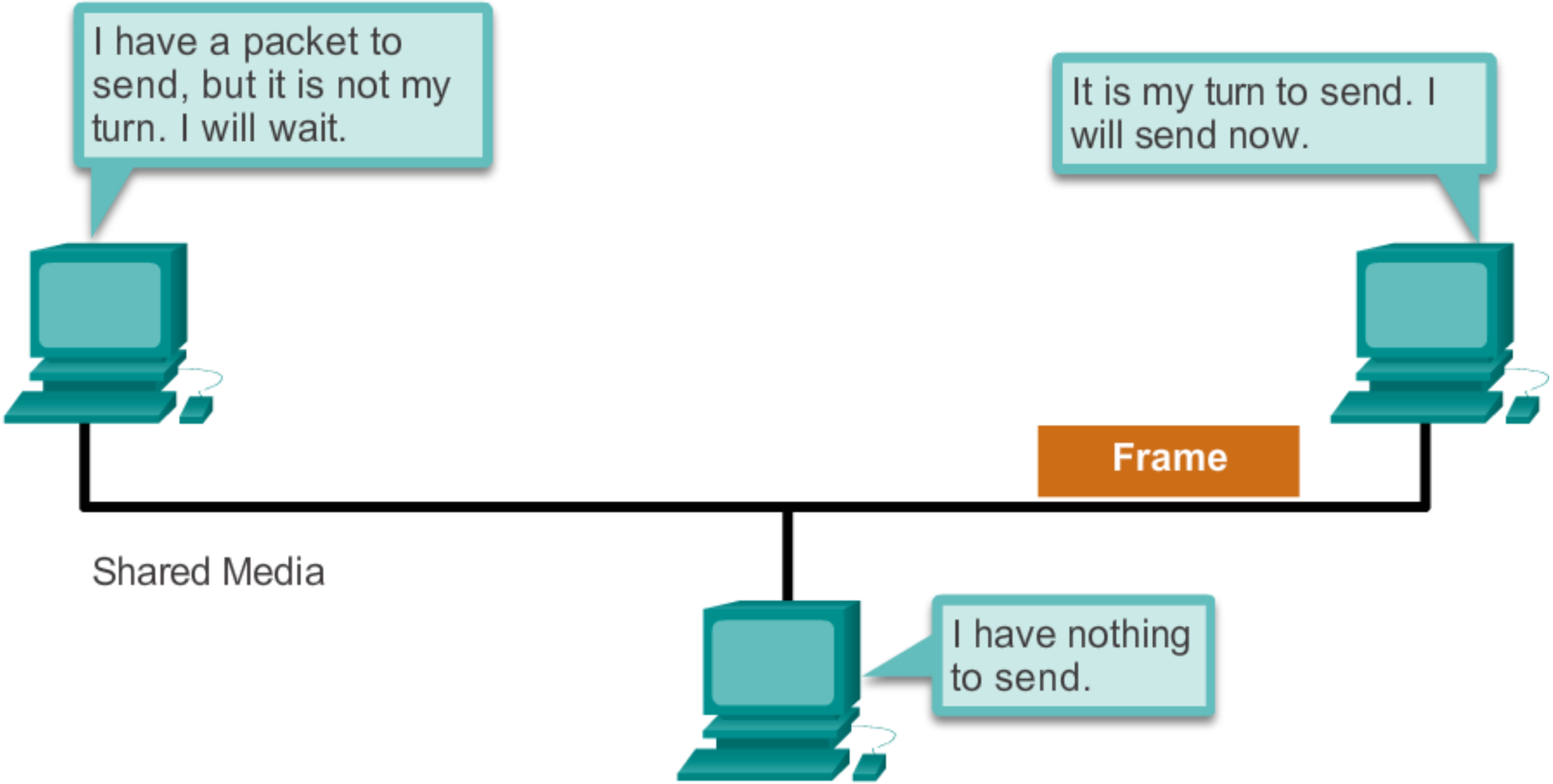
Logical Topology for Shared Media

- Logical topology of a network is closely related to the mechanism used to manage network access. Access methods provide the procedures to manage network access so that all stations have access. When several entities share the same media, some mechanism must be in place to control access. Access methods are applied to networks to regulate this media access.
- Some network topologies share a common medium with multiple nodes. At any one time, there may be a number of devices attempting to send and receive data using the network media. There are rules that govern how these devices share the media.
- There are two basic media access control methods for shared media:
    - **Contention-based access**: All nodes compete for the use of the medium but have a plan if there are collisions. Figure 1 shows contention-based access.
    - **Controlled-based access**: Each node has its own time to use the medium. Figure 2 shows controlled access.

