



Jaringan Komputer (CCNA-1)

#5 Ethernet

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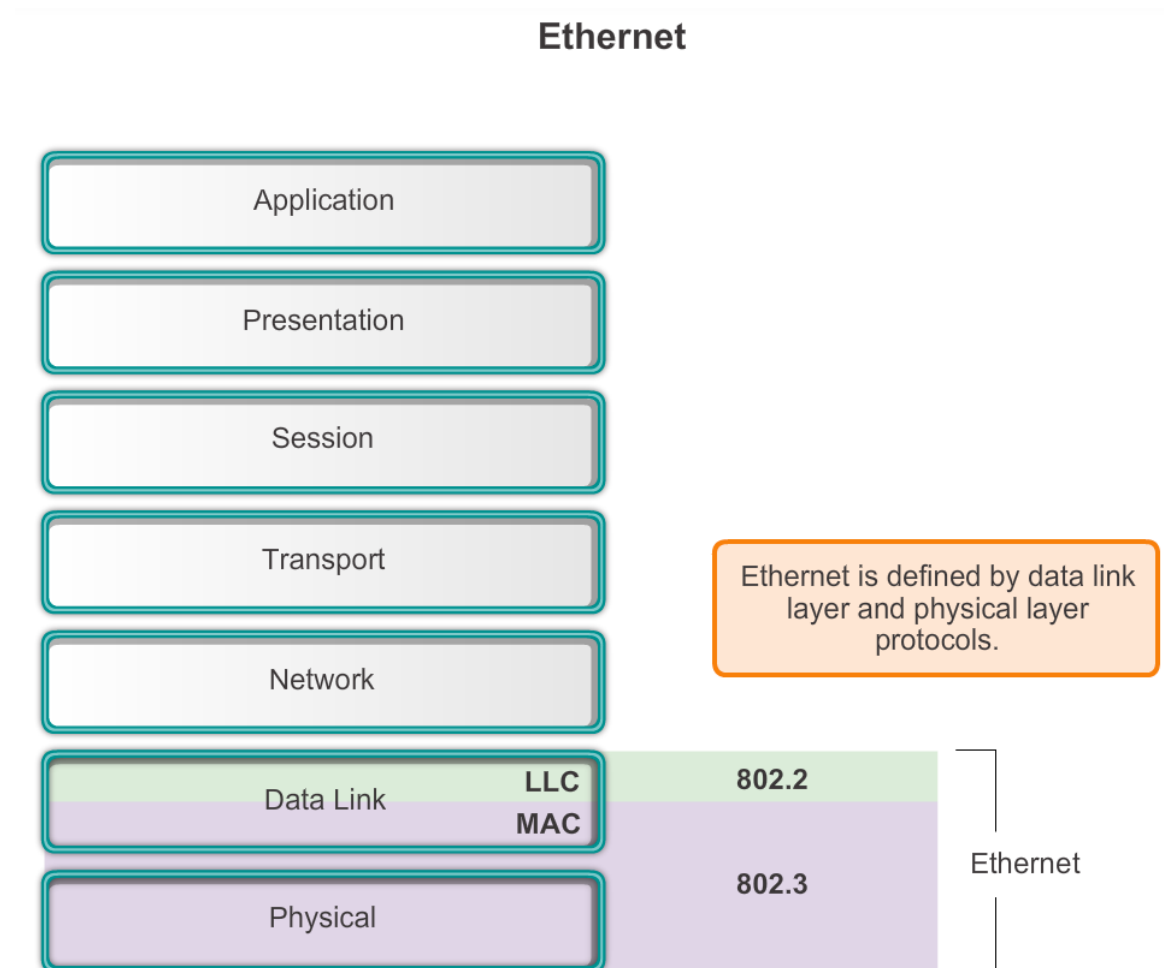
5.0. Introduction

- The OSI physical layer provides the means to transport the bits that make up a data link layer frame across the network media.
- **Ethernet** is now the predominant LAN technology in the world. Ethernet operates in the data link layer and the physical layer.
- The Ethernet protocol standards define many aspects of network communication including frame format, frame size, timing, and encoding.
- When messages are sent between hosts on an Ethernet network, the hosts format the messages into the frame layout that is specified by the standards.
- Frames are also referred to as Protocol Data Units (PDUs).
- Ethernet standards define both the Layer 2 protocols and the Layer 1 technologies.
- Although Ethernet specifications support different media, bandwidths, and other Layer 1 and 2 variations, the basic frame format and address scheme is the same for all varieties of Ethernet.

5.1. Ethernet Protocol

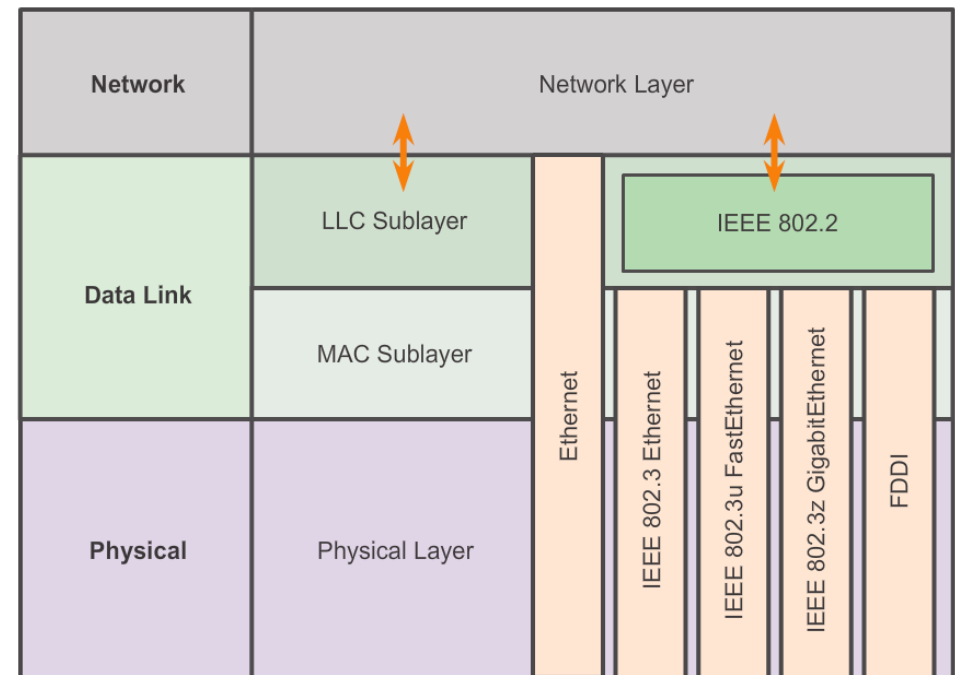
5.1.1. Ethernet Operation

- Ethernet is the most widely used LAN technology used today.
- Ethernet operates in the data link layer and the physical layer. It is a family of networking technologies that are defined in the IEEE 802.2 and 802.3 standards. Ethernet supports data bandwidths of:
 - 10 Mb/s
 - 100 Mb/s
 - 1000 Mb/s (1 Gb/s)
 - 10,000 Mb/s (10 Gb/s)
 - 40,000 Mb/s (40 Gb/s)
 - 100,000 Mb/s (100 Gb/s)



5.1.1.1. LLC and MAC Sublayer

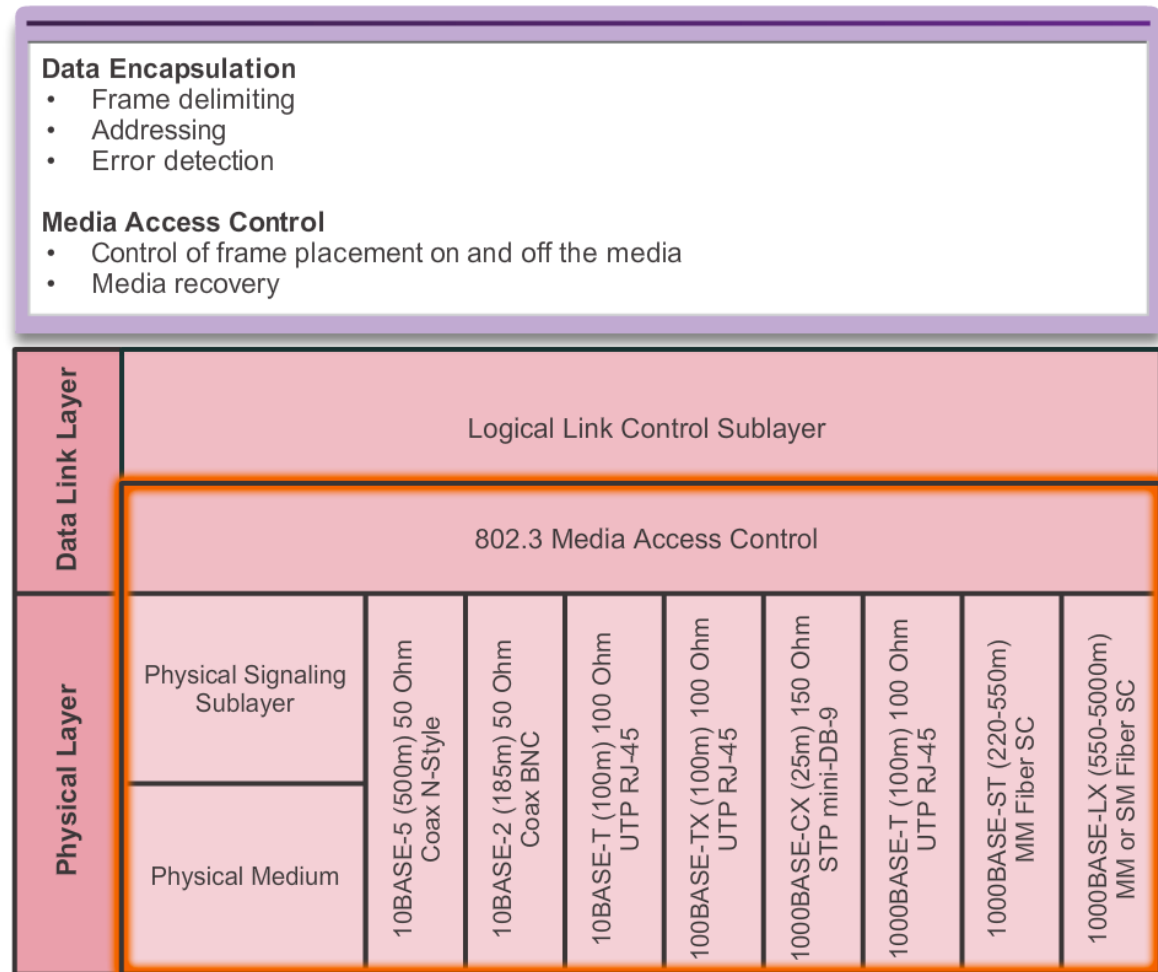
- As shown in Figure 1, Ethernet standards define both the Layer 2 protocols and the Layer 1 technologies.
- For the Layer 2 protocols, as with all 802 IEEE standards, Ethernet relies on the two separate sublayers of the data link layer to operate, the Logical Link Control (LLC) and the MAC sublayers.
- **LLC sublayer**
 - The Ethernet LLC sublayer handles the communication between the upper layers and the lower layers. This is typically between the networking software and the device hardware. The LLC sublayer takes the network protocol data, which is typically an IPv4 packet, and adds control information to help deliver the packet to the destination node. The LLC is used to communicate with the upper layers of the application, and transition the packet to the lower layers for delivery.
 - LLC is implemented in software, and its implementation is independent of the hardware. In a computer, the LLC can be considered the driver software for the NIC. The NIC driver is a program that interacts directly with the hardware on the NIC to pass the data between the MAC sublayer and the physical media.



- **MAC sublayer**
 - MAC constitutes the lower sublayer of the data link layer. MAC is implemented by hardware, typically in the computer NIC. The specifics are specified in the IEEE 802.3 standards. Figure 2 lists common IEEE Ethernet standards.

5.1.1.2. MAC Sublayer

- As shown in the figure, the Ethernet MAC sublayer has two primary responsibilities:
 - Data encapsulation
 - Media access control



MAC Sublayer

- **Data encapsulation**

- The data encapsulation process includes frame assembly before transmission, and frame disassembly upon reception of a frame. In forming the frame, the MAC layer adds a header and trailer to the network layer PDU.
- Data encapsulation provides three primary functions:
 - **Frame delimiting:** The framing process provides important delimiters that are used to identify a group of bits that make up a frame. This process provides synchronization between the transmitting and receiving nodes.
 - **Addressing:** The encapsulation process also provides for data link layer addressing. Each Ethernet header added in the frame contains the physical address (MAC address) that enables a frame to be delivered to a destination node.
 - **Error detection:** Each Ethernet frame contains a trailer with a cyclic redundancy check (CRC) of the frame contents. After reception of a frame, the receiving node creates a CRC to compare to the one in the frame. If these two CRC calculations match, the frame can be trusted to have been received without error.
- The use of frames aids in the transmission of bits as they are placed on the media and in the grouping of bits at the receiving node.

MAC Sublayer

- **Media Access Control**

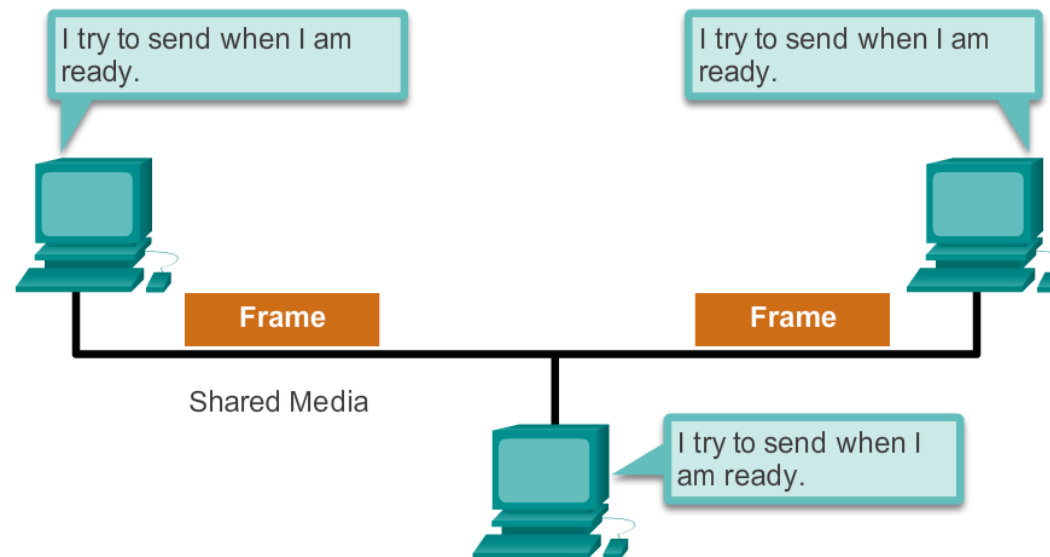
- The second responsibility of the MAC sublayer is media access control. Media access control is responsible for the placement of frames on the media and the removal of frames from the media. As its name implies, it controls access to the media. This sublayer communicates directly with the physical layer.
- The underlying logical topology of Ethernet is a multi-access bus; therefore, all nodes (devices) on a single network segment share the medium.
- Ethernet is a contention-based method of networking. Recall that a contention-based method, or non-deterministic method, means that any device can try to transmit data across the shared medium whenever it has data to send.
- However, much like if two people try to talk simultaneously, if multiple devices on a single medium attempt to forward data simultaneously, the data will collide resulting in corrupted, unusable data.
- For this reason, Ethernet provides a method for controlling how the nodes share access through the use of a Carrier Sense Multiple Access (CSMA) technology.

5.1.1.3. Media Access Control

- The CSMA process is used to first detect if the media is carrying a signal. If a carrier signal on the media from another node is detected, it means that another device is transmitting. When the device attempting to transmit sees that the media is busy, it will wait and try again after a short time period. If no carrier signal is detected, the device transmits its data. It is possible that the CSMA process will fail and two devices will transmit at the same time. This is called a data collision. If this occurs, the data sent by both devices will be corrupted and will need to be resent.
- Contention-based media access control methods do not require mechanisms for tracking whose turn it is to access the media; therefore, they do not have the overhead of controlled access methods. However, the contention-based systems do not scale well under heavy media use. As use and the number of nodes increases, the probability of successful media access without a collision decreases. Additionally, the recovery mechanisms required to correct errors due to these collisions further diminishes the throughput.

Media Access Control

Contention-Based Access



Method	Characteristics	Example
Contention-Based Access	<ul style="list-style-type: none">Stations can transmit at any timeCollisions existMechanisms exist to resolve contention problems<ul style="list-style-type: none">CSMA/CD for Ethernet networksCSMA/CA for 802.11 wireless networks	<ul style="list-style-type: none">EthernetWireless

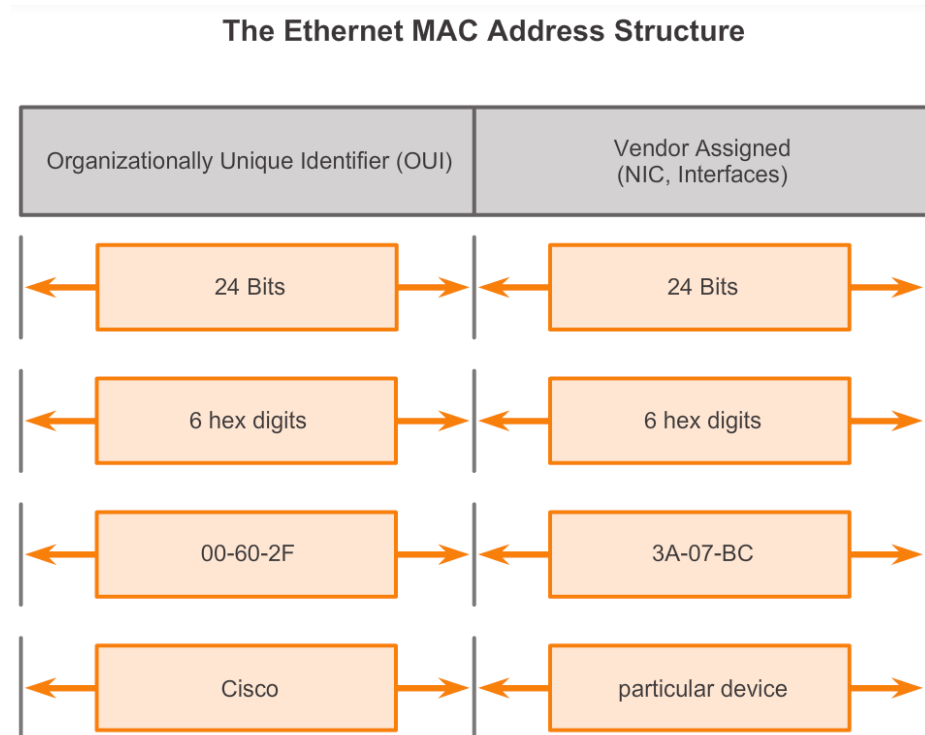
Media Access Control

- As shown in the figure, CSMA is usually implemented in conjunction with a method for resolving media contention. The two commonly used methods are:
- **CSMA/Collision Detection**
 - In CSMA/Collision Detection (CSMA/CD), the device monitors the media for the presence of a data signal. If a data signal is absent, indicating that the media is free, the device transmits the data. If signals are then detected that show another device was transmitting at the same time, all devices stop sending and try again later. Traditional forms of Ethernet were developed to use this method.
 - The widespread incorporation of switched technologies in modern networks has largely displaced the original need for CSMA/CD in local-area networks. Almost all wired connections between devices in a LAN today are full-duplex connections - a device is able to send and receive simultaneously. This means, that while Ethernet networks are designed with CSMA/CD technology, with today's intermediate devices, collisions do not occur and the processes utilized by CSMA/CD are really unnecessary.
 - However, wireless connections in a LAN environment still have to take collisions into account. Wireless LAN devices utilize the CSMA/Collision Avoidance (CSMA/CA) media access method.
- **CSMA/Collision Avoidance**
 - In CSMA/CA, the device examines the media for the presence of a data signal. If the media is free, the device sends a notification across the media of its intent to use it. The device then sends the data. This method is used by 802.11 wireless networking technologies.

5.1.1.4. MAC Address: Ethernet Identity

• MAC Address Structure

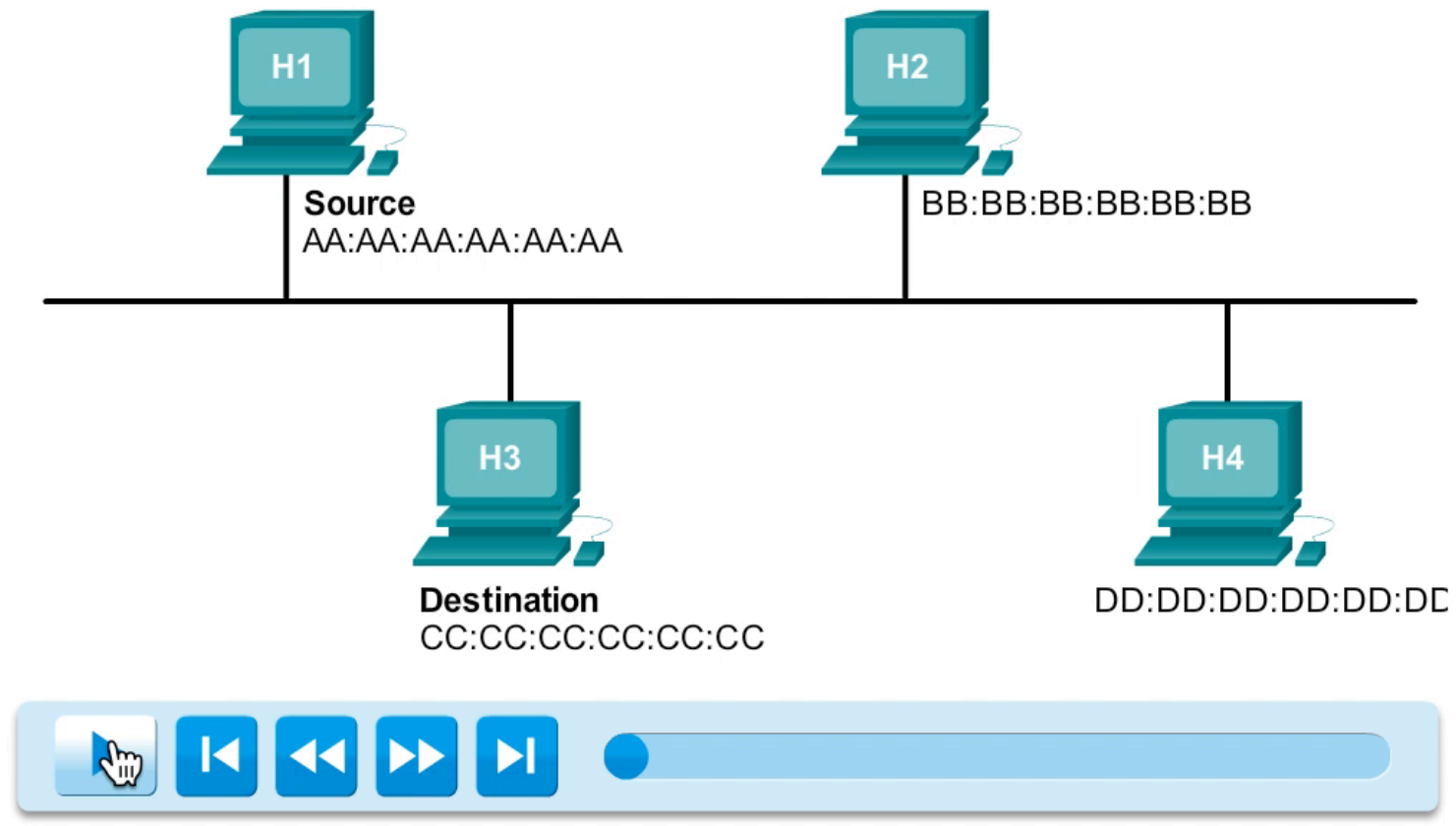
- MAC addresses must be globally unique. The MAC address value is a direct result of IEEE-enforced rules for vendors to ensure globally unique addresses for each Ethernet device. The rules established by IEEE require any vendor that sells Ethernet devices to register with IEEE. The IEEE assigns the vendor a 3-byte (24-bit) code, called the Organizationally Unique Identifier (OUI).
- IEEE requires a vendor to follow two simple rules, as shown in the figure:
 - All MAC addresses assigned to a NIC or other Ethernet device must use that vendor's assigned OUI as the first 3 bytes.
- All MAC addresses with the same OUI must be assigned a unique value (vendor code or serial number) in the last 3 bytes.



5.1.1.5. Frame Processing

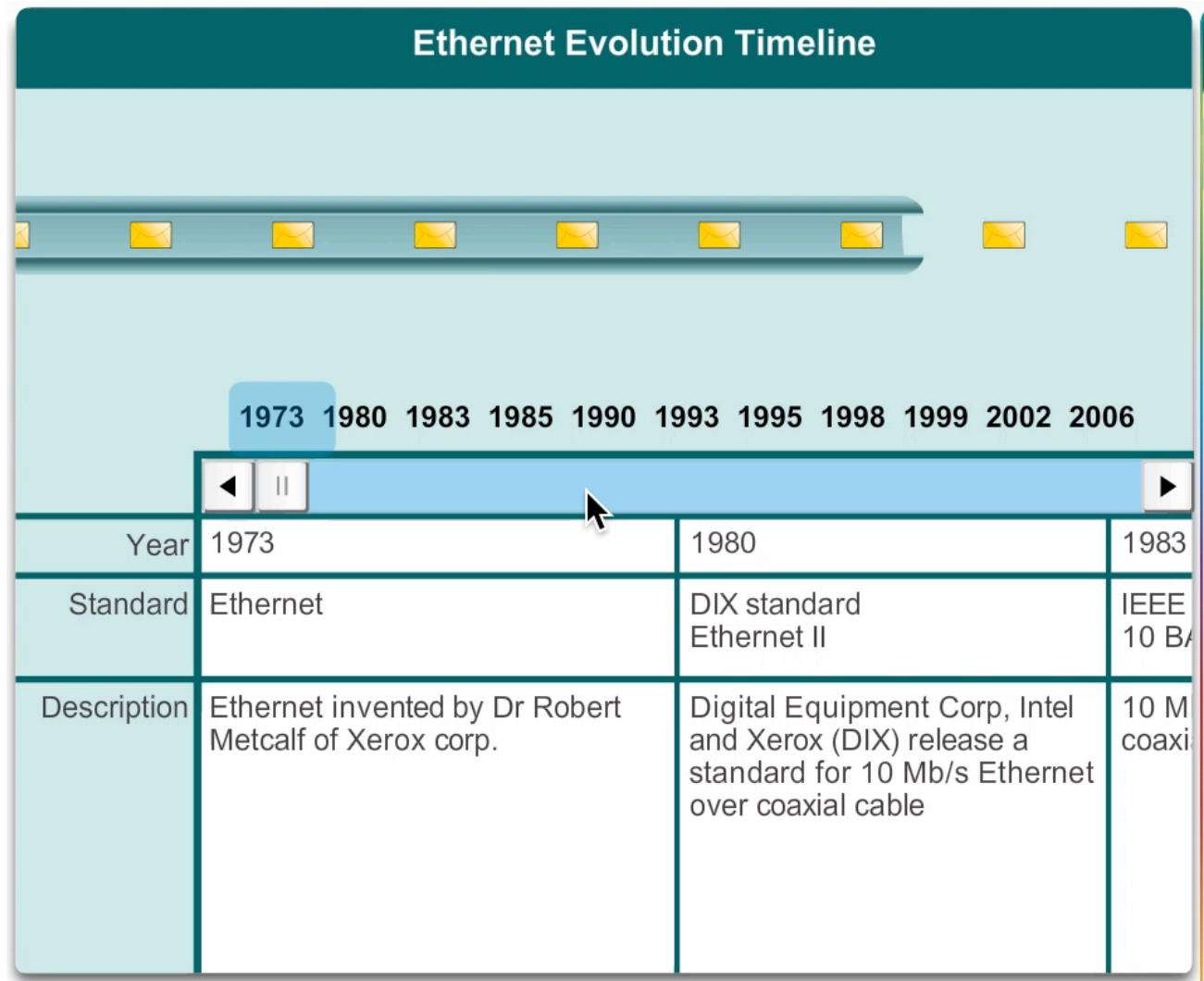
- The MAC address is often referred to as a burned-in address (BIA) because, historically, this address is burned into ROM (Read-Only Memory) on the NIC. This means that the address is encoded into the ROM chip permanently - it cannot be changed by software.
- MAC addresses are assigned to workstations, servers, printers, switches, and routers - any device that must originate and/or receive data on the network. All devices connected to an Ethernet LAN have MAC-addressed interfaces. Different hardware and software manufacturers might represent the MAC address in different hexadecimal formats. The address formats might be similar to:
 - 00-05-9A-3C-78-00
 - 00:05:9A:3C:78:00
 - 0005.9A3C.7800
- When the computer starts up, the first thing the NIC does is copies the MAC address from ROM into RAM. When a device is forwarding a message to an Ethernet network, it attaches header information to the packet. The header information contains the source and destination MAC address. The source device sends the data through the network.
- Each NIC in the network views the information, at the MAC sublayer, to see if the destination MAC address in the frame matches the device's physical MAC address stored in RAM. If there is no match, the device discards the frame. When the frame reaches the destination where the MAC of the NIC matches the destination MAC of the frame, the NIC passes the frame up the OSI layers, where the de-encapsulation process takes place.

Frame Forwarding



5.1.2. Ethernet Frame

- Since the creation of Ethernet in 1973, standards have evolved for specifying faster and more flexible versions of the technology. This ability for Ethernet to improve over time is one of the main reasons that it has become so popular. Early versions of Ethernet were relatively slow at 10 Mbps. The latest versions of Ethernet operate at 10 Gigabits per second and faster. Figure 1 highlights changes in the various versions of Ethernet.



5.1.2.1. Ethernet Encapsulation

- At the data link layer, the frame structure is nearly identical for all speeds of Ethernet. The Ethernet frame structure adds headers and trailers around the Layer 3 PDU to encapsulate the message being sent.
- Both the Ethernet header and trailer have several sections of information that are used by the Ethernet protocol. Each section of the frame is called a field. As shown in Figure 2, there are two styles of Ethernet framing:
 - IEEE 802.3 Ethernet standard which has been updated several times to include new technologies
 - The DIX Ethernet standard which is now referred to Ethernet II
- The differences between framing styles are minimal. The most significant difference between the two standards is the addition of a Start Frame Delimiter (SFD) and the change of the Type field to a Length field in the 802.3.
- Ethernet II is the Ethernet frame format used in TCP/IP networks.

Comparison of 802.3 and Ethernet II Frame Structures and Field Size

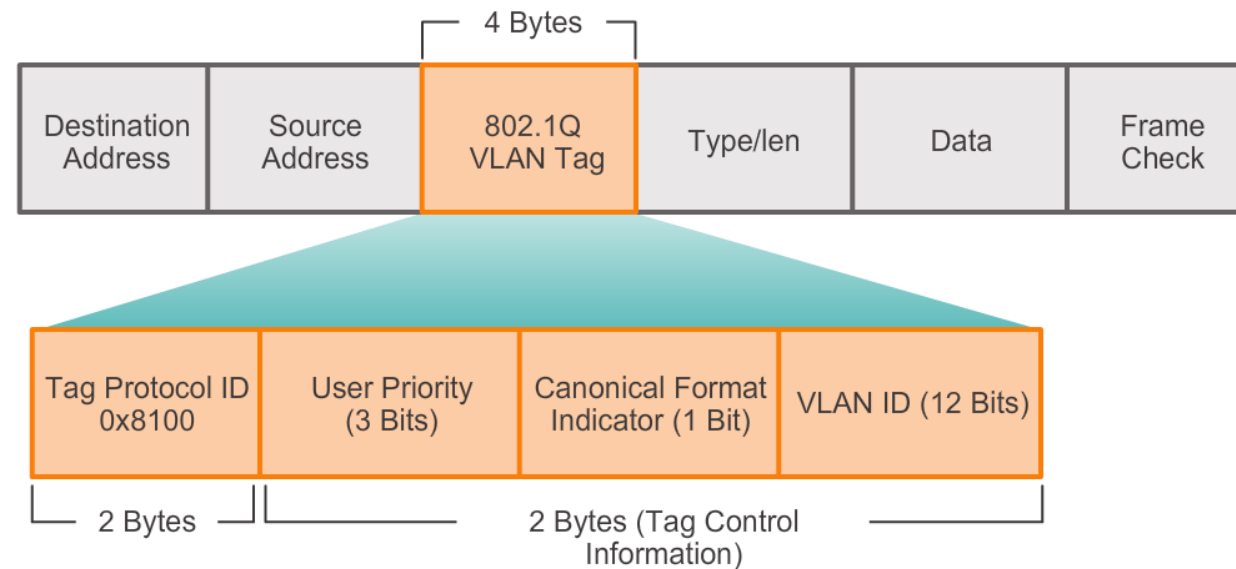
IEEE 802.3						
7	1	6	6	2	46 to 1500	4
Preamble	Start of Frame Delimiter	Destination Address	Source Address	Length	802.2 Header and Data	Frame Check Sequence

Ethernet II					
8	6	6	2	46 to 1500	4
Preamble	Destination Address	Source Address	Type	Data	Frame Check Sequence

Field size in bytes

5.1.2.2. Ethernet Frame Size

- Both the Ethernet II and IEEE 802.3 standards define the minimum frame size as 64 bytes and the maximum as 1518 bytes. This includes all bytes from the Destination MAC Address field through the Frame Check Sequence (FCS) field. The Preamble and Start Frame Delimiter fields are not included when describing the size of a frame.
- Any frame less than 64 bytes in length is considered a "collision fragment" or "runt frame" and is automatically discarded by receiving stations.
- The IEEE 802.3ac standard, released in 1998, extended the maximum allowable frame size to 1522 bytes. The frame size was increased to accommodate a technology called Virtual Local Area Network (VLAN). VLANs are created within a switched network and will be presented in a later course. Also, many quality of service (QoS) technologies leverage the User Priority field to implement various levels of service, such as priority service for voice traffic. The figure displays the fields contained in the 802.1Q VLAN tag.
- If the size of a transmitted frame is less than the minimum or greater than the maximum, the receiving device drops the frame. Dropped frames are likely to be the result of collisions or other unwanted signals and are therefore considered invalid.
- At the data link layer the frame structure is nearly identical. At the physical layer different versions of Ethernet vary in their method for detecting and placing data on the media.

IEEE 802.3**Extra 4 bytes allows for QoS and VLAN Technology**

The primary fields in the Ethernet frame are:

- **Preamble and Start Frame Delimiter Fields:** The Preamble (7 bytes) and Start Frame Delimiter (SFD), also called the Start of Frame (1 byte), fields are used for synchronization between the sending and receiving devices. These first eight bytes of the frame are used to get the attention of the receiving nodes. Essentially, the first few bytes tell the receivers to get ready to receive a new frame.
- **Destination MAC Address Field:** This 6-byte field is the identifier for the intended recipient. As you will recall, this address is used by Layer 2 to assist devices in determining if a frame is addressed to them. The address in the frame is compared to the MAC address in the device. If there is a match, the device accepts the frame.
- **Source MAC Address Field:** This 6-byte field identifies the frame's originating NIC or interface.
- **Length Field:** For any IEEE 802.3 standard earlier than 1997 the Length field defines the exact length of the frame's data field. This is used later as part of the FCS to ensure that the message was received properly. Otherwise the purpose of the field is to describe which higher-layer protocol is present. If the two-octet value is equal to or greater than 0x0600 hexadecimal or 1536 decimal, then the contents of the Data field are decoded according to the EtherType protocol indicated. Whereas if the value is equal to or less than 0x05DC hexadecimal or 1500 decimal then the Length field is being used to indicate the use of the IEEE 802.3 frame format. This is how Ethernet II and 802.3 frames are differentiated.
- **Data Field:** This field (46 - 1500 bytes) contains the encapsulated data from a higher layer, which is a generic Layer 3 PDU, or more commonly, an IPv4 packet. All frames must be at least 64 bytes long. If a small packet is encapsulated, additional bits called a pad are used to increase the size of the frame to this minimum size.
- **Frame Check Sequence Field:** The Frame Check Sequence (FCS) field (4 bytes) is used to detect errors in a frame. It uses a cyclic redundancy check (CRC). The sending device includes the results of a CRC in the FCS field of the frame. The receiving device receives the frame and generates a CRC to look for errors. If the calculations match, no error occurred. Calculations that do not match are an indication that the data has changed; therefore, the frame is dropped. A change in the data could be the result of a disruption of the electrical signals that represent the bits.

5.3. Ethernet MAC

5.1.3.1 MAC Addresses and Hexadecimal

- The use of the MAC address is one of the most important aspects of the Ethernet LAN technology. MAC addresses use hexadecimal numbering.
- **Hexadecimal Conversions**
 - Number conversions between decimal and hexadecimal values are straightforward, but quickly dividing or multiplying by 16 is not always convenient. If such conversions are required, it is usually easier to convert the decimal or hexadecimal value to binary, and then to convert the binary value to either decimal or hexadecimal as appropriate.

5.1.3.2. MAC Representations

- On a Windows host, the `ipconfig /all` command can be used to identify the MAC address of an Ethernet adapter. In Figure 1, notice the display indicates the Physical Address (MAC) of the computer to be 00-18-DE-C7-F3-FB. If you have access, you may wish to try this on your own computer.
- Depending on the device and the operating system, you will see various representations of MAC addresses, as displayed in Figure 2. Cisco routers and switches use the form XXXX.XXXX.XXXX where X is a hexadecimal character.

```
C:\>ipconfig/all

Ethernet adapter Local Area Connection:

    Connection-specific DNS Suffix  . : example.com
    Description . . . . . : Intel(R) Gigabit Network Connection
    Physical Address. . . . . : 00-18-DE-C7-F3-FB
    DHCP Enabled. . . . . : Yes
    Autoconfiguration Enabled . . . . : Yes
    IPv4 Address. . . . . : 192.168.1.67 (Preferred)
    Subnet Mask . . . . . : 255.255.255.0
    Lease Obtained. . . . . : Monday, November 26, 2012 12:14:48 PM
    Lease Expires . . . . . : Saturday, December 01, 2012 12:15:02 AM
    Default Gateway . . . . . : 192.168.1.254
    DHCP Server . . . . . : 192.168.1.254
    DNS Servers . . . . . : 192.168.1.254
```

Different Representation of MAC Addresses

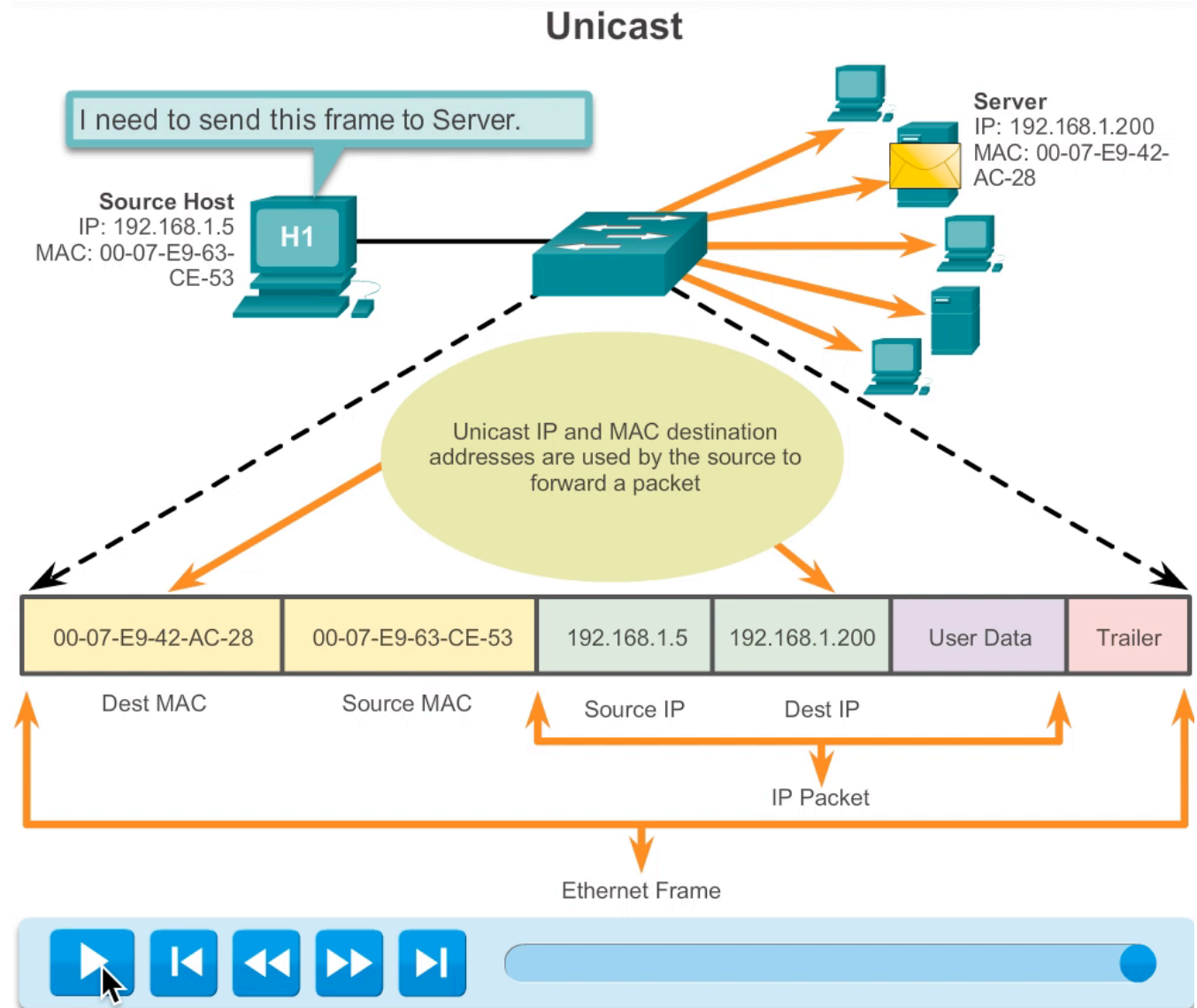
With Dashes 00-60-2F-3A-07-BC

With Colons 00:60:2F:3A:07:BC

With Periods 0060.2F3A.07BC

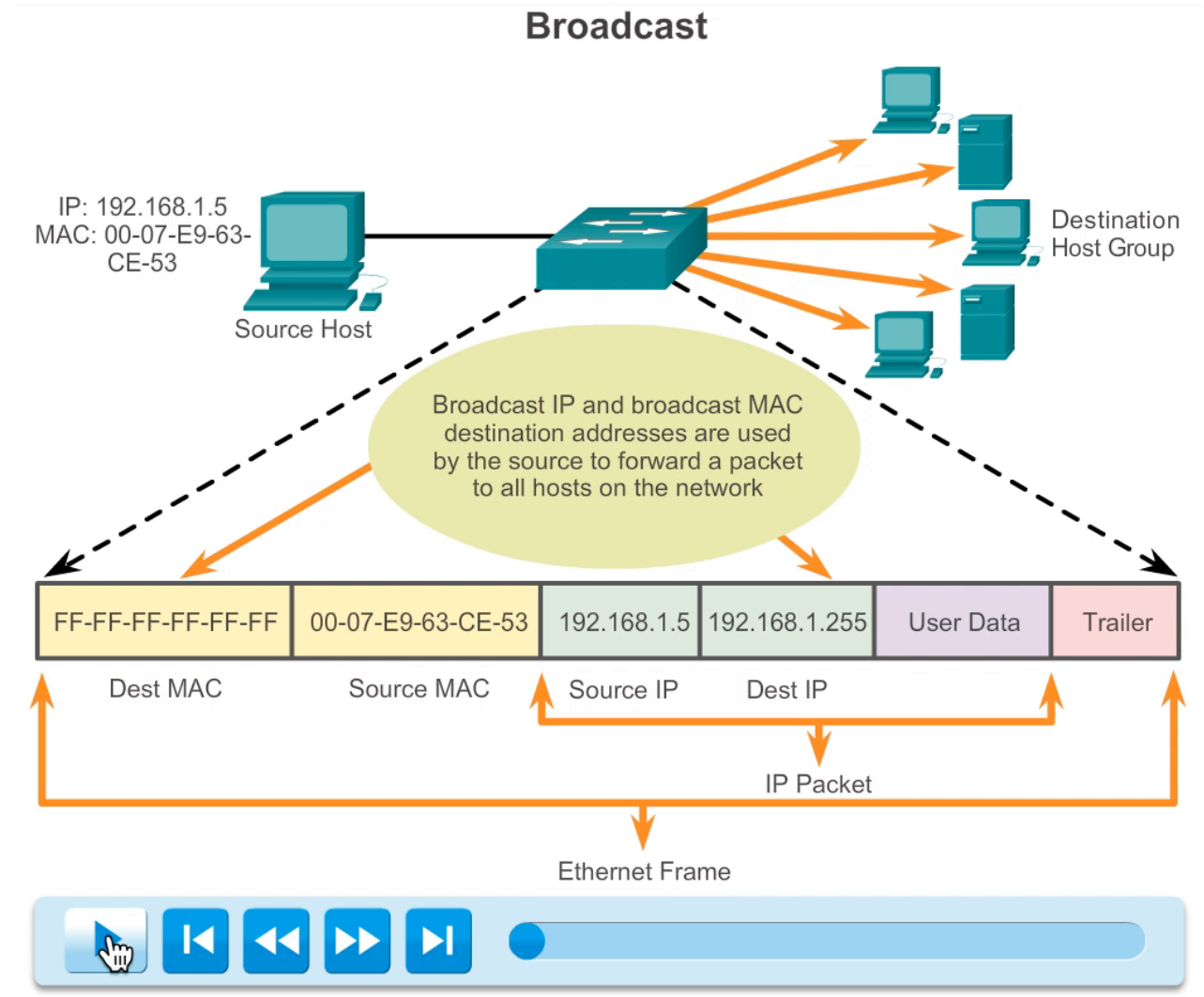
5.1.3.3. Unicast MAC Address

- In Ethernet, different MAC addresses are used for Layer 2 unicast, broadcast, and multicast communications.
- A unicast MAC address is the unique address used when a frame is sent from a single transmitting device to a single destination device.
- In the example shown in the figure, a host with IP address 192.168.1.5 (source) requests a web page from the server at IP address 192.168.1.200. For a unicast packet to be sent and received, a destination IP address must be in the IP packet header. A corresponding destination MAC address must also be present in the Ethernet frame header. The IP address and MAC address combine to deliver data to one specific destination host.



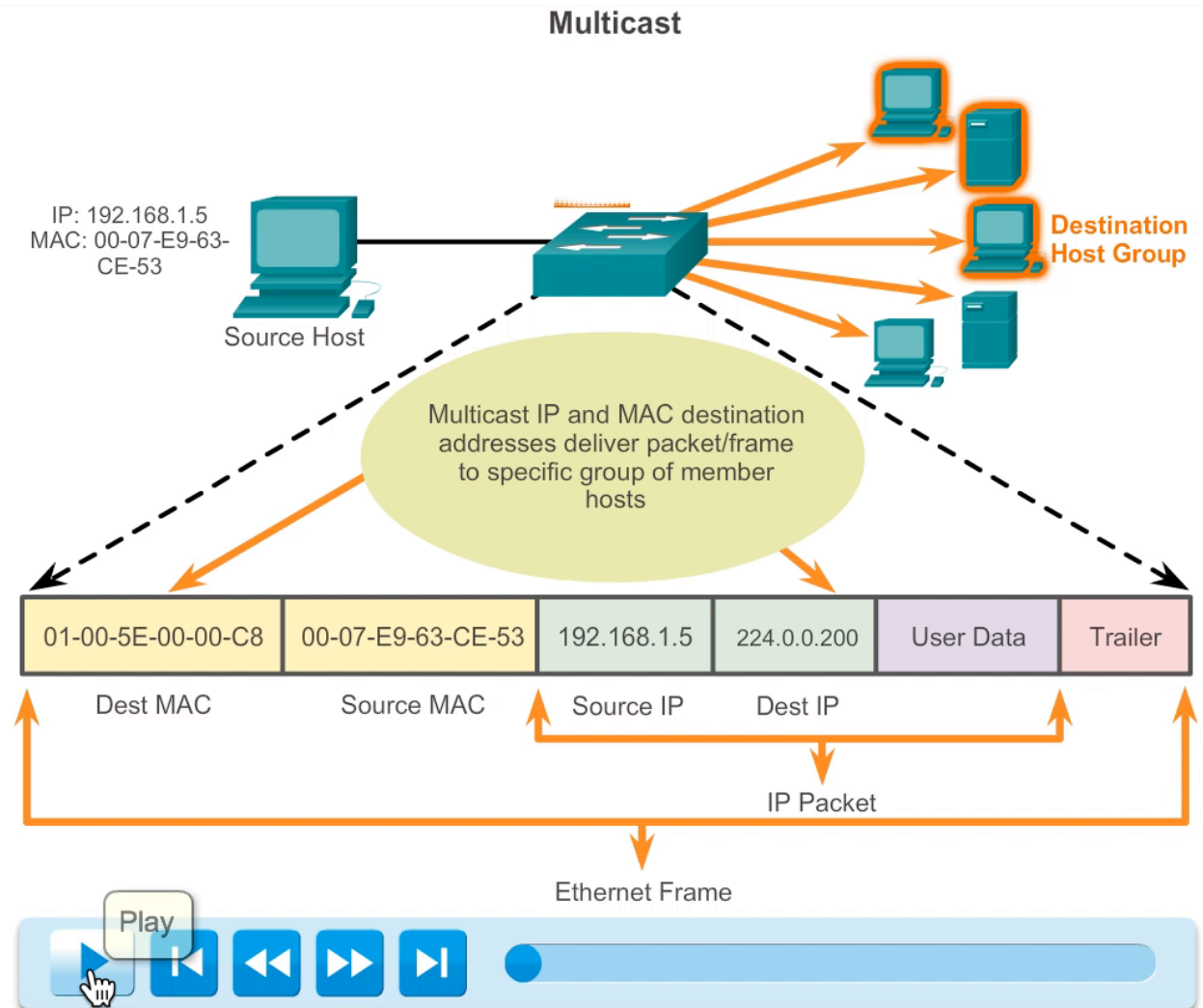
5.1.3.4. Broadcast MAC Address

- A broadcast packet contains a destination IP address that has all ones (1s) in the host portion. This numbering in the address means that all hosts on that local network (broadcast domain) will receive and process the packet. Many network protocols, such as DHCP and Address Resolution Protocol (ARP), use broadcasts. How ARP uses broadcasts to map Layer 2 to Layer 3 addresses is discussed later in this chapter.
- As shown in the figure, a broadcast IP address for a network needs a corresponding broadcast MAC address in the Ethernet frame. On Ethernet networks, the broadcast MAC address is 48 ones displayed as hexadecimal FF-FF-FF-FF-FF-FF.



5.1.3.4. Multicast MAC Address

- Multicast addresses allow a source device to send a packet to a group of devices. Devices that belong to a multicast group are assigned a multicast group IP address.
- The range of IPv4 multicast addresses is 224.0.0.0 to 239.255.255.255. Because multicast addresses represent a group of addresses (sometimes called a host group), they can only be used as the destination of a packet. The source will always have a unicast address.
- Multicast addresses would be used in remote gaming, where many players are connected remotely but playing the same game. Another use of multicast addresses is in distance learning through video conferencing, where many students are connected to the same class.
- As with the unicast and broadcast addresses, the multicast IP address requires a corresponding multicast MAC address to actually deliver frames on a local network. The multicast MAC address is a special value that begins with 01-00-5E in hexadecimal. The remaining portion of the multicast MAC address is created by converting the lower 23 bits of the IP multicast group address into 6 hexadecimal characters.
- An example, as shown in the animation, is the multicast hexadecimal address 01-00-5E-00-00-C8.



5.1.4. MAC and IP

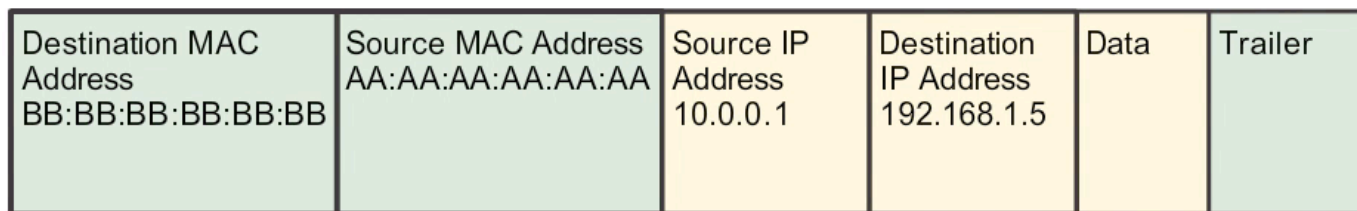
5.1.4.1. MAC and IP

- There are two primary addresses assigned to a host device:
 - Physical address (the MAC address)
 - Logical address (the IP address)
- Both the MAC address and IP address work together to identify a device on the network. The process of using the MAC address and the IP address to find a computer is similar to the process of using a name and address of an individual to send a letter.
- Both the physical MAC and logical IP addresses are required for a computer to communicate on a hierarchical network, just like both the name and address of a person are required to send a letter.

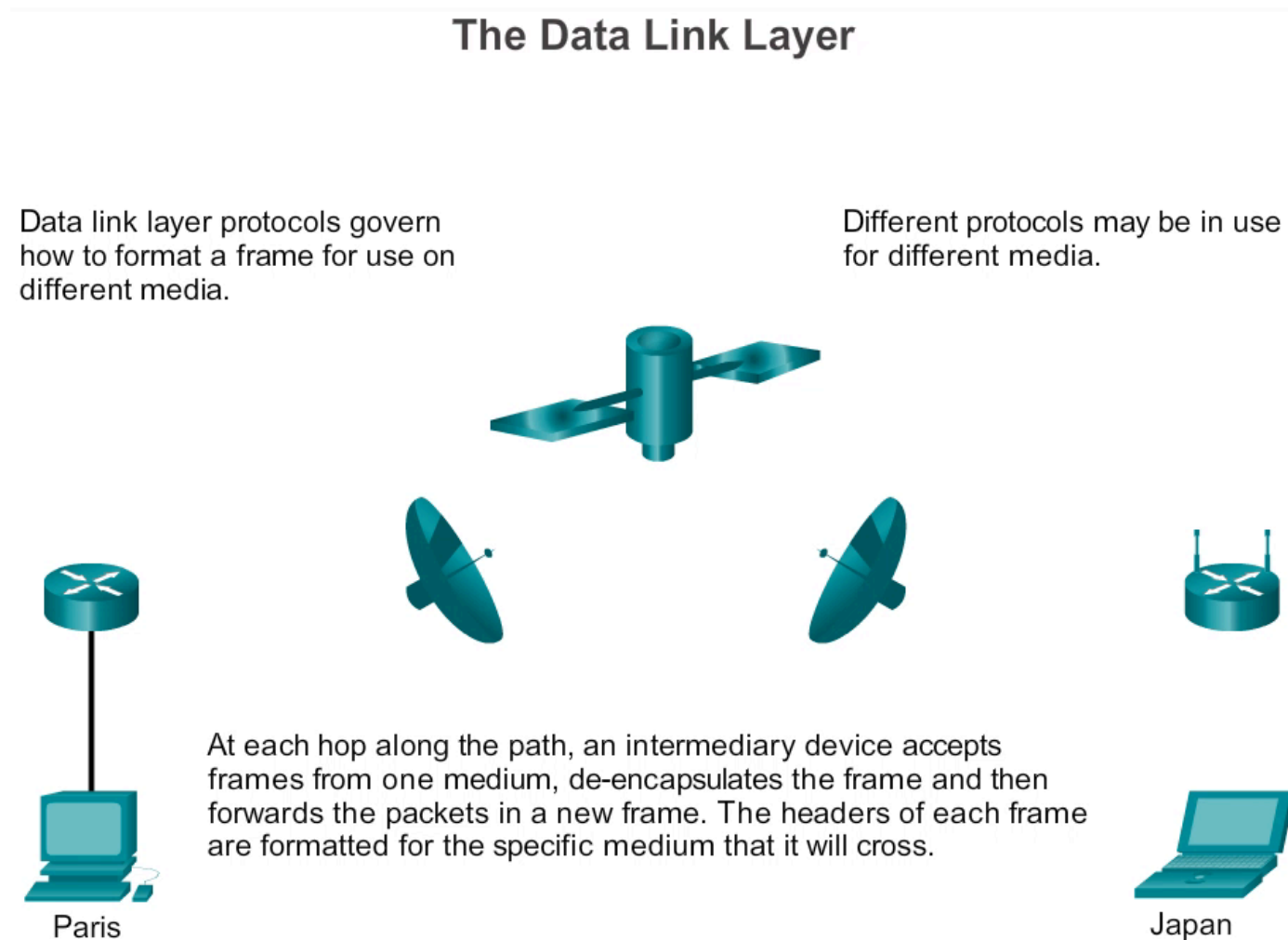
5.1.4.2. End to End Connectivity, MAC and IP

- A source device will send a packet based on an IP address. One of the most common ways a source device determines the IP address of a destination device is through Domain Name Service (DNS), in which an IP address is associated to a domain name. For example, `www.cisco.com` is equal to `209.165.200.225`. This IP address will get the packet to the network location of the destination device. It is this IP address that routers will use to determine the best path to reach a destination. So, in short, IP addressing determines the end-to-end behaviour of an IP packet.
- However, along each link in a path, an IP packet is encapsulated in a frame specific to the particular data link technology associated with that link, such as Ethernet. End devices on an Ethernet network do not accept and process frames based on IP addresses, rather, a frame is accepted and processed based on MAC addresses.
- On Ethernet networks, MAC addresses are used to identify, at a lower level, the source and destination hosts. When a host on an Ethernet network communicates, it sends frames containing its own MAC address as the source and the MAC address of the intended recipient as the destination. All hosts that receive the frame will read the destination MAC address. If the destination MAC address matches the MAC address configured on the host NIC, only then will the host process the message.

- Figure 1 shows how a data packet, containing IP address information, is encapsulated with data link layer framing containing the MAC address information.



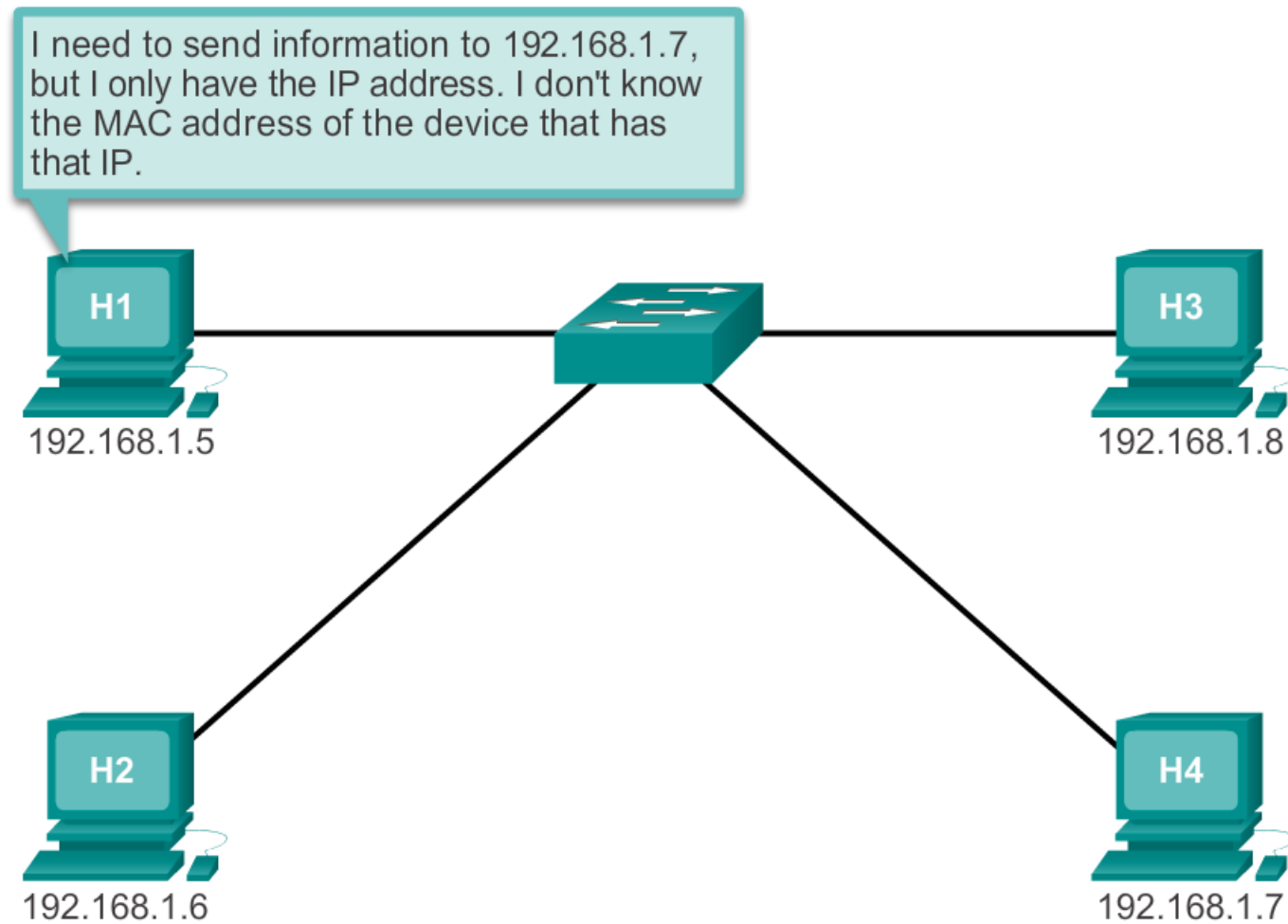
- Figure 2 shows how frames are encapsulated based on the technology of the actual link.



5.2.1. ARP

5.2.1.1. Introduction to ARP

- Recall that each node on an IP network has both a MAC address and an IP address. In order to send data, the node must use both of these addresses. The node must use its own MAC and IP addresses in the source fields and must provide both a MAC address and an IP address for the destination. While the IP address of the destination will be provided by a higher OSI layer, the sending node needs a way to find the MAC address of the destination for a given Ethernet link. This is the purpose of ARP.
- ARP relies on certain types of Ethernet broadcast messages and Ethernet unicast messages, called ARP requests and ARP replies.
- The ARP protocol provides two basic functions:
 - Resolving IPv4 addresses to MAC addresses
 - Maintaining a table of mappings



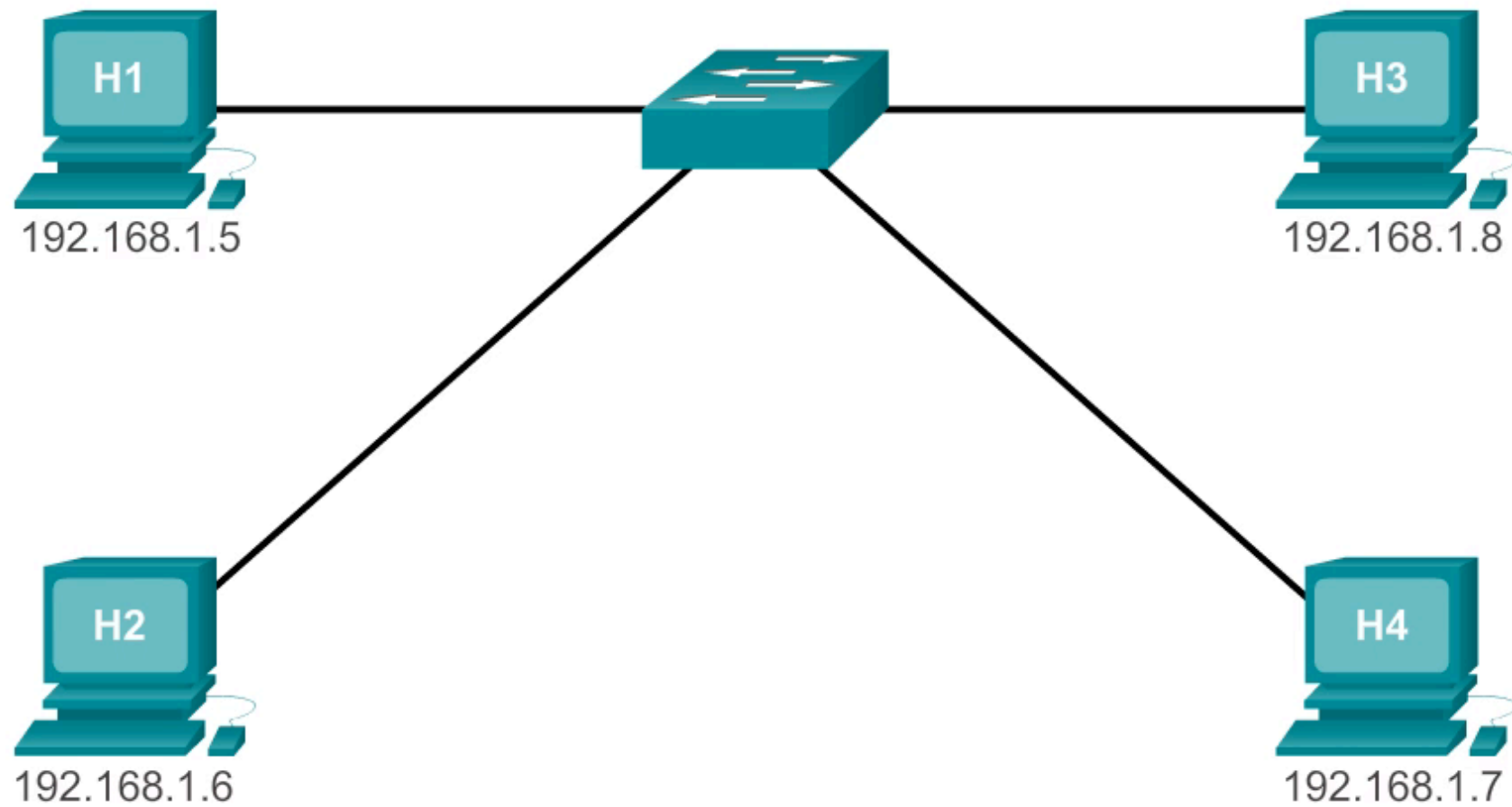
5.2.1.2. ARP Functions

- **Resolving IPv4 Addresses to MAC Addresses**

- For a frame to be placed on the LAN media, it must have a destination MAC address. When a packet is sent to the data link layer to be encapsulated into a frame, the node refers to a table in its memory to find the data link layer address that is mapped to the destination IPv4 address. This table is called the ARP table or the ARP cache. The ARP table is stored in the RAM of the device.
- Each entry, or row, of the ARP table binds an IP address with a MAC address. We call the relationship between the two values a map - it simply means that you can locate an IP address in the table and discover the corresponding MAC address. The ARP table temporarily saves (caches) the mapping for the devices on the local LAN.
- To begin the process, a transmitting node attempts to locate the MAC address mapped to an IPv4 destination. If this map is found in the table, the node uses the MAC address as the destination MAC in the frame that encapsulates the IPv4 packet. The frame is then encoded onto the networking media.

- **Maintaining the ARP Table**

- The ARP table is maintained dynamically. There are two ways that a device can gather MAC addresses. One way is to monitor the traffic that occurs on the local network segment. As a node receives frames from the media, it can record the source IP and MAC address as a mapping in the ARP table. As frames are transmitted on the network, the device populates the ARP table with address pairs.
- Another way a device can get an address pair is to send an ARP request as shown in the figure. An ARP request is a Layer 2 broadcast to all devices on the Ethernet LAN. The ARP request contains the IP address of the destination host and the broadcast MAC address, FFFF.FFFF.FFFF. Since this is a broadcast, all nodes on the Ethernet LAN will receive it and look at the contents. The node with the IP address that matches the IP address in the ARP request will reply. The reply will be a unicast frame that includes the MAC address that corresponds to the IP address in the request. This response is then used to make a new entry in the ARP table of the sending node.
- Entries in the ARP table are time stamped in much the same way that MAC table entries are time stamped in switches. If a device does not receive a frame from a particular device by the time the time stamp expires, the entry for this device is removed from the ARP table.
- Additionally, static map entries can be entered in an ARP table, but this is rarely done. Static ARP table entries do not expire over time and must be manually removed.

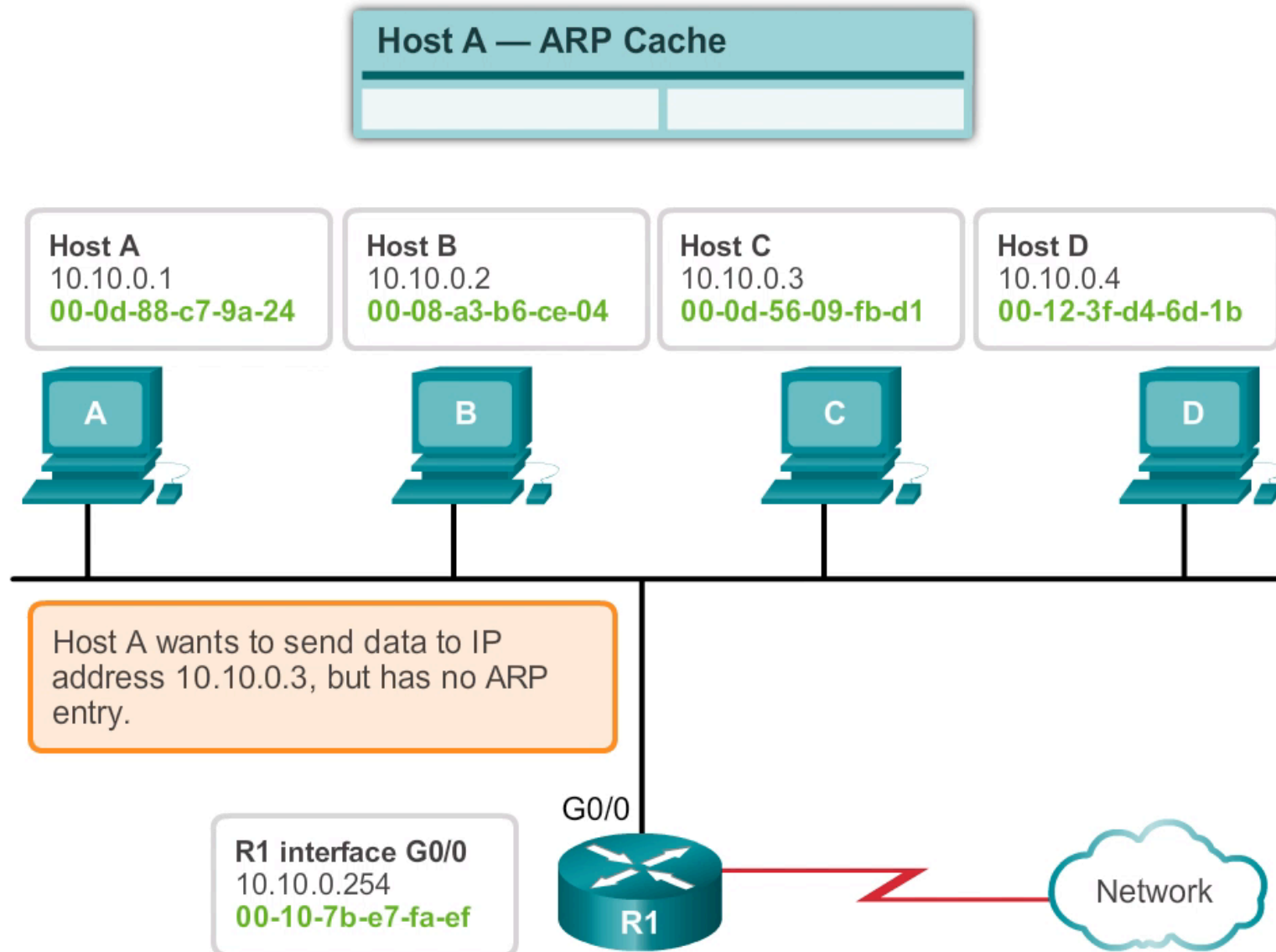


5.2.1.3 ARP Operation

Creating the Frame

- What does a node do when it needs to create a frame and the ARP cache does not contain a map of an IP address to a destination MAC address? It generates an ARP request!
- When ARP receives a request to map an IPv4 address to a MAC address, it looks for the cached map in its ARP table. If an entry is not found, the encapsulation of the IPv4 packet fails and the Layer 2 processes notify ARP that it needs a map. The ARP processes then send out an ARP request packet to discover the MAC address of the destination device on the local network. If a device receiving the request has the destination IP address, it responds with an ARP reply. A map is created in the ARP table. Packets for that IPv4 address can now be encapsulated in frames.
- If no device responds to the ARP request, the packet is dropped because a frame cannot be created. This encapsulation failure is reported to the upper layers of the device. If the device is an intermediary device, like a router, the upper layers may choose to respond to the source host with an error in an ICMPv4 packet.
- See Figures 1-5 to view the process used to get the MAC address of the node on the local physical network.

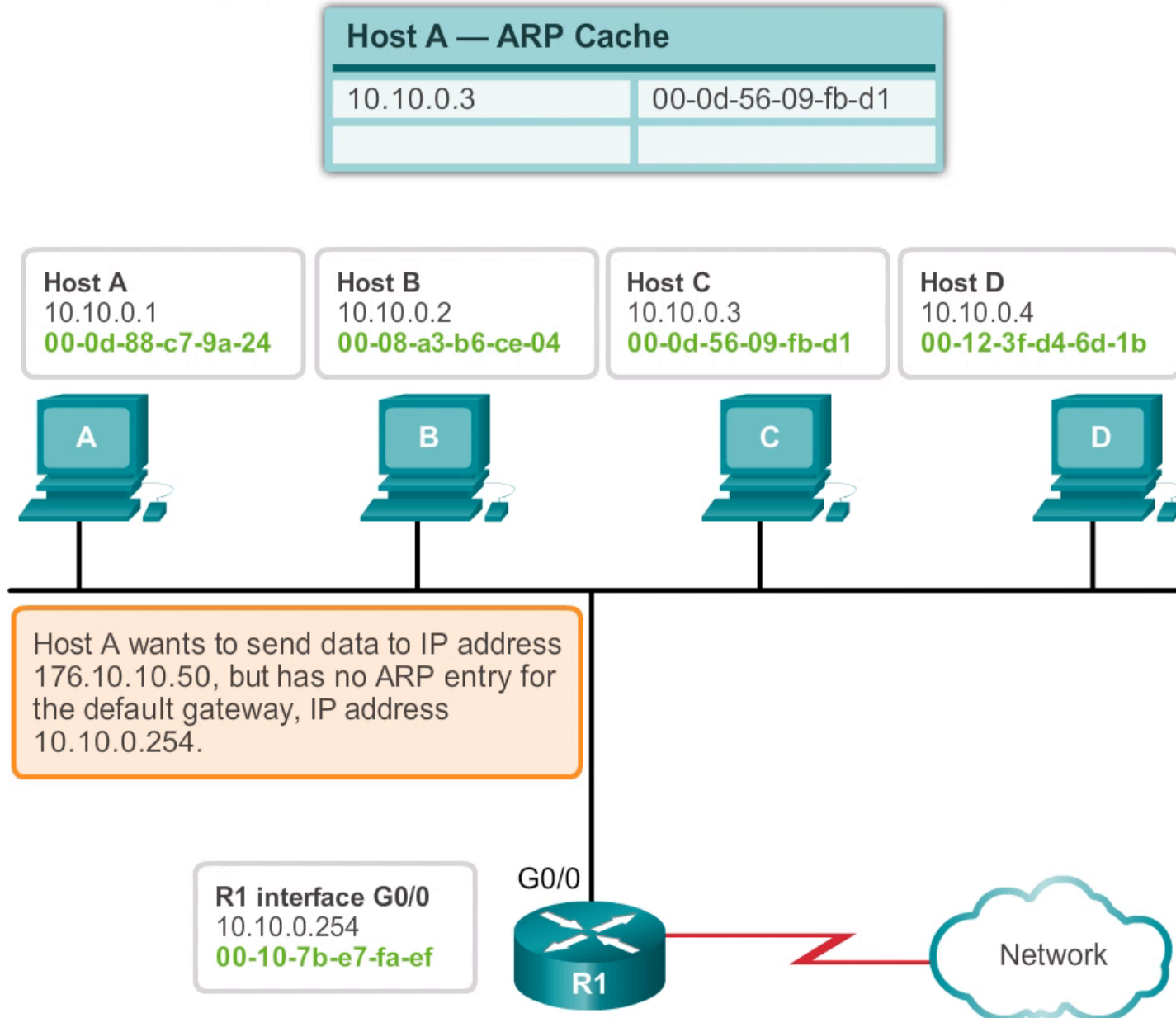
The ARP Process — Communicating Locally



5.2.1.4. ARP Role in Remote Communication

- All frames must be delivered to a node on the local network segment. If the destination IPv4 host is on the local network, the frame will use the MAC address of this device as the destination MAC address.
- If the destination IPv4 host is not on the local network, the source node needs to deliver the frame to the router interface that is the gateway or next hop used to reach that destination. The source node will use the MAC address of the gateway as the destination address for frames containing an IPv4 packet addressed to hosts on other networks.
- The gateway address of the router interface is stored in the IPv4 configuration of the hosts. When a host creates a packet for a destination, it compares the destination IP address and its own IP address to determine if the two IP addresses are located on the same Layer 3 network. If the receiving host is not on the same network, the source uses the ARP process to determine a MAC address for the router interface serving as the gateway.
- In the event that the gateway entry is not in the table, the normal ARP process will send an ARP request to retrieve the MAC address associated with the IP address of the router interface.
- See Figures 1-5 to view the process used to get the MAC address of the gateway.

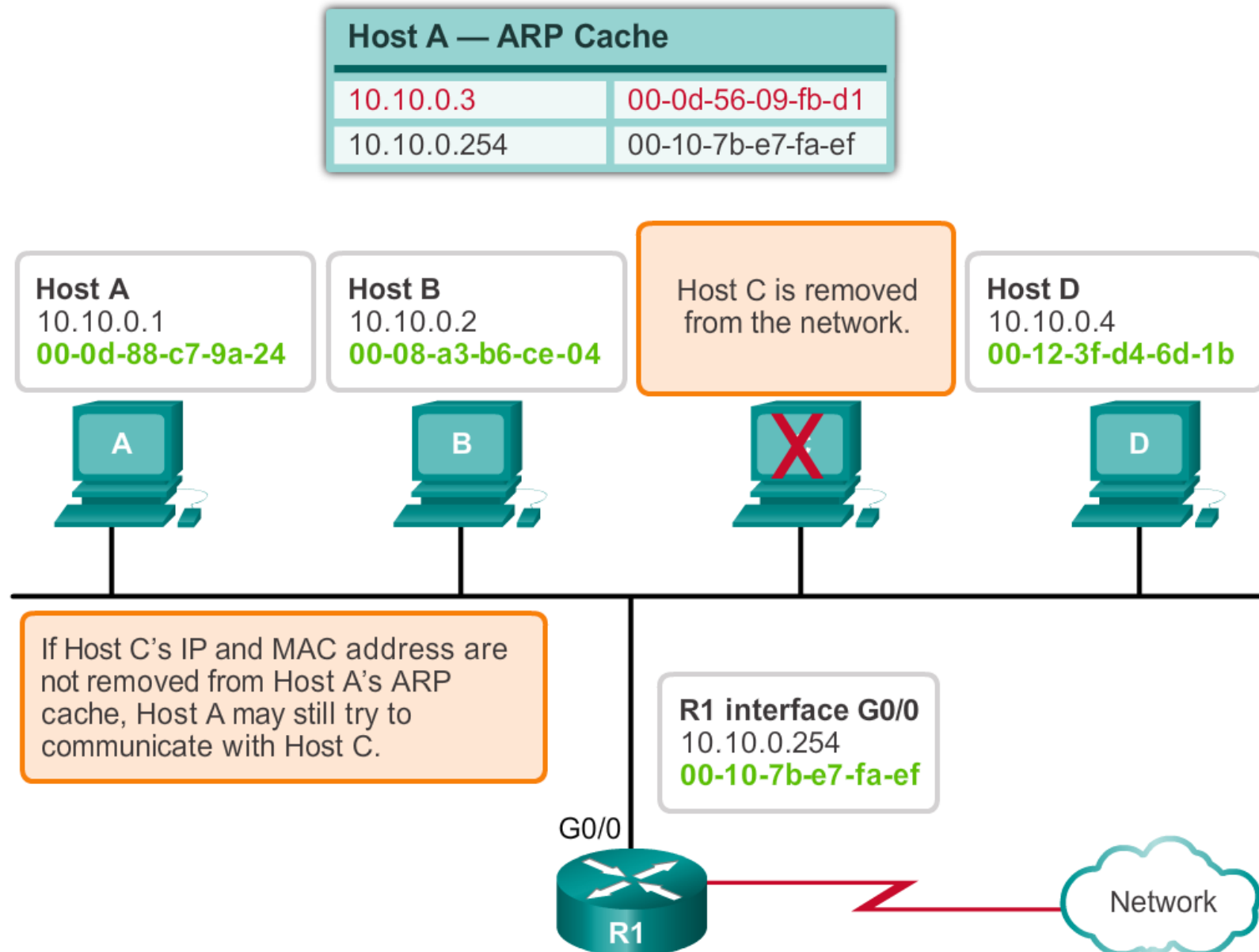
The ARP Process — Communicating Remotely



5.2.1.5. Removing Entries from an ARP Table

- For each device, an ARP cache timer removes ARP entries that have not been used for a specified period of time. The times differ depending on the device and its operating system. For example, some Windows operating systems store ARP cache entries for 2 minutes. If the entry is used again during that time, the ARP timer for that entry is extended to 10 minutes.
- Commands may also be used to manually remove all or some of the entries in the ARP table. After an entry has been removed, the process for sending an ARP request and receiving an ARP reply must occur again to enter the map in the ARP table.
- Each device has an operating system-specific command to delete the contents of the ARP cache. These commands do not invoke the execution of ARP in any way. They merely remove the entries of the ARP table. ARP service is integrated within the IPv4 protocol and implemented by the device. Its operation is transparent to both upper layer applications and users.
- As shown in the figure, it is sometimes necessary to remove an ARP table entry.

Removing MAC-to-IP Address Mappings



5.2.1.6. ARP Tables on Networking Devices

- On a Cisco router, the show ip arp command is used to display the ARP table, as shown in Figure 1.

```
Router#show ip arp
```

Protocol	Address	Age (min)	Hardware Addr	Type	Interface
Internet	172.16.233.229	-	0000.0c59.f892	ARPA	Ethernet0/0
Internet	172.16.233.218	-	0000.0c07.ac00	ARPA	Ethernet0/0
Internet	172.16.168.11	-	0000.0c63.1300	ARPA	Ethernet0/0
Internet	172.16.168.254	9	0000.0c36.6965	ARPA	Ethernