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Introduction

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1. Why Should I Take This Module?

Welcome to Data Link Layer!

Every network has physical components and media connecting the components. Different types of media need different information about the data in order to accept it and move it across the physical network. Think of it this way: A well-hit golf ball moves through the air fast and far. It can also move through water but not as fast or as far unless it is helped by a more forceful hit. This is because the golf ball is traveling through a different medium; water instead of air.

Data must have help to move it across different media. The data link layer provides this help. As you might have guessed, this help differs based on a number of factors. This module gives you an overview of these factors, how they affect data, and the protocols designed to ensure successful delivery.

Let's get started!

2. What Will I Learn To Do In This Module?

2A. Module Title

- Data Link Layer

2B. Module Objective

- Explain how media access control in the data link layer supports communication across networks.

Topic Title	Topic Objective
Purpose of the Data Link Layer	Describe the purpose and function of the data link layer in preparing communication for transmission on specific media.
Topologies	Compare the characteristics of media access control methods on WAN and LAN topologies.
Data Link Frame	Describe the characteristics and functions of the data link frame.

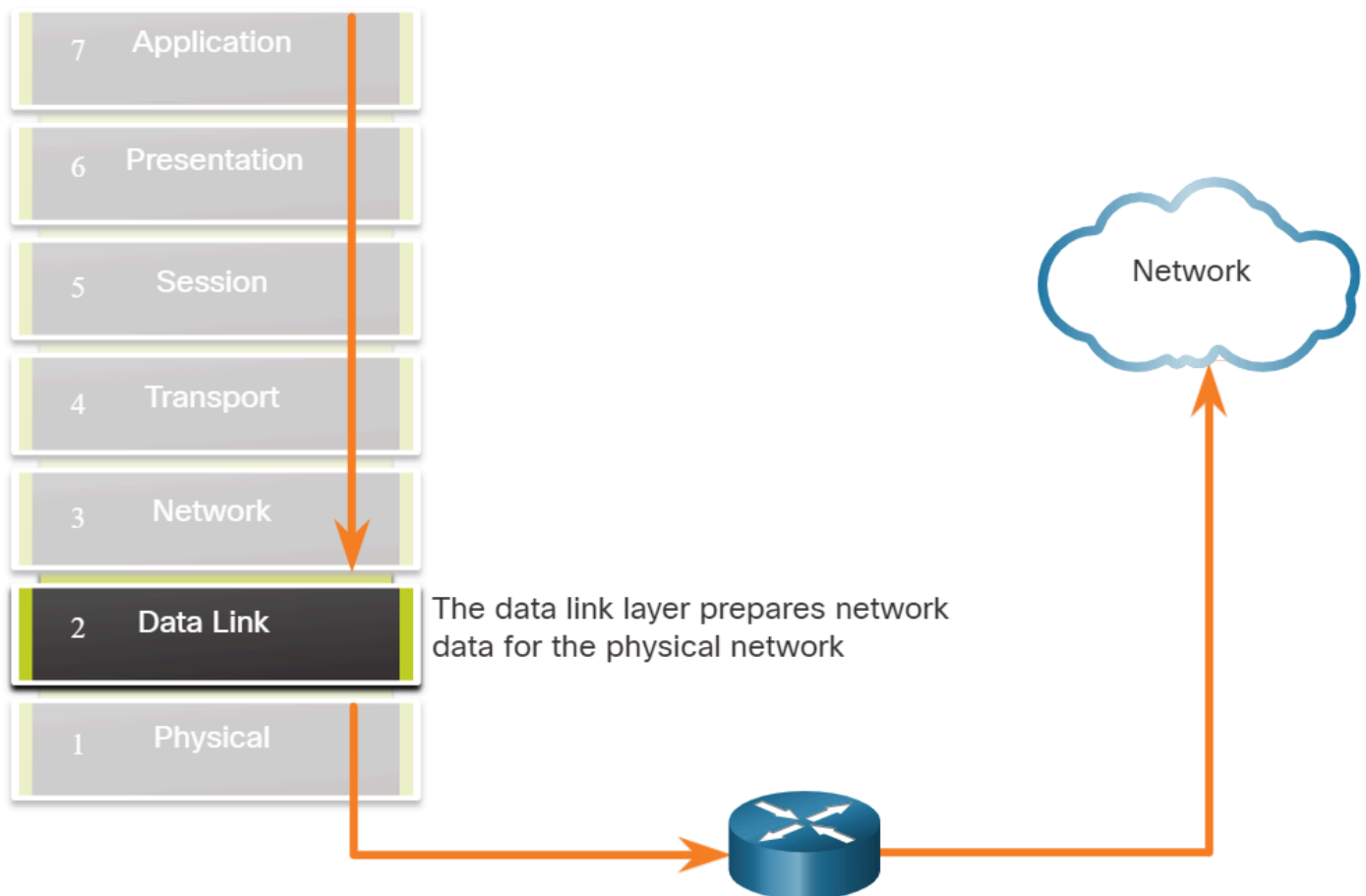
Purpose of the Data Link Layer

1. The Data Link Layer

The data link layer of the OSI model (Layer 2), as shown in the figure, prepares network data for the physical network. The data link layer is responsible for network interface card (NIC) to network interface card communications.

The data link layer does the following:

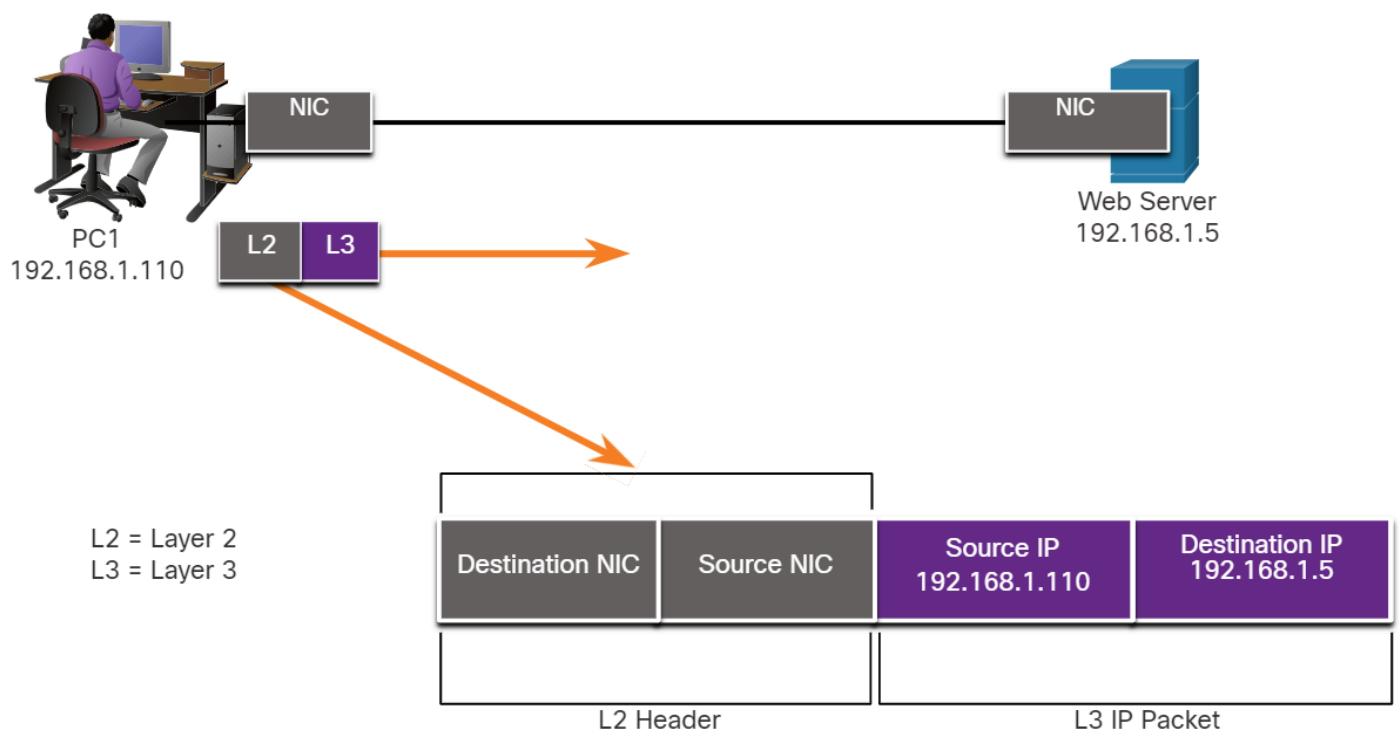
- Enables upper layers to access the media. The upper layer protocol is completely unaware of the type of media that is used to forward the data.
- Accepts data, usually Layer 3 packets (i.e., IPv4 or IPv6), and encapsulates them into Layer 2 frames.
- Controls how data is placed and received on the media.
- Exchanges frames between endpoints over the network media.
- Receives encapsulated data, usually Layer 3 packets, and directs them to the proper upper-layer protocol.
- Performs error detection and rejects any corrupt frame.



In computer networks, a node is a device that can receive, create, store, or forward data along a communications path. A node can be either an end device such as a laptop or mobile phone, or an intermediary device such as an Ethernet switch.

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. Additionally, every time a new network technology or medium was developed IP, would have to adapt.

The figure displays an example of how the data link layer adds Layer 2 Ethernet destination and source NIC information to a Layer 3 packet. It would then convert this information to a format supported by the physical layer (i.e., Layer 1).



2. IEEE 802 LAN/MAN Data Link Sublayers

IEEE 802 LAN/MAN standards are specific to Ethernet LANs, wireless LANs (WLANs), wireless personal area networks (WPAN) and other types of local and metropolitan area networks.

The IEEE 802 LAN/MAN data link layer consists of the following two sublayers:

- **Logical Link Control (LLC)** - This IEEE 802.2 sublayer communicates between the networking software at the upper layers and the device hardware at the lower layers. 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 use the same network interface and media.
- **Media Access Control (MAC)** – Implements this sublayer (IEEE 802.3, 802.11, or 802.15) in hardware. It is responsible for data encapsulation and media access control. It provides data link layer addressing and it is integrated with various physical layer technologies.

The figure shows the two sublayers (LLC and MAC) of the data link layer.

Network	Network Layer Protocol			
Data Link	LLC Sublayer	LLC Sublayer - IEEE 802.2		
	MAC Sublayer	Ethernet IEEE 802.3	WLAN IEEE 802.11	WPAN IEEE 802.15
		Various Ethernet standards for Fast Ethernet, Gigabit Ethernet, etc.	Various WLAN standards for different types of wireless communications	Various WPAN standards for Bluetooth, RFID, etc.
Physical				

The LLC sublayer takes the network protocol data, which is typically an IPv4 or IPv6 packet, and adds Layer 2 control information to help deliver the packet to the destination node.

The MAC sublayer controls the NIC and other hardware that is responsible for sending and receiving data on the wired or wireless LAN/MAN medium.

The MAC sublayer provides data encapsulation:

- **Frame delimiting** - The framing process provides important delimiters to identify fields within a frame. These delimiting bits provide synchronization between the transmitting and receiving nodes.
- **Addressing** - Provides source and destination addressing for transporting the Layer 2 frame between devices on the same shared medium.
- **Error detection** - Includes a trailer used to detect transmission errors.

The MAC sublayer also provides media access control, allowing multiple devices to communicate over a shared (half-duplex) medium. Full-duplex communications do not require access control.

3. Providing Access to Media

Each network environment that packets encounter as they travel from a local host to a remote host can have different characteristics. For example, an Ethernet LAN usually consists of many hosts contending for access on the network medium. The MAC sublayer resolves this.

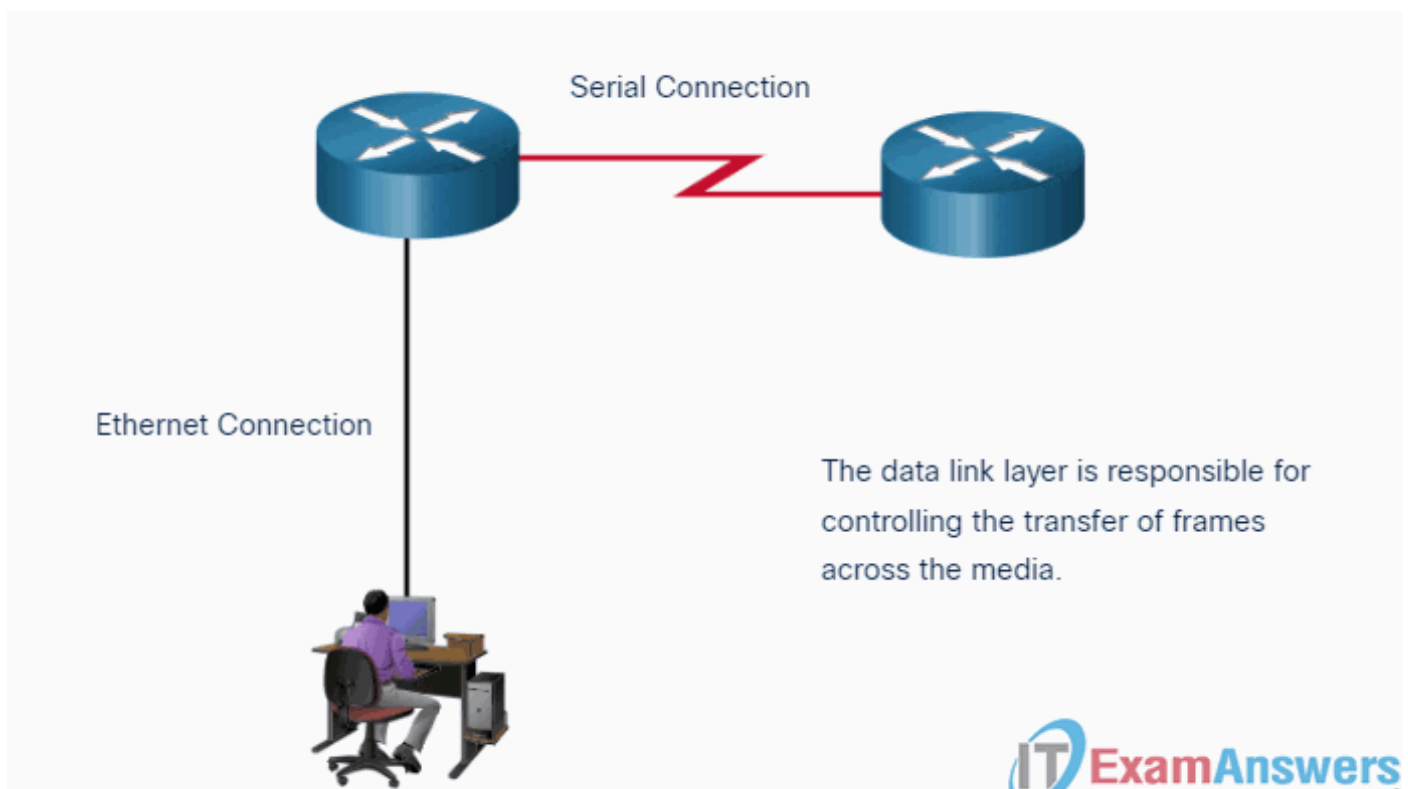
With serial links, the access method may only consist of a direct connection between only two devices, usually two routers. Therefore, they do not require the techniques employed by the IEEE 802 MAC sublayer.

Router interfaces encapsulate the packet into the appropriate frame. A suitable media access control method is used to access each link. In any given exchange of network layer packets, there may be numerous data link layers and media transitions.

At each hop along the path, a router performs the following Layer 2 functions:

- Accepts a frame from a medium
- De-encapsulates the frame
- Re-encapsulates the packet into a new frame
- Forwards the new frame appropriate to the medium of that segment of the physical network

Press play to view the animation. The router in the figure has an Ethernet interface to connect to the LAN and a serial interface to connect to the WAN. As the router processes frames, it will use data link layer services to receive the frame from one medium, de-encapsulate it to the Layer 3 PDU, re-encapsulate the PDU into a new frame, and place the frame on the medium of the next link of the network.



4. Data Link Layer Standards

Data link layer protocols are generally not defined by Request for Comments (RFCs), unlike the protocols of the upper layers of the TCP/IP suite.

The Internet Engineering Task Force (IETF) maintains the functional protocols and services for the TCP/IP protocol suite in the upper layers, but they do not define the functions and operation of the TCP/IP network access layer.

Engineering organizations that define open standards and protocols that apply to the network access layer (i.e., the OSI physical and data link layers) include the following:

- Institute of Electrical and Electronics Engineers (IEEE)
- International Telecommunication Union (ITU)
- International Organization for Standardization (ISO)
- American National Standards Institute (ANSI)

The logos for these organizations are shown in the figure.

4A. Engineering Organization Logos



5. Check Your Understanding - Purpose of the Data Link Layer

Check your understanding of the data link layer by choosing the BEST answer to the following questions.

Question 1: What is another name for the OSI data link layer?

- (a) Layer 1
- (b) Layer 2
- (c) Layer 3
- (d) Layer 6

Answer: (b) - The data link layer is Layer 2 of the OSI model.

Question 2: The IEEE 802 LAN/MAN data link layer consists of which two sublayers? (Choose two.)

- (a) Network Control Protocol
- (b) Logical Link Control
- (c) Media Access Control
- (d) Link Control Protocol

Answer: (b & c) - The data link layer consists of two sublayers. These are Logical Link Control (LLC) and Media Access Control (MAC)

Question 3: What is the responsibility of the MAC sublayer?

- (a) Adds Layer 3 addresses to the frame
- (b) Communicates with the network layer (Layer 3)
- (c) Provides the method to get the frame on and off the media
- (d) Transmits the bits on the media

Answer: (c) - The MAC sublayer of the data link layer is responsible for getting frames on and off the media.

Question 4: What Layer 2 function does a router perform? (Choose three.)

- (a) Accepts a frame from a medium
- (b) De-encapsulates the frame
- (c) Refers to its Layer 3 routing table for a matching destination network
- (d) Re-encapsulates the packet into a new frame

Answer: (a & b & d) - Routers perform four functions at Layer 2. They accept a frame from the media, de-encapsulate the packet from a frame, re-encapsulate the packet into a new frame, and forwards the new frame appropriate to the medium of that segment of the physical network.

Question 5: The media access control method used depends on which two criteria?

- (a) Layer 3 IP protocol
- (b) Media sharing
- (c) Topology
- (d) Transport layer protocol
- (e) Type of data

Answer: (b & c) - The two criteria for determining the media access control method used are the type of media sharing involved and the topology.

Question 6: Which organization defines standards for the network access layer (i.e., the OSI physical and data link layers)?

- (a) Cisco
- (b) IANA
- (c) IEEE
- (d) IETF

Answer: (c) - The IEEE defines standards for the TCP/IP network access layer, which are the OSI physical and data link layers.

Topologies

1. Physical and Logical Topologies

As you learned in the previous topic, the data link layer prepares network data for the physical network. It must know the logical topology of a network in order to be able to determine what is needed to transfer frames from one device to another. This topic explains the ways in which the data link layer works with different logical network topologies.

The topology of a network is the arrangement, or the relationship, of the network devices and the interconnections between them.

There are two types of topologies used when describing LAN and WAN networks:

- **Physical topology** – Identifies the physical connections and how end devices and intermediary devices (i.e., routers, switches, and wireless access points) are interconnected. The topology may also include specific device locations such as room number and location on the equipment rack. Physical topologies are usually point-to-point or star.
- **Logical topology** - Refers to the way a network transfers frames from one node to the next. This topology identifies virtual connections using device interfaces and Layer 3 IP addressing schemes.

The data link layer "sees" the logical topology of a network when controlling data access to the media. It is the logical topology that influences the type of network framing and media access control used.

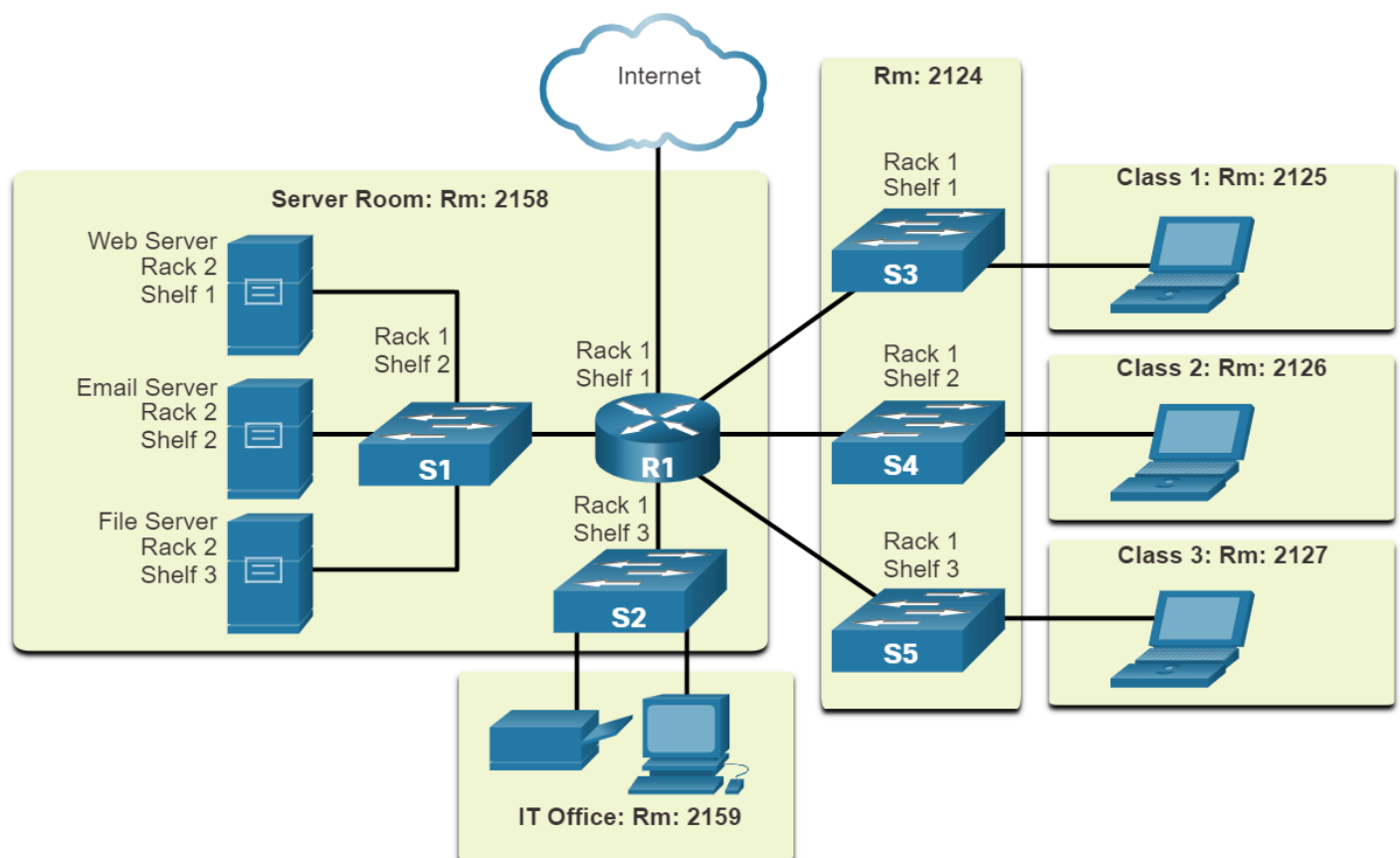
1A. Physical Topology

The figure displays a sample **physical** topology for a small sample network.

The physical network topology shows six rooms, each highlighted in a light yellow box, with various networking devices and cabling. On the left side is the server room labeled room 2158. It contains a router labeled R1 mounted on rack 1 shelf 1 with six cable connections. A cable at the top connects to a cloud labeled Internet. A cable to the left connects to a switch labeled S1 mounted on rack 1 shelf 2. S1 is connected to three servers: a web server mounted on rack 2 shelf 1, an email server mounted on rack 2 shelf 2, and a file server mounted on rack 2 shelf 3.

A cable connected to the bottom of R1 connects to a switch labeled S2 mounted on rack 1 shelf 3. S2 has two connections leading to a printer and a PC in the IT office labeled room 2159. R1 has three cables to the right connected to three switches located in room 2124. The top switch is labeled S3 and mounted on rack 1 shelf 1. The middle switch is labeled S4 and mounted on rack 1 shelf 2.

The bottom switch is labeled S5 and mounted on rack 1 shelf 3. S3 has a cable on the left connected to a laptop in a room labeled class 1 room 2125. S4 has a cable on the left connected to a laptop in a room labeled class 2 room 2126. S5 has a cable on the left connected to a laptop in a room labeled class 3 room 2127.



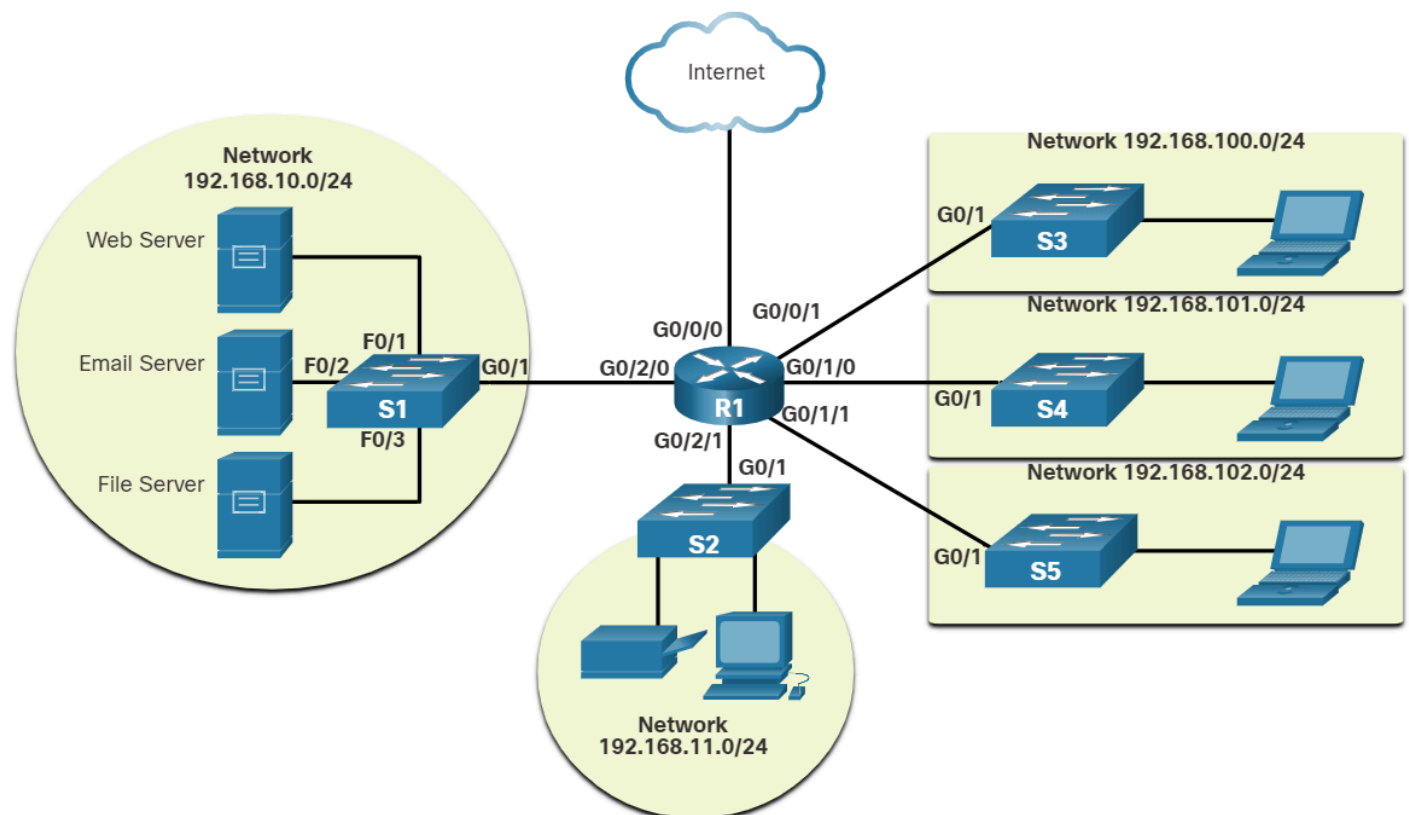
1B. Logical Topology

The next figure displays a sample **logical** topology for the same network.

The logical network topology shows devices, port labels, and the network addressing scheme. In the middle of the picture is a router labeled R1. A port labeled G0/0/0 connects to a cloud at the top labeled Internet. A port labeled G0/2/0 connects at the left to a switch labeled S1 at port G0/1. S1 is connected to three servers. S1 and the servers are highlighted in a light yellow circle with the network 192.168.10.0/24 written at the top. Port F0/1 on S1 connects to a web server. Port F0/2 on S1 connects to an email server. Port F0/3 on S1 connects to a file server.

Port G0/0/1 on R1 connects at the bottom to a switch labeled S2. S2 connects to a printer and a PC, all of which are highlighted in a light yellow circle with the network 192.168.11.0/24 written on the bottom. At the right of R1 are three additional connections, each connecting to a switch at port G0/1 which is then connected to a laptop at port F0/1. Each switch and laptop are highlighted in yellow and the network address shown.

Port G0/0/1 of R1 connects at the top to a switch labeled S3 on network 192.168.100.0. Port G0/1/0 of R1 connects in the middle to a switch labeled S4 on network 192.169.101.0. Port G0/1/1 on R1 connects at the bottom to a switch labeled S5 on network 192.168.102.0. R1 connects to the Internet on interface G0/0/0.



2. WAN Topologies

The figures illustrate how WANs are commonly interconnected using three common physical WAN topologies.

Note: A hybrid is a variation or combination of any topologies. For example, a partial mesh is a hybrid topology in which some, but not all, end devices are interconnected.

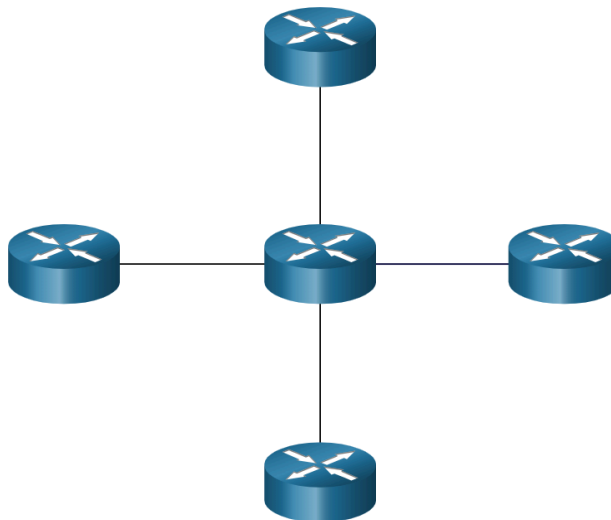
2A. Point-to-Point

This is the simplest and most common WAN topology. It consists of a permanent link between two endpoints.



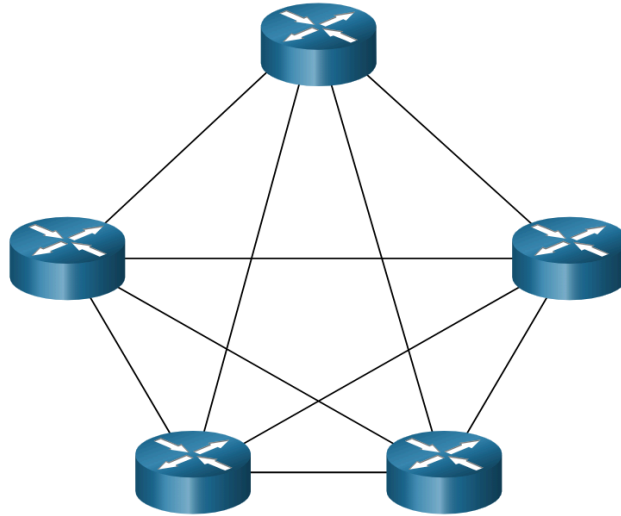
2B. Hub and Spoke

This is a WAN version of the star topology in which a central site interconnects branch sites through the use of point-to-point links. Branch sites cannot exchange data with other branch sites without going through the central site.



2C. Mesh

This topology provides high availability but requires that every end system is 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.



3. Point-to-Point WAN 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, when using a serial communications protocol such as Point-to-Point Protocol (PPP), 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 node places the frames on the media at one end and those frames are taken from the media by the node at the other end of the point-to-point circuit.

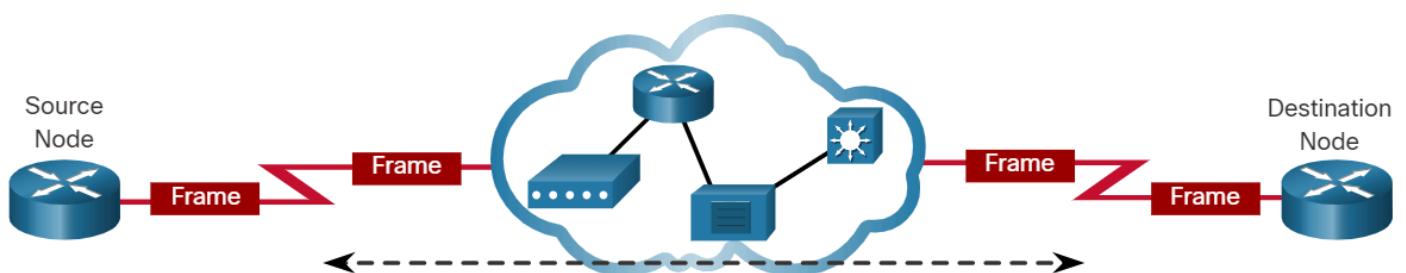
Point-to-point topologies are limited to two nodes.



Note: A point-to-point connection over Ethernet requires the device to determine if the incoming frame is destined for this node.

A source and destination node may be indirectly connected to each other over some geographical distance using multiple intermediary devices. However, the use of physical devices in the network does not affect the logical topology, as illustrated in the figure.

In the figure, adding intermediary physical connections may not change the logical topology. The logical point-to-point connection is the same.



4. LAN Topologies

In multi-access LANs, end devices (i.e., nodes) are interconnected using star or extended star topologies, as shown in the figure. In this type of topology, end devices are connected to a central intermediary device, in this case, an Ethernet switch.

An **extended star** extends this topology by interconnecting multiple Ethernet switches. The star and extended topologies are easy to install, very scalable (easy to add and remove end devices), and easy to troubleshoot. Early star topologies interconnected end devices using Ethernet hubs.

At times there may be only two devices connected on the Ethernet LAN. An example is two interconnected routers. This would be an example of Ethernet used on a point-to-point topology.

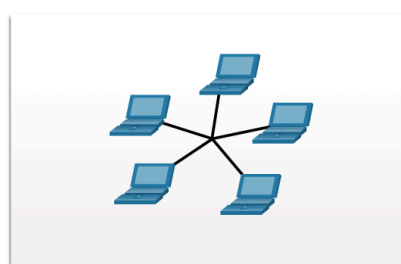
4A. Legacy LAN Topologies

Early Ethernet and legacy Token Ring LAN technologies included two other types of topologies:

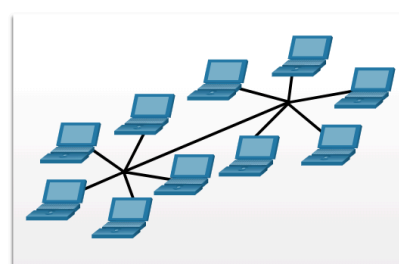
- **Bus** - All end systems are chained to each other and terminated in some form on each end. Infrastructure devices such as switches are not required to interconnect the end devices. Legacy Ethernet networks were often bus topologies using coax cables because it was inexpensive and easy to set up.
- **Ring** - End systems are connected to their respective neighbour forming a ring. The ring does not need to be terminated, unlike in the bus topology. Legacy Fiber Distributed Data Interface (FDDI) and Token Ring networks used ring topologies.

The figures illustrate how end devices are interconnected on LANs. It is common for a straight line in networking graphics to represent an Ethernet LAN including a simple star and an extended star.

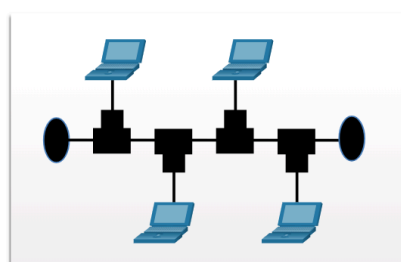
Physical Topologies



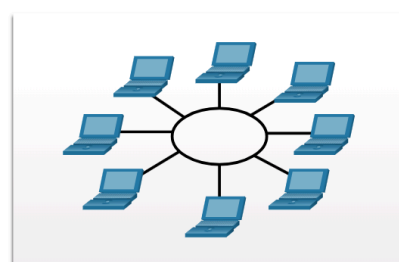
Star Topology



Extended Star Topology



Bus Topology



Ring Topology

5. Half and Full Duplex Communication

Understanding duplex communication is important when discussing LAN topologies because it refers to the direction of data transmission between two devices. There are two common modes of duplex.

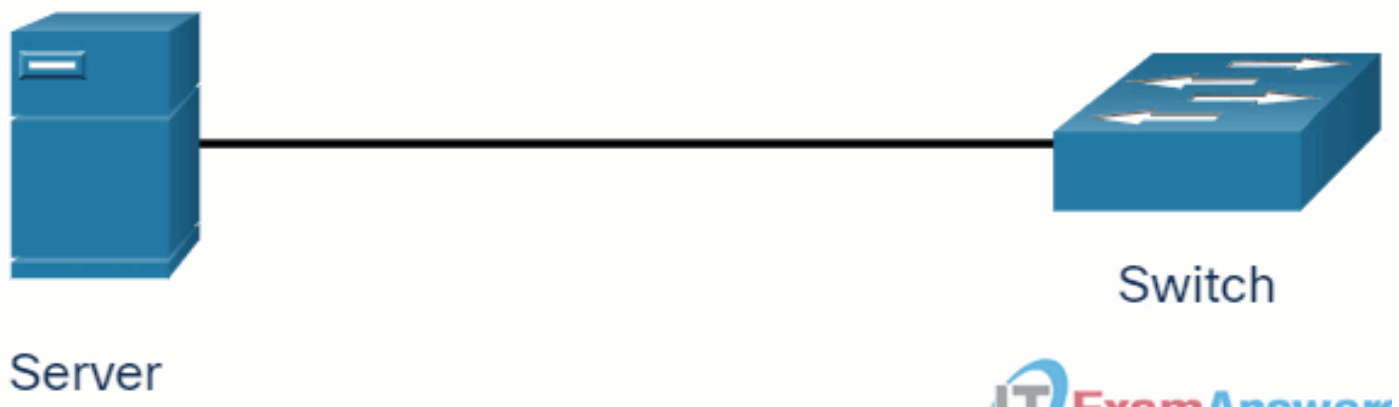
5A. Half-Duplex Communication

Both devices can transmit and receive on the media but cannot do so simultaneously. WLANs and legacy bus topologies with Ethernet hubs use the half-duplex mode. Half-duplex allows only one device to send or receive at a time on the shared medium. Click play in the figure to see the animation showing half-duplex communication.



5B. Full-Duplex Communication

Both devices can simultaneously transmit and receive on the shared media. The data link layer assumes that the media is available for transmission for both nodes at any time. Ethernet switches operate in full-duplex mode by default, but they can operate in half-duplex if connecting to a device such as an Ethernet hub. Click play in the figure to see the animation showing full-duplex communication.



In summary, half-duplex communications restrict the exchange of data to one direction at a time. Full-duplex allows the sending and receiving of data to happen simultaneously.

It is important that two interconnected interfaces, such as a host NIC and an interface on an Ethernet switch, operate using the same duplex mode. Otherwise, there will be a duplex mismatch creating inefficiency and latency on the link.

6. Access Control Methods

Ethernet LANs and WLANs are examples of multiaccess networks. A multiaccess network is a network that can have two or more end devices attempting to access the network simultaneously.

Some multiaccess networks require rules to govern how devices share the physical media. There are two basic access control methods for shared media:

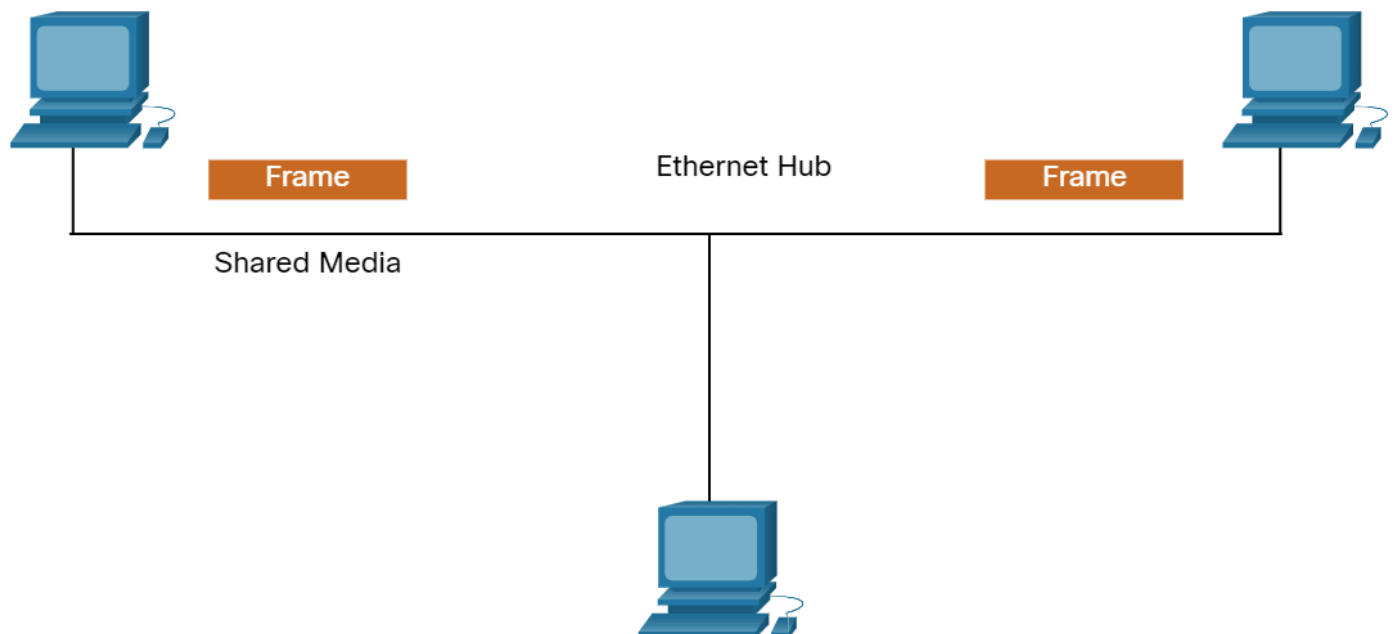
- **Contention-based access**
- **Controlled access**

6A. Contention-based access

In contention-based multiaccess networks, **all nodes are operating in half-duplex, competing for the use of the medium**. However, only one device can send at a time.

Therefore, there is a process if more than one device transmits at the same time. **Examples of contention-based** access methods include the following:

- **Carrier sense multiple access with collision detection (CSMA/CD) used on legacy bus-topology Ethernet LANs.**
- **Carrier sense multiple access with collision avoidance (CSMA/CA) used on Wireless LANs.**



6B. Controlled Access

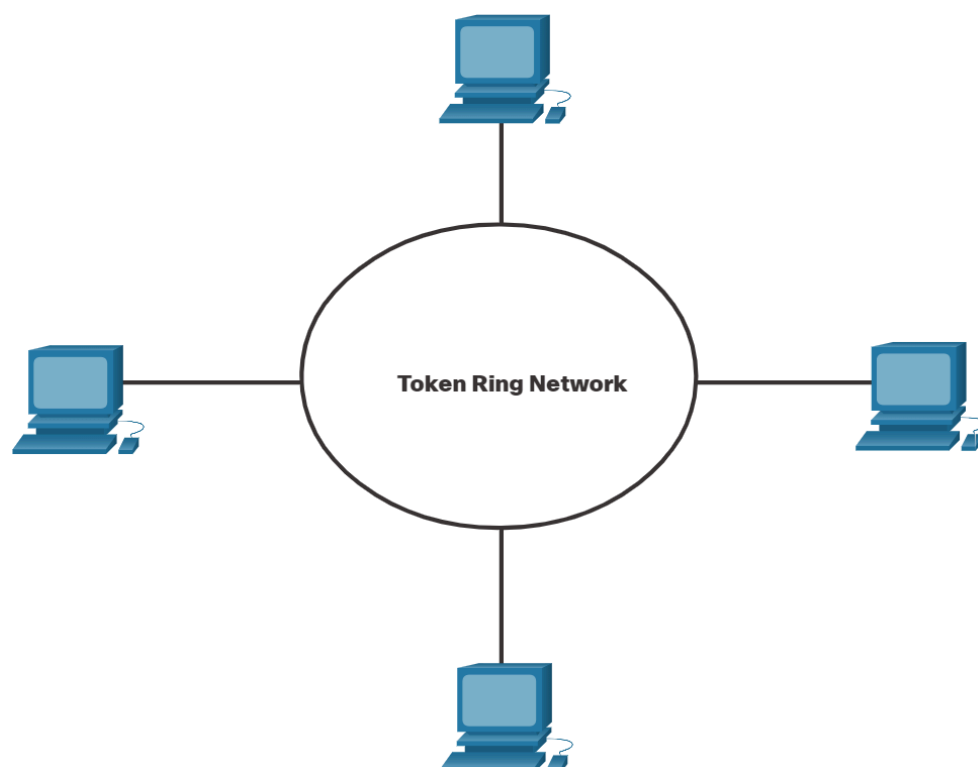
In a controlled-based multiaccess network, each node has its own time to use the medium. These deterministic types of legacy networks are inefficient because a device must wait its turn to access the medium.

Examples of multiaccess networks that use controlled access include the following:

- Legacy Token Ring
- Legacy ARCNET

Each node must wait for its turn to access the network medium.

Note: Today, Ethernet networks operate in full-duplex and do not require an access method.



7. Contention-Based Access - CSMA/CD

Examples of contention-based access networks include the following:

- Wireless LAN (uses CSMA/CA)
- Legacy bus-topology Ethernet LAN (uses CSMA/CD)
- Legacy Ethernet LAN using a hub (uses CSMA/CD)

These networks operate in half-duplex mode, meaning only one device can send or receive at a time. This requires a process to govern when a device can send and what happens when multiple devices send at the same time.

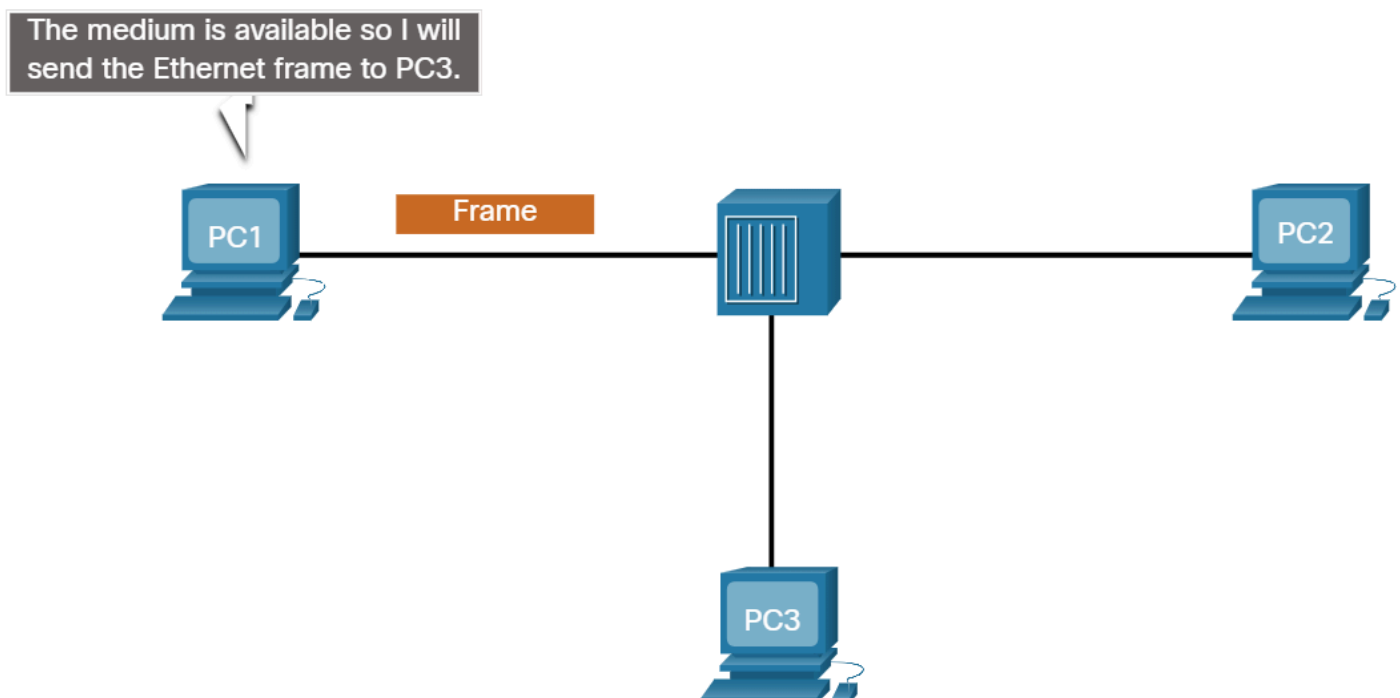
If two devices transmit at the same time, a collision will occur. For legacy Ethernet LANs, both devices will detect the collision on the network. This is the collision detection (CD) portion of CSMA/CD. The NIC compares data transmitted with data received, or by recognizing that the signal amplitude is higher than normal on the media.

The data sent by both devices will be corrupted and will need to be resent.

7A. PC1 Sends a Frame

PC1 has an Ethernet frame to send to PC3. The PC1 NIC needs to determine if any device is transmitting on the medium. If it does not detect a carrier signal (in other words, it is not receiving transmissions from another device), it will assume the network is available to send.

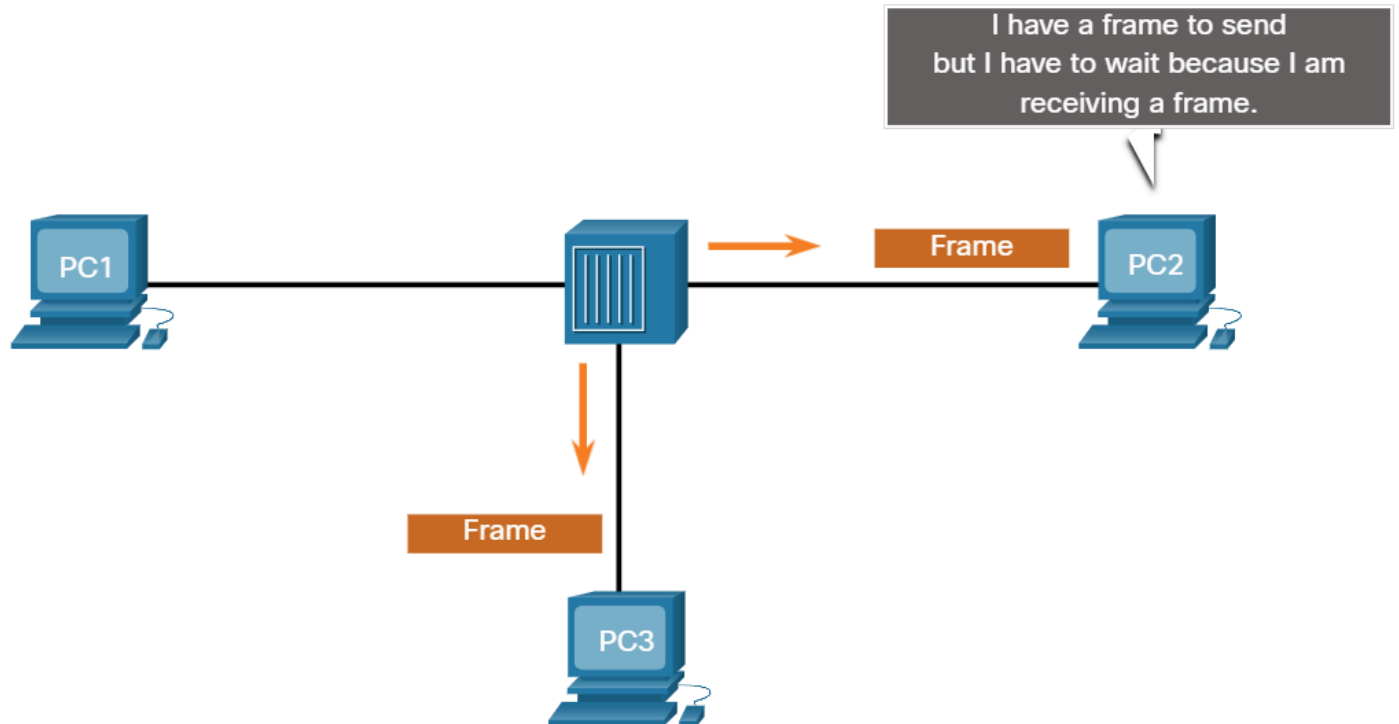
The PC1 NIC sends the Ethernet Frame when the medium is available, as shown in the figure.



7B. The Hub Receives the Frame

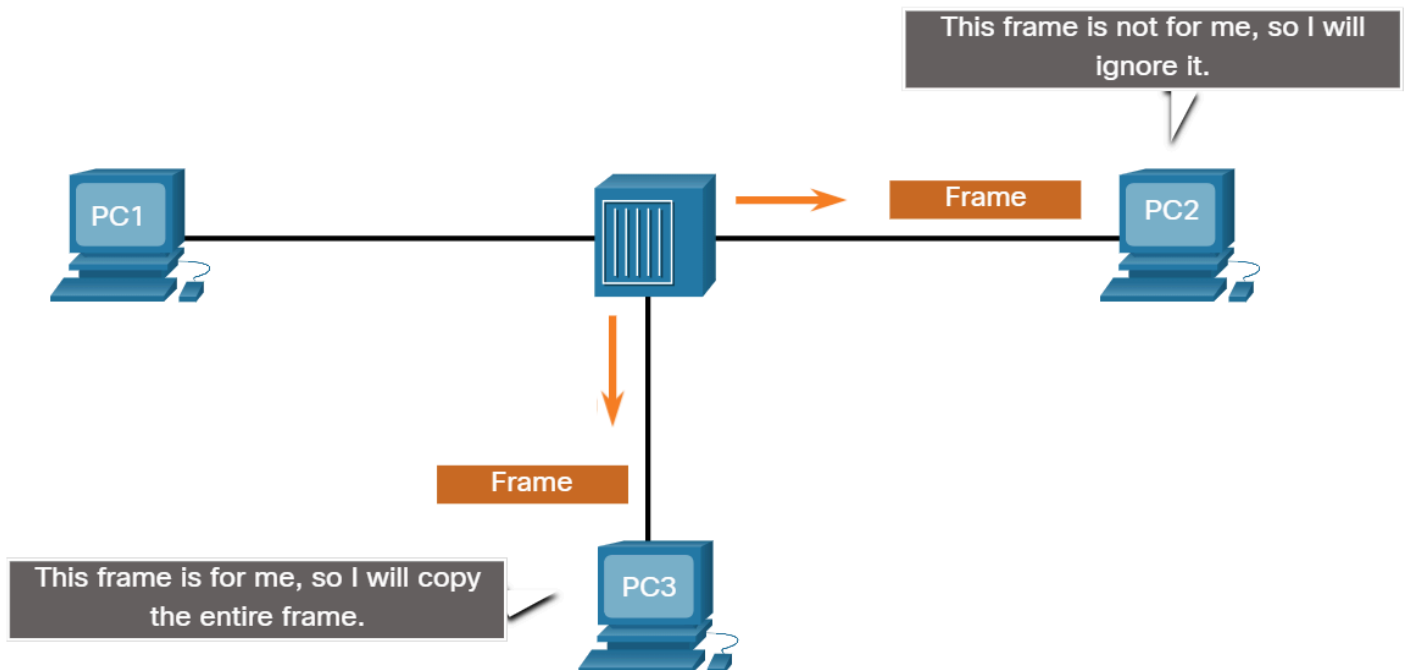
The Ethernet hub receives and sends the frame. An Ethernet hub is also known as a multiport repeater. Any bits received on an incoming port are regenerated and sent out to all other ports, as shown in the figure.

If another device, such as PC2, wants to transmit but is currently receiving a frame, it must wait until the channel is clear, as shown in the figure.



7C. The Hub Sends the Frame

All devices attached to the hub will receive the frame. However, because the frame has a destination data link address for PC3, only that device will accept and copy in the entire frame. All other device NICs will ignore the frame, as shown in the figure.



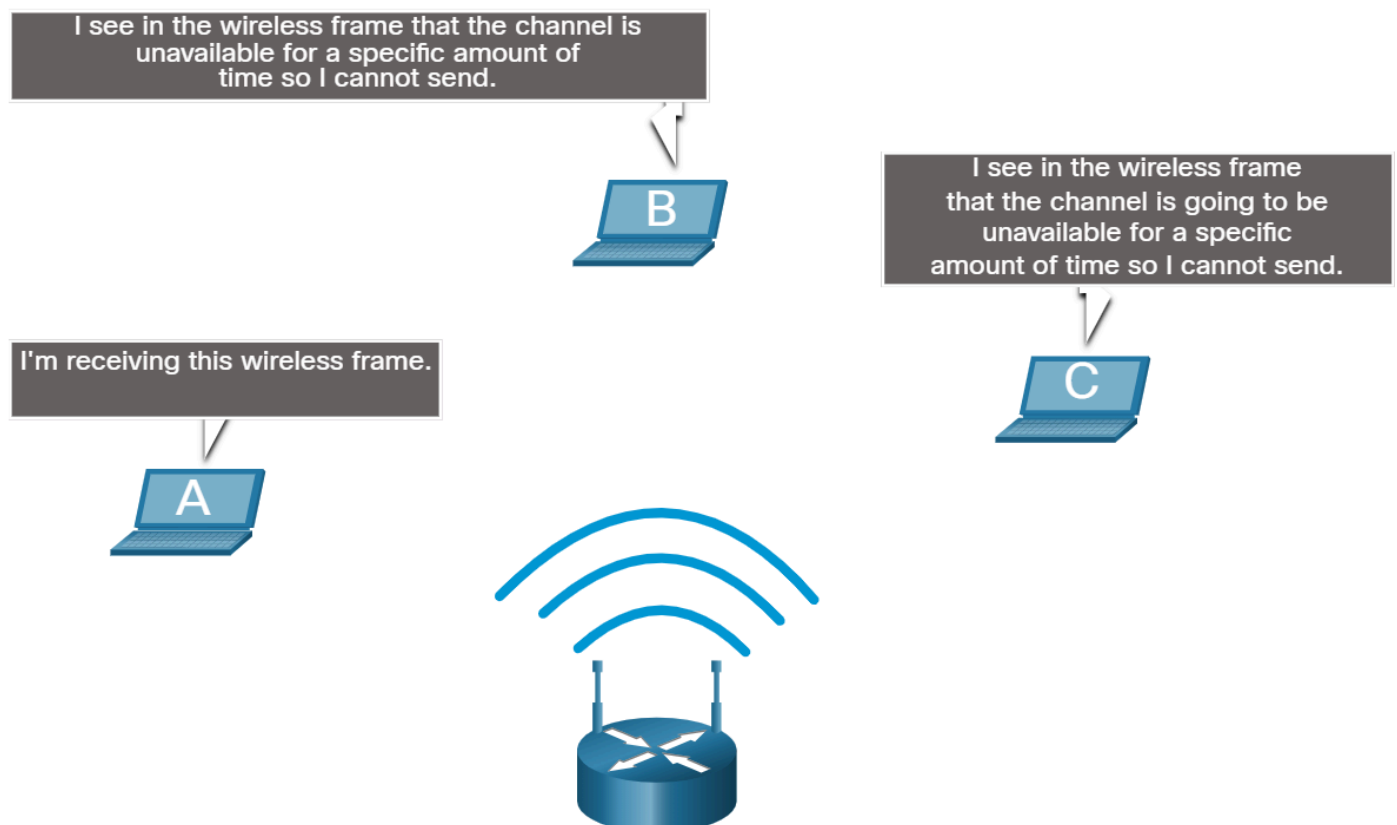
8. Contention-Based Access - CSMA/CA

Another form of CSMA used by IEEE 802.11 WLANs is carrier sense multiple access/collision avoidance (CSMA/CA).

CSMA/CA uses a method similar to CSMA/CD to detect if the media is clear. CSMA/CA uses additional techniques. In wireless environments it may not be possible for a device to detect a collision. CSMA/CA does not detect collisions but attempts to avoid them by waiting before transmitting. Each device that transmits includes the time duration that it needs for the transmission. All other wireless devices receive this information and know how long the medium will be unavailable.

In the figure, if host A is receiving a wireless frame from the access point, hosts B, and C will also see the frame and how long the medium will be unavailable.

The image shows a wireless network consisting of an access point and three laptops, laptops A, B, and C. Laptop A has a text box that reads I'm receiving this wireless frame. Laptop B has a text box that reads I see in the wireless frame that the channel is unavailable for a specific amount of time so I cannot send. Laptop C has a text box that reads I see in the wireless frame that the channel is going to be unavailable for a specific amount of time so I cannot send.



After a wireless device sends an 802.11 frame, the receiver returns an acknowledgement so that the sender knows the frame arrived.

Whether it is an Ethernet LAN using hubs, or a WLAN, contention-based systems do not scale well under heavy media use.

Note: Ethernet LANs using switches do not use a contention-based system because the switch and the host NIC operate in full-duplex mode.

9. Check Your Understanding - Topologies

Check your understanding of topologies by choosing the BEST answer to the following questions.

Question 1: Which topology displays networking device layer IP addresses?

- (a) aerial topology
- (b) IP address topology
- (c) logical topology
- (d) physical topology

Answer: (c) - The logical topology shows the IP addresses assigned to device interfaces.

Question 2: What kind of network would use point-to-point, hub and spoke, or mesh topologies?

- (a) PAN
- (b) LAN
- (c) WLAN
- (d) WAN

Answer: (d) - Wide Area Networks (WANs) come in many topologies, including point-to-point, hub-and-spoke, and mesh.

Question 3: Which LAN topology is a hybrid topology?

- (a) bus
- (b) extended star
- (c) ring
- (d) star

Answer: (b) - The extended star topology is considered a hybrid topology because it combines multiple star topologies.

Question 4: Which duplex communication method is used in WLANs?

- (a) full-duplex
- (b) half-duplex
- (c) simplex

Answer: (b) - Wireless LANs (WLANs) only support half-duplex because only one device can access the media at a time.

Question 5: Which media access control method is used in legacy Ethernet LANs?

- (a) carrier sense multiple access/collision annoyance
- (b) carrier sense multiple access/collision avoidance
- (c) carrier sense multiple access/collision destruction
- (d) carrier sense multiple access/collision detection

Answer: (d) - Carrier sense multiple access /collision detection (CSMA/CD) is the media access control method used in legacy Ethernet LANs.

Question 6: Which LAN topology has all end systems chained to each other and terminated at the end?

- (a) extended star
- (b) ring
- (c) bus
- (d) star

Answer: (c) - A bus has all end systems chained to each other and terminated at the end.

Question 7: What kind of physical networks are commonly used in WANs? (Choose three.)

- (a) hub and spoke
- (b) bus
- (c) point-to-point
- (d) ring
- (e) extended star
- (f) mesh

Answer: (a & c & f) - Wide Area Networks (WANs) commonly include point-to-point, hub-and-spoke, and mesh physical topologies.

Data Link Frame

1. The Frame

This topic discusses in detail what happens to the data link frame as it moves through a network. The information appended to a frame is determined by the protocol being used.

The data link layer prepares the encapsulated data (usually an IPv4 or IPv6 packet) for transport across the local media by encapsulating it with a header and a trailer to create a frame.

The data link protocol is responsible for NIC-to-NIC communications within the same network. Although many different data link layer protocols describe data link layer frames, each frame type has three basic parts:

- Header
- Data
- Trailer

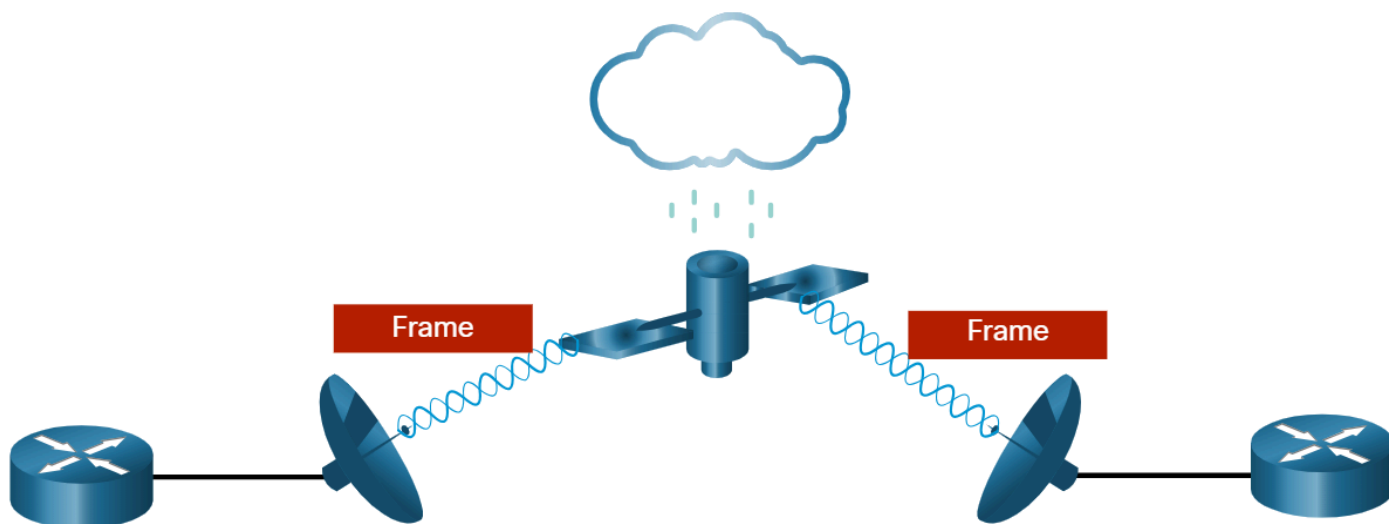
Unlike other encapsulation protocols, the data link layer appends information in the form of a trailer at the end of the frame.

All data link layer protocols encapsulate the data within the data field of the frame. However, the structure of the frame and the fields contained in the header and trailer vary according to the protocol.

No one frame structure meets the needs of all data transportation across all types of media. Depending on the environment, the amount of control information needed in the frame varies to match the access control requirements of the media and logical topology. For example, a WLAN frame must include procedures for collision avoidance and therefore requires additional control information when compared to an Ethernet frame.

As shown in the figure, in a fragile environment, more controls are needed to ensure delivery. The header and trailer fields are larger as more control information is needed.

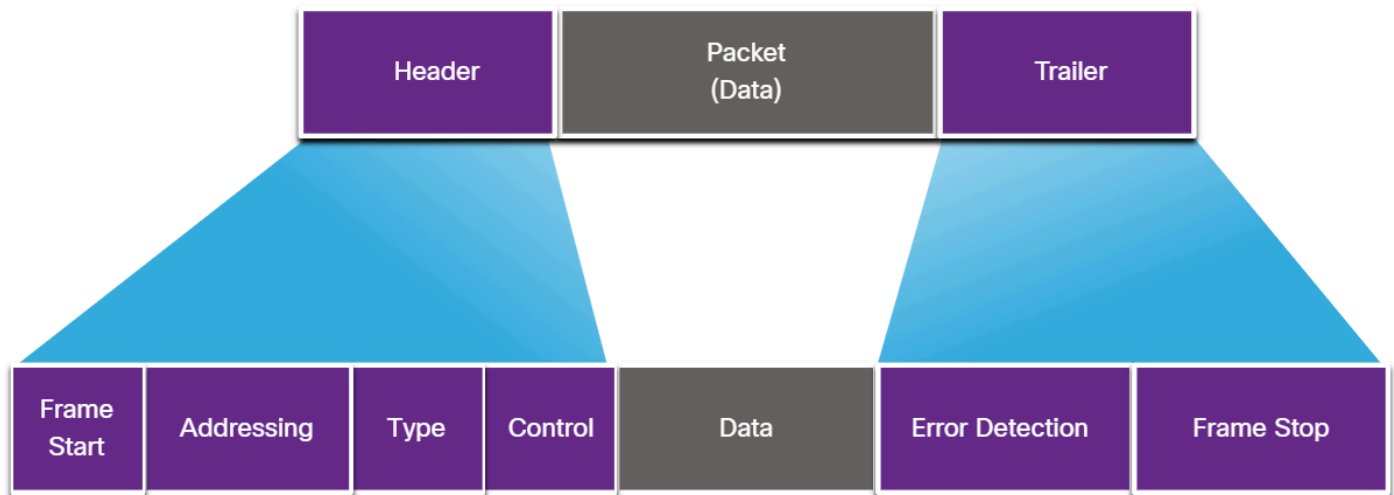
Greater effort is needed to ensure delivery. This means higher overhead and slower transmission rates.



2. Frame Fields

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 is recognized by nodes and decoded into packets at the destination.

The generic frame fields are shown in the figure. Not all protocols include all these fields. The standards for a specific data link protocol define the actual frame format.



Frame fields include the following:

- **Frame start and stop** indicator flags – Used to identify the beginning and end limits of the frame.
- **Addressing** – Indicates the source and destination nodes on the media.
- **Type** – Identifies the Layer 3 protocol in the data field.
- **Control** – Identifies special flow control services such as quality of service (QoS). QoS gives forwarding priority to certain types of messages. For example, voice over IP (VoIP) frames normally receive priority because they are sensitive to delay.
- **Data** – Contains the frame payload (i.e., packet header, segment header, and the data).
- **Error Detection** – Included after the data to form the trailer. Used for determine transmission errors.

Data link layer protocols add a trailer to the end of each frame. In a process called error detection, the trailer determines if the frame arrived without error. It places a logical or mathematical summary of the bits that comprise the frame in the trailer.

The data link layer adds error detection because the signals on the media could be subject to interference, distortion, or loss that would substantially change the bit values that those signals represent.

A transmitting node creates a logical summary of the contents of the frame, known as the cyclic redundancy check (CRC) value. This value is placed in the frame check sequence (FCS) field to represent the contents of the frame. In the Ethernet trailer, the FCS provides a method for the receiving node to determine whether the frame experienced transmission errors.

3. Layer 2 Addresses

The data link layer provides the addressing used in transporting a frame across a shared local media. **Device addresses at this layer are referred to as physical addresses. Data link layer addressing is contained within the frame header and specifies the frame destination node on the local network.**

It is typically at the beginning of the frame, so the NIC can quickly determine if it matches its own Layer 2 address before accepting the rest of the frame. The frame header may also contain the source address of the frame.

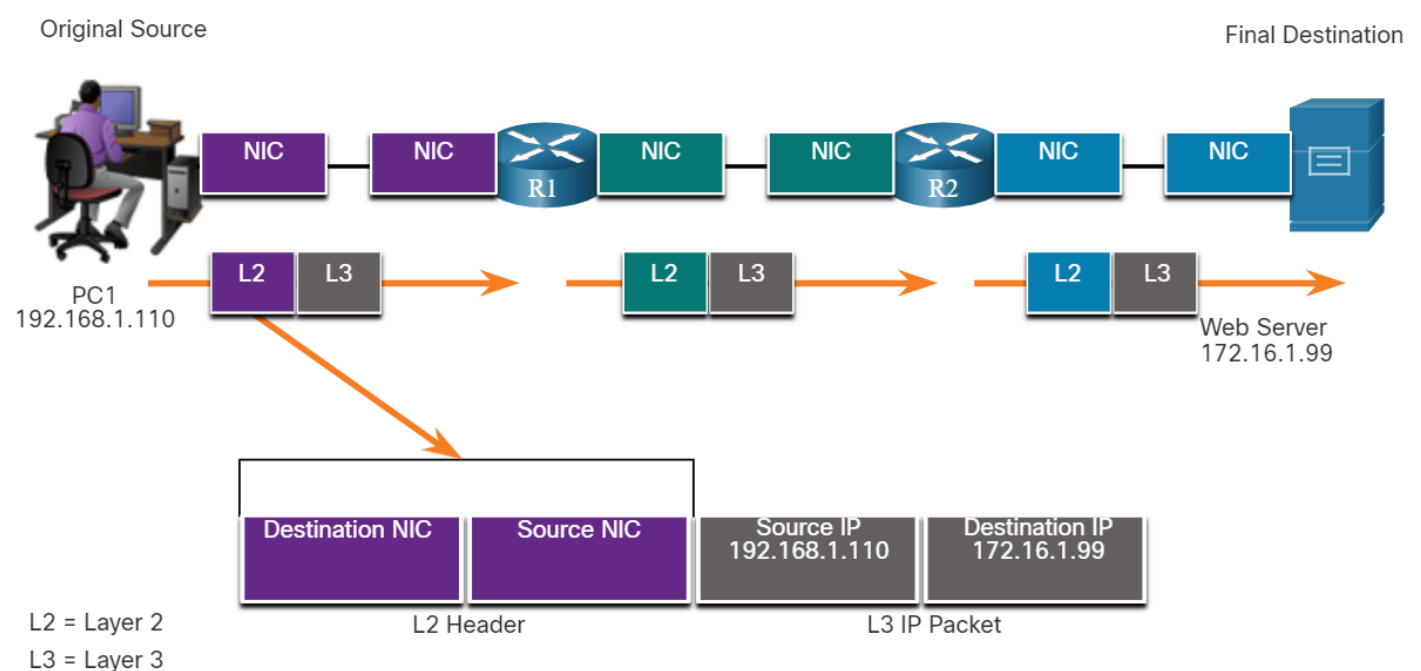
Unlike Layer 3 logical addresses, which are hierarchical, physical addresses do not indicate on what network the device is located. Rather, the physical address is unique to the specific device. **A device will still function with the same Layer 2 physical address even if the device moves to another network or subnet.** Therefore, Layer 2 addresses are only used to connect devices within the same shared media, on the same IP network.

The figures illustrate the function of the Layer 2 and Layer 3 addresses. As the IP packet travels from host to router, router to router, and finally router to host, at each point along the way the IP packet is encapsulated in a new data link frame.

Each data link frame contains the source data link address of the NIC sending the frame, and the destination data link address of the NIC receiving the frame.

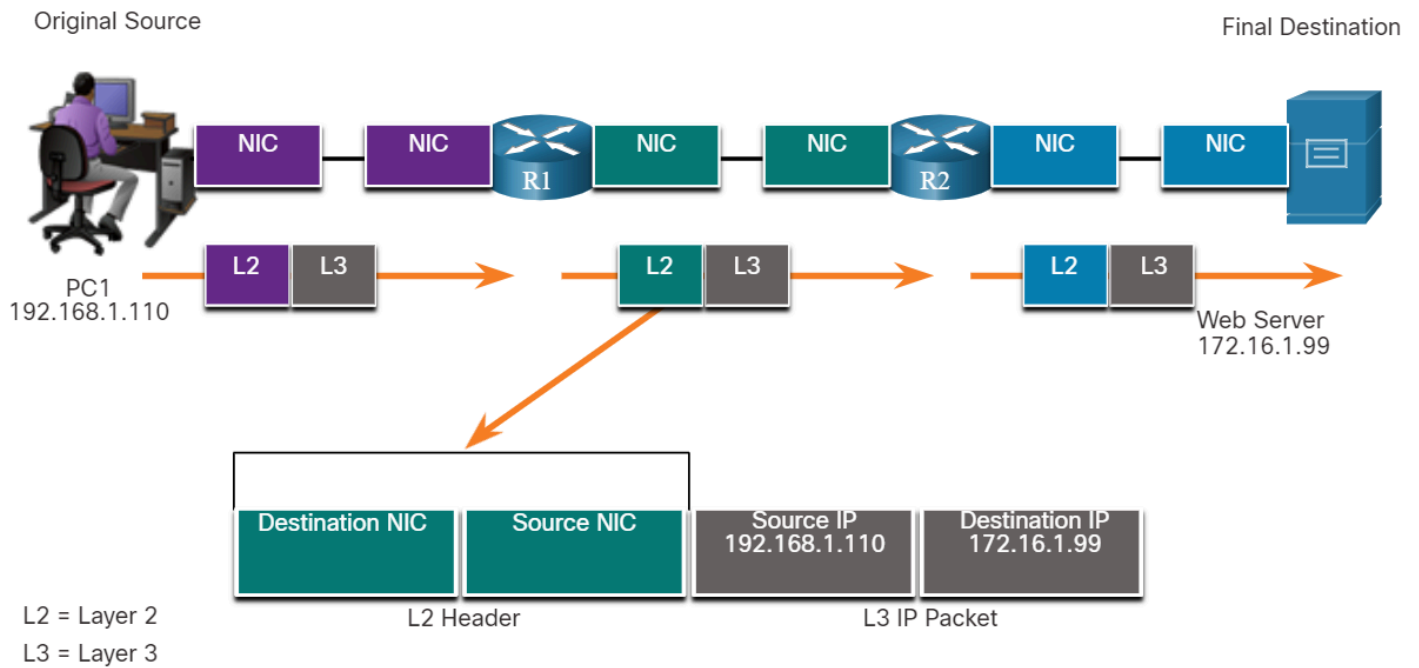
3A. Host-to-Router

The source host encapsulates the Layer 3 IP packet in a Layer 2 frame. In the frame header, the host adds its Layer 2 address as the source and the Layer 2 address for R1 as the destination.



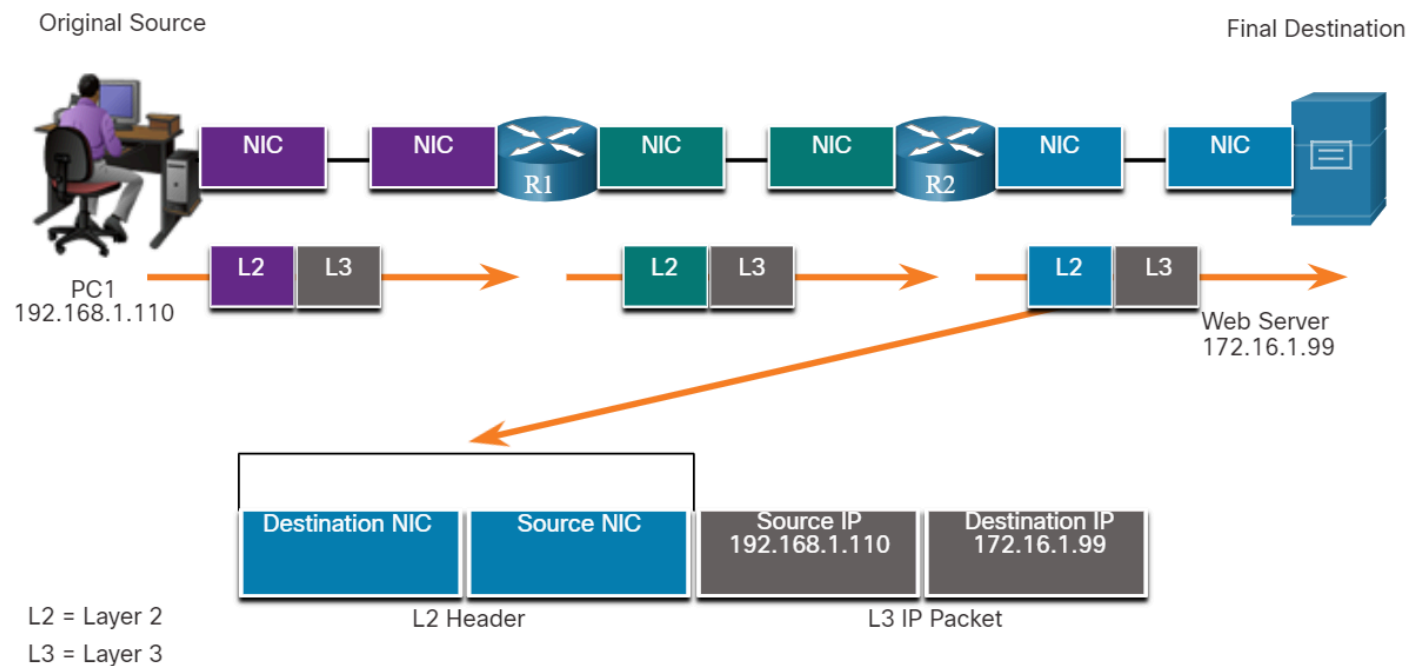
3B. Router-to-Router

R1 encapsulates the Layer 3 IP packet in a new Layer 2 frame. In the frame header, R1 adds its Layer 2 address as the source and the Layer 2 address for R2 as the destination.



3C. Router-to-Host

R2 encapsulates the Layer 3 IP packet in a new Layer 2 frame. In the frame header, R2 adds its Layer 2 address as the source and the Layer 2 address for the server as the destination.



The data link layer address is only used for local delivery. Addresses at this layer have no meaning beyond the local network. Compare this to Layer 3, where addresses in the packet header are carried from the source host to the destination host, regardless of the number of network hops along the route.

If the data must pass onto another network segment, an intermediary device, such as a router, is necessary. The router must accept the frame based on the physical address and de-encapsulate the frame in order to examine the hierarchical address, which is the IP address. Using the IP address, the router can determine the network location of the destination device and the best path to reach it.

When it knows where to forward the packet, the router then creates a new frame for the packet, and the new frame is sent on to the next network segment toward its final destination.

4. LAN and WAN Frames

Ethernet protocols are used by wired LANs. Wireless communications fall under WLAN (IEEE 802.11) protocols. These protocols were designed for multiaccess networks.

WANs traditionally used other types of protocols for various types of point-to-point, hub-spoke, and full-mesh topologies. Some of the common WAN protocols over the years have included:

- Point-to-Point Protocol (PPP)
- High-Level Data Link Control (HDLC)
- Frame Relay
- Asynchronous Transfer Mode (ATM)
- X.25

These Layer 2 protocols are now being replaced in the WAN by Ethernet.

In a TCP/IP network, all OSI Layer 2 protocols work with IP at OSI Layer 3. However, the Layer 2 protocol used depends on the logical topology and the physical media.

Each protocol performs media access control for specified Layer 2 logical topologies. This means that a number of different network devices can act as nodes that operate at the data link layer when implementing these protocols. These devices include the NICs on computers as well as the interfaces on routers and Layer 2 switches.

The Layer 2 protocol that is used for a particular network topology is determined by the technology used to implement that topology. The technology used is determined by the size of the network, in terms of the number of hosts and the geographic scope, and the services to be provided over the network.

A LAN typically uses a high bandwidth technology capable of supporting large numbers of hosts. The relatively small geographic area of a LAN (a single building or a multi-building campus) and its high density of users make this technology cost-effective.

However, using a high bandwidth technology is usually not cost-effective for WANs that cover large geographic areas (cities or multiple cities, for example). The cost of the long-distance physical links and the technology used to carry the signals over those distances typically result in lower bandwidth capacity.

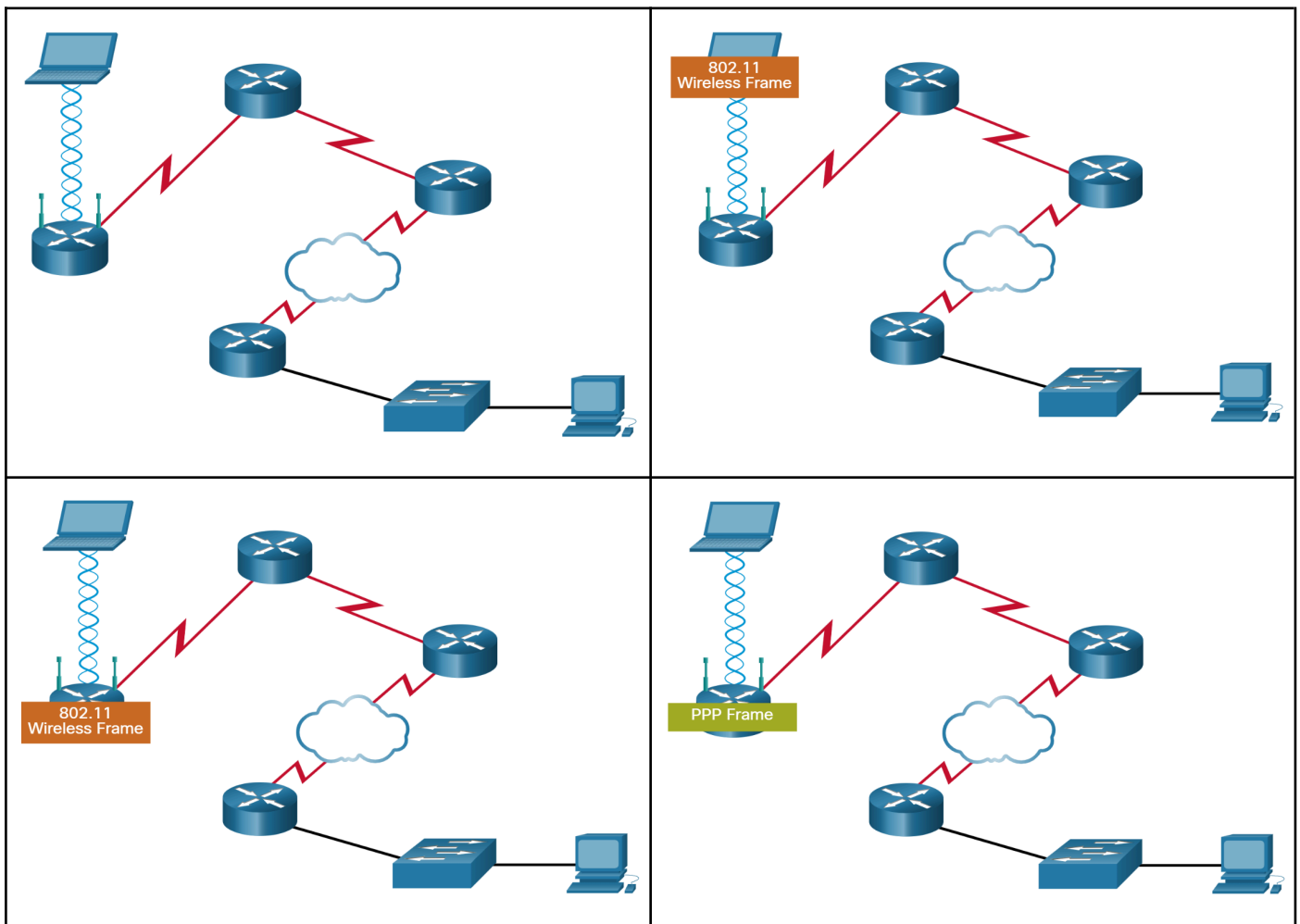
The difference in bandwidth normally results in the use of different protocols for LANs and WANs.

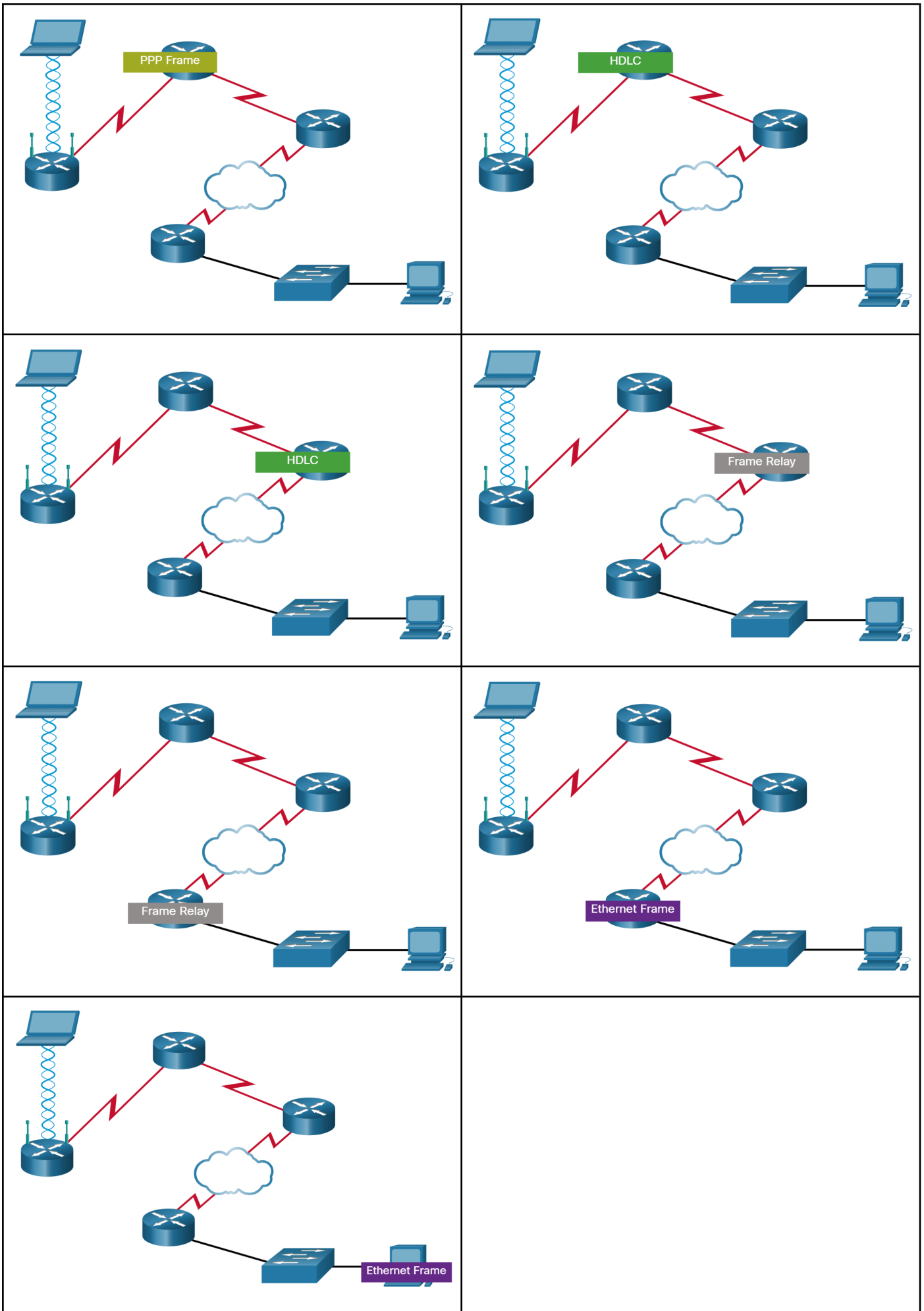
Data link layer protocols include: (The logical topology and physical media determine the data link protocol used)

- Ethernet
- 802.11 Wireless
- Point-to-Point Protocol (PPP)
- High-Level Data Link Control (HDLC)
- Frame Relay

Each protocol performs media access control for specified logical topologies.

Examples Of Layer 2 Protocols:





5. Check Your Understanding - Data Link Frame

Check your understanding of topologies by choosing the BEST answer to the following questions.

Question 1: What does the data link layer add to a Layer 3 packet to create a frame? (Choose two.)

- (a) flags
- (b) sequence number
- (c) header
- (d) trailer

Answer: (c & d) - The data link layer adds a header which contains the source and destination Layer 2 address and a trailer that contains a frame check sequence (FCS).

Question 2: What is the function of the last field in a data link layer frame?

- (a) To determine whether the frame experienced transmission errors
- (b) To identify special flow control services such as quality of service (QoS)
- (c) To identify the beginning and end limits of the frame
- (d) To identify the Layer 3 protocol in the data field

Answer: (a) - The last field in the data link frame is the frame check sequence (FCS) which is used to determine if the frame has experienced transmission errors.

Question 3: Which lists the Layer 2 and Layer 3 address fields in the correct order?

- (a) destination NIC address, source NIC address, source IP address, destination IP address
- (b) source NIC address, destination NIC address, source IP address, destination IP address
- (c) destination NIC address, source NIC address, destination IP address, source IP address
- (d) source NIC address, destination NIC address, destination IP address, source IP address

Answer: (a) - The correct order of Layer 2 and Layer 3 address fields is: destination NIC address, source NIC address, source IP address, destination IP address

Question 4: Which of the following are data link layer protocols? (Choose three)

- (a) 802.11
- (b) Ethernet
- (c) IP
- (d) PPP
- (e) UDP

Answer: (a & b & d) - 802.11, Ethernet, and PPP are Layer 2 protocols. IP is Layer 3 and UDP is Layer 4.

1. What Did I Learn In This Module?

1A. Purpose of the Data Link Layer

The data link layer of the OSI model (Layer 2) prepares network data for the physical network. The data link layer is responsible for network interface card (NIC) to network interface card communications. 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. The IEEE 802 LAN/MAN data link layer consists of the following two sublayers: LLC and MAC.

The MAC sublayer provides data encapsulation through frame delimiting, addressing, and error detection. Router interfaces encapsulate the packet into the appropriate frame. A suitable media access control method is used to access each link. Engineering organizations that define open standards and protocols that apply to the network access layer include IEEE, ITU, ISO, and ANSI.

1B. Topologies

The two types of topologies used in LAN and WAN networks are physical and logical. The data link layer "sees" the logical topology of a network when controlling data access to the media. The logical topology influences the type of network framing and media access control used. Three common types of physical WAN topologies are: point-to-point, hub and spoke, and mesh. Physical point-to-point topologies directly connect two end devices (nodes). Adding intermediate physical connections may not change the logical topology. In multi-access LANs, nodes are interconnected using star or extended star topologies.

In this type of topology, nodes are connected to a central intermediary device. Physical LAN topologies include star, extended star, bus, and ring. Half-duplex communications exchange data in one direction at a time. Full-duplex sends and receives data simultaneously. Two interconnected interfaces must use the same duplex mode or there will be a duplex mismatch creating inefficiency and latency on the link. Ethernet LANs and WLANs are examples of multi-access networks.

A multi-access network is a network that can have multiple nodes accessing the network simultaneously. Some multi-access networks require rules to govern how devices share the physical media. There are two basic access control methods for shared media: contention-based access and controlled access. In contention-based multi-access networks, all nodes are operating in half-duplex. There is a process if more than one device transmits at the same time. Examples of contention-based access methods include CSMA/CD for bus-topology Ethernet LANs and CSMA/CA for WLANs.

1C. Data Link Frame

The data link layer prepares the encapsulated data (usually an IPv4 or IPv6 packet) for transport across the local media by encapsulating it with a header and a trailer to create a frame. The data link protocol is responsible for NIC-to-NIC communications within the same network. There are many different data link layer protocols that describe data link layer frames, each frame type has three basic parts: header, data, and trailer. Unlike other encapsulation protocols, the data link layer appends information in the trailer.

There is no one frame structure that meets the needs of all data transportation across all types of media. Depending on the environment, the amount of control information needed in the frame varies to match the access control requirements of the media and logical topology. Frame fields include: frame start and stop indicator flags, addressing type, control, data, and error detection. The data link layer provides addressing used to transport a frame across shared local media. Device addresses at this layer are physical addresses.

Data link layer addressing is contained within the frame header and specifies the frame destination node on the local network. The data link layer address is only used for local delivery. In a TCP/IP network, all OSI Layer 2 protocols work with IP at OSI Layer 3. However, the Layer 2 protocol used depends on the logical topology and the physical media. Each protocol performs media access control for specified Layer 2 logical topologies.

The Layer 2 protocol that is used for a particular network topology is determined by the technology used to implement that topology. Data link layer protocols include: Ethernet, 802.11 Wireless, PPP, HDLC, and Frame Relay.

2. Module Quiz - Data Link Layer

Question 1: What identifier is used at the data link layer to uniquely identify an Ethernet device?

- (a) IP address
- (b) MAC address
- (c) sequence number
- (d) TCP port number
- (e) UDP port number

Answer: (b) - Ethernet frames are identified at the data link layer by their MAC addresses, which are unique to each NIC. IP addresses are used at the network layer, and TCP and UDP port numbers are used at the transport layer. Sequence numbers are fields in TCP headers.

Question 2: What attribute of a NIC would place it at the data link layer of the OSI model?

- (a) attached Ethernet cable
- (b) IP address
- (c) MAC address
- (d) RJ-45 port
- (e) TCP/IP protocol stack

Answer: (c) - The data link layer describes media access and physical addressing. The encoding of a MAC address on a NIC places it at that layer. Ports and cables are placed at the physical layer of the OSI model. IP addresses are placed at the network layer. The TCP/IP protocol stack describes a different model.

Question 3: Which two engineering organizations define open standards and protocols that apply to the data link layer? (Choose two.)

- (a) Institute of Electrical and Electronics Engineers (IEEE)
- (b) Internet Assigned Numbers Authority (IANA)
- (c) International Telecommunication Union (ITU)
- (d) Electronic Industries Alliance (EIA)
- (e) Internet Society (ISOC)

Answer: (a & c)

Question 4: What is true concerning physical and logical topologies?

- (a) The logical topology is always the same as the physical topology.
- (b) Physical topologies are concerned with how a network transfers frames.
- (c) Physical topologies display the IP addressing scheme of each network.
- (d) Logical topologies refer to how a network transfers data between devices.

Answer: (d) - Physical topologies show the physical interconnection of devices. Logical topologies show the way the network will transfer data between connected nodes.

Question 5: What method is used to manage contention-based access on a wireless network?

- (a) CSMA/CD
- (b) priority ordering
- (c) CSMA/CA
- (d) token passing

Answer: (c) - Carrier sense multiple access with collision avoidance (CSMA/CA) is used with wireless networking technology to mediate media contention. Carrier sense multiple access with collision detection (CSMA/CD) is used with wired Ethernet technology to mediate media contention. Priority ordering and token passing are not used (or not a method) for media access control.

Question 6: A technician has been asked to develop a physical topology for a network that provides a high level of redundancy. Which physical topology requires that every node is attached to every other node on the network?

- (a) bus
- (b) hierarchical
- (c) mesh
- (d) ring
- (e) star

Answer: (c) - The mesh topology provides high availability because every node is connected to all other nodes. Mesh topologies can be found in WANs. A partial mesh topology can also be used where some, but not all, end points connect to one another.

Question 7: Which statement describes the half-duplex mode of data transmission?

- (a) Data that is transmitted over the network can only flow in one direction.
- (b) Data that is transmitted over the network flows in one direction at a time.
- (c) Data that is transmitted over the network flows in one direction to many different destinations simultaneously.
- (d) Data that is transmitted over the network flows in both directions at the same time.

Answer: (b) - The data that is transmitted over the network can flow using one of three modes:

Simplex – Data can only flow in one direction.

Half-duplex – Data flows in one direction at a time.

Full-duplex – Data flows in both directions at the same time.

Question 8: Which is a function of the Logical Link Control (LLC) sublayer?

- (a) to define the media access processes that are performed by the hardware
- (b) to provide data link layer addressing
- (c) to identify which network layer protocol is being used
- (d) to accept segments and package them into data units that are called packets

Answer: (c) - Defining the media access processes that are performed by the hardware and providing data link layer addressing are functions of the MAC sublayer. The data link layer accepts Layer 3 packets and packages them into data units that are called frames.

Question 9: Which data link layer media access control method does Ethernet use with legacy Ethernet hubs?

- (a) CSMA/CD
- (b) determinism
- (c) turn taking
- (d) token passing

Answer: (a) - CSMA/CD is used by Ethernet networks. CSMA/CA is used by 802.11-based wireless networks.

Question 10: What are the two sublayers of the OSI model data link layer? (Choose two.)

- (a) internet
- (b) physical
- (c) LLC
- (d) transport
- (e) MAC
- (f) network access

Answer: (c & e) - The data link layer of the OSI model is divided into two sublayers: the Media Access Control (MAC) sublayer and the Logical Link Control (LLC) sublayer.

Question 11: Which layer of the OSI model is responsible for specifying the encapsulation method used for specific types of media?

- (a) application
- (b) transport
- (c) data link
- (d) physical

Answer: (c) - Encapsulation is a function of the data link layer. Different media types require different data link layer encapsulation.

Question 12: What type of physical topology can be created by connecting all Ethernet cables to a central device?

- (a) bus
- (b) ring
- (c) star
- (d) mesh

Answer: (c) - Devices connected to the Ethernet star topology connect to either a hub or a switch.

Question 13: Although CSMA/CD is still a feature of Ethernet, why is it no longer necessary?

- (a) the virtually unlimited availability of IPv6 addresses
- (b) the use of CSMA/CA
- (c) the use of full-duplex capable Layer 2 switches
- (d) the development of a half-duplex switch operation
- (e) the use of Gigabit Ethernet speeds

Answer: (c) - The use of Layer 2 switches operating in full-duplex mode eliminates collisions, thereby eliminating the need for CSMA/CD.

Question 14: What are two services performed by the data link layer of the OSI model? (Choose two.)

- (a) It encrypts data packets.
- (b) It determines the path to forward packets.
- (c) It accepts Layer 3 packets and encapsulates them into frames.
- (d) It provides media access control and performs error detection.
- (e) It monitors the Layer 2 communication by building a MAC address table.

Answer: (c & d) -

The data link layer is responsible for the exchange of frames between nodes over a physical network media. Specifically, the data link layer performs two basic services:

- It accepts Layer 3 packets and encapsulates them into frames.
- It provides media access control and performs error detection.

Path determination is a service provided at Layer 3. A Layer 2 switch builds a MAC address table as part of its operation, but path determination is not the service that is provided by the data link layer.