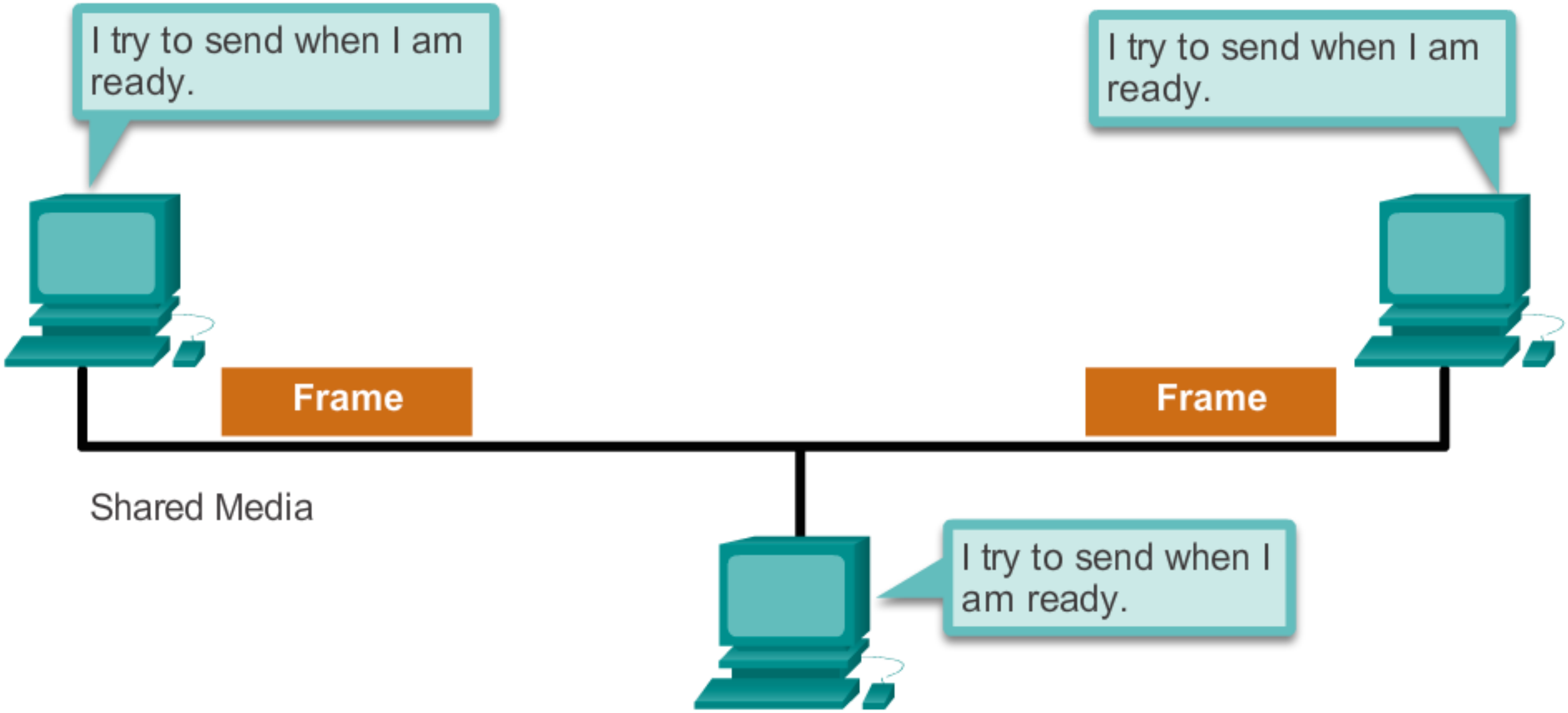
Contention Based



Controlled Based



Contention Based Access

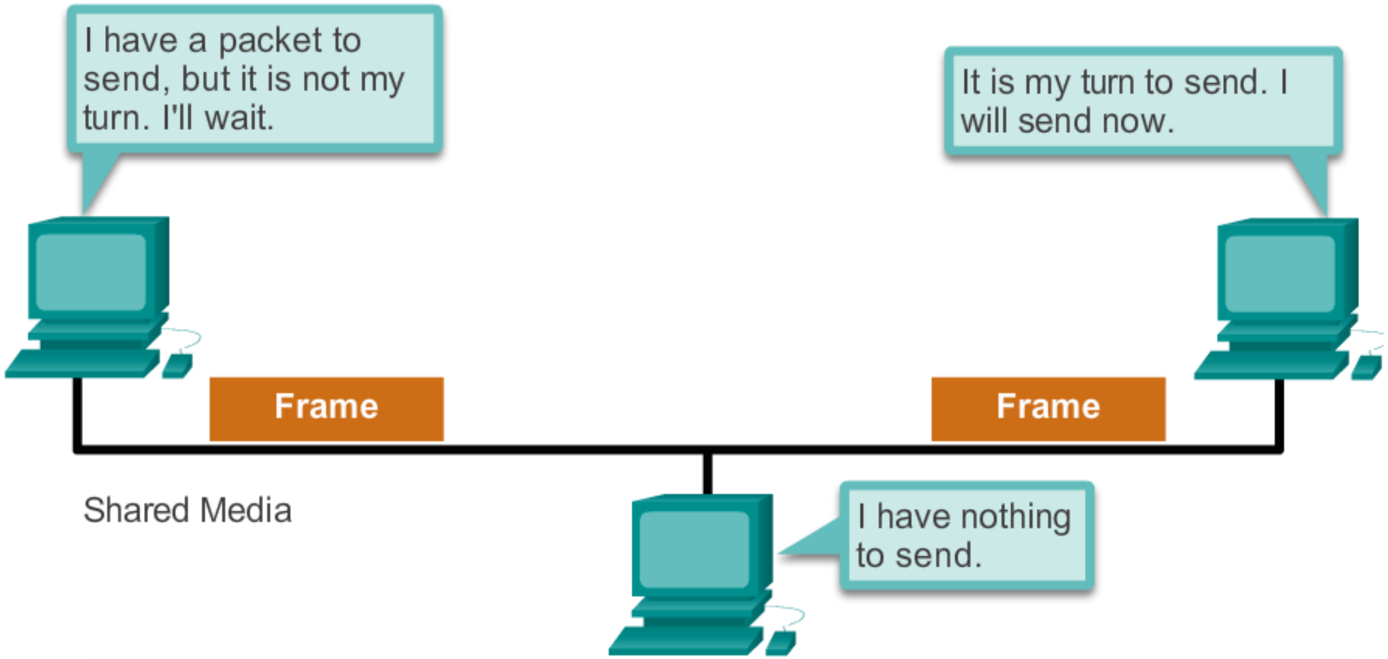


Characteristics	Contention-Based Technologies
• Stations can transmit at any time • Collisions exist • There are mechanisms to resolve contention for the media	• CSMA/CD for 802.3 Ethernet networks • CSMA/CA for 802.11 wireless networks

Controlled Access

- When using the controlled access method, network devices take turns, in sequence, to access the medium. If an end device does not need to access the medium, then the opportunity passes to the next end device. This process is facilitated by use of a token. An end device acquires the token and places a frame on the media, no other device can do so until the frame has arrived and been processed at the destination, releasing the token.
- Although controlled access is well-ordered and provides predictable throughput, deterministic methods can be inefficient because a device has to wait for its turn before it can use the medium.
- Controlled access examples include:
  - Token Ring (IEEE 802.5)
  - Fiber Distributed Data Interface (FDDI) which is based on the IEEE 802.4 token bus protocol.

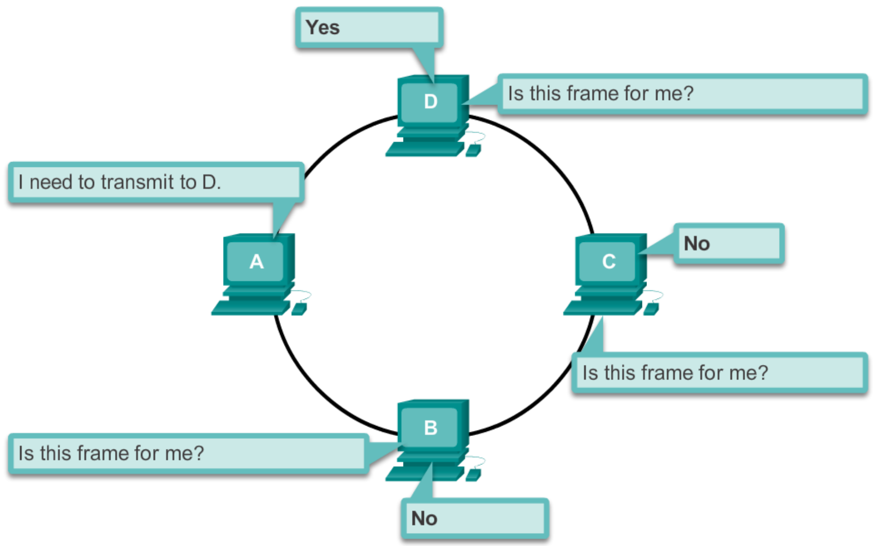
Controlled Access



Characteristics	Controlled Access Technologies
• Only one station transmits at a time • Devices wishing to transmit must wait their turn • No collisions • May use a token passing method	• Token Ring (IEEE 802.5) • Fiber Distributed Data Interface (FDDI)

Ring Topology

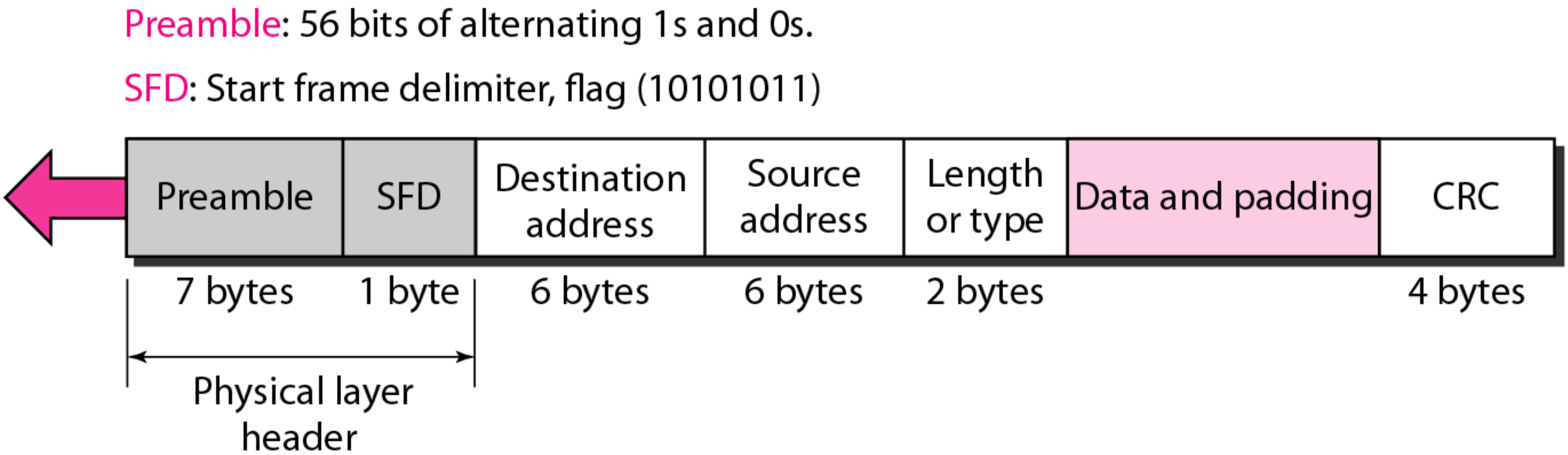
- In a logical ring topology, each node in turn receives a frame. If the frame is not addressed to the node, the node passes the frame to the next node. This allows a ring to use a controlled media access control technique called token passing.
- Nodes in a logical ring topology remove the frame from the ring, examine the address, and send it on if it is not addressed for that node. In a ring, all nodes around the ring (between the source and destination node) examine the frame.



Activity

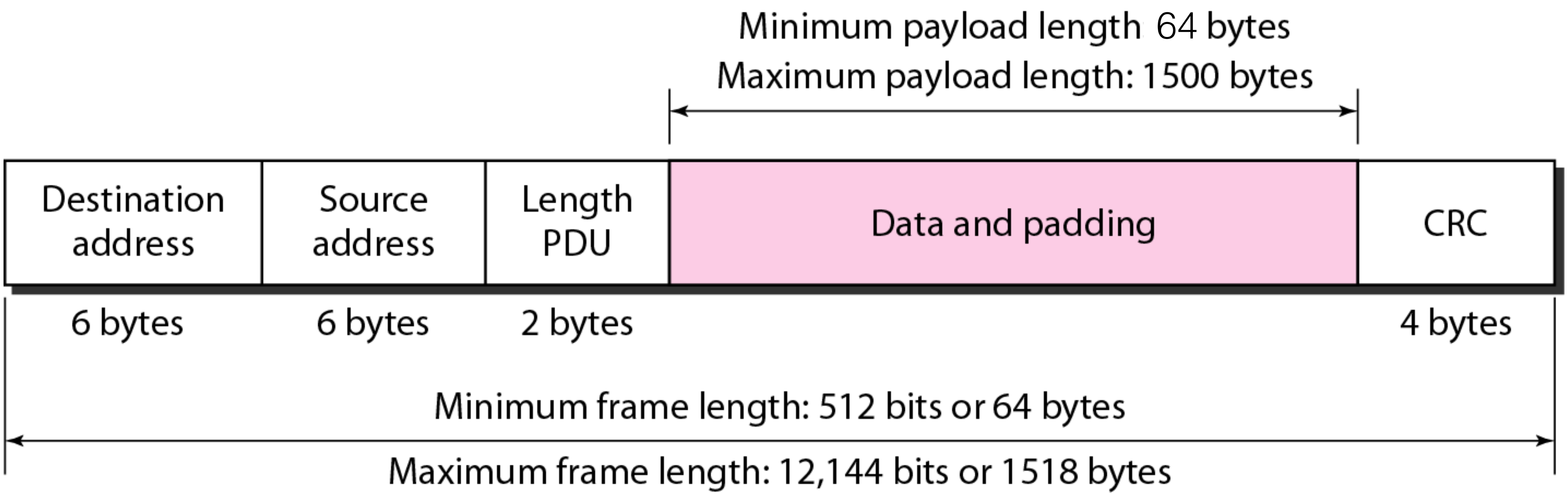
	Physical Topology	Logical Topology
1. CSMA/CD		
2. Star		
3. Contention-based access		
4. Bus		
5. CSMA/CA		
6. Controlled access		
7. Point-to-Point		
8. Ring		
9. Hub and Spoke		

802.3 MAC Frame




06 : 01 : 02 : 01 : 2C : 4B
6 bytes = 12 hex digits = 48 bits

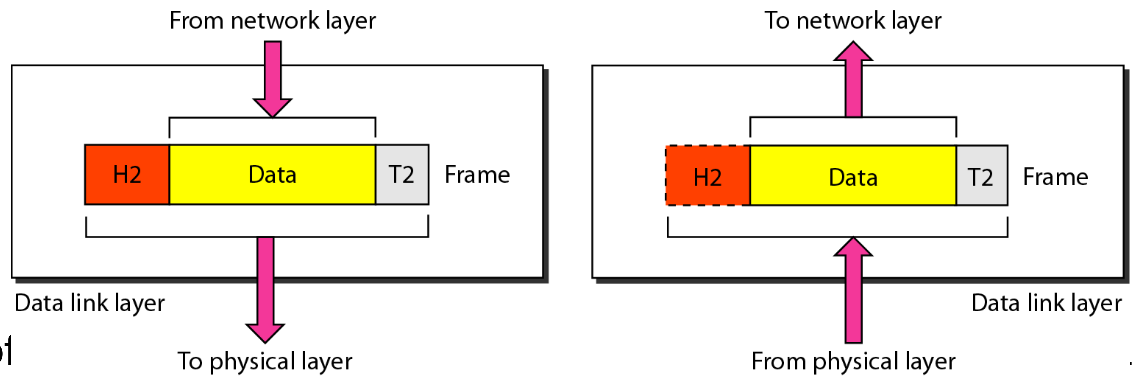
Minimum and Maximum Length



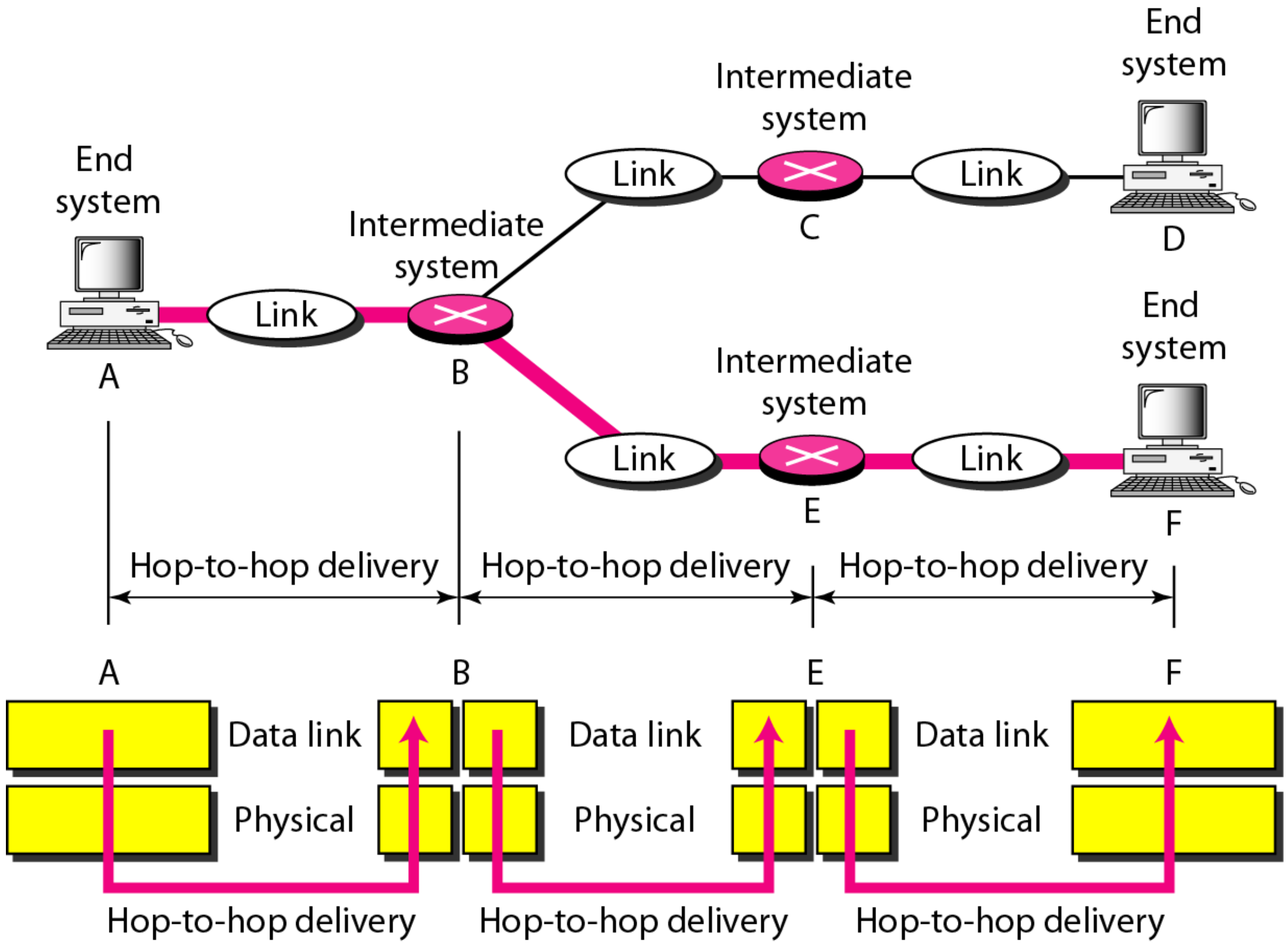
Frame length:
Minimum: 64 bytes (512 bits)
Maximum: 1518 bytes (12,144 bits)

Introduction to Data Link Layer

- The data link layer transforms the physical layer, a raw transmission facility, to a link responsible for node-to-node (hop-to-hop) communication.
- Specific responsibilities of the data link layer include
  - framing,
  - addressing,
  - flow control,
  - error control, and
  - media access control.



- The data link layer divides the stream of
units called frames.
- The data link layer adds a header to the frame to define the addresses of the sender and receiver of the frame.



- The data link layer also adds reliability to the physical layer by adding mechanisms to detect and retransmit damaged, duplicate, or lost frames. When two or more devices are connected to the same link, data link layer protocols are necessary to determine which device has control over the link at any given time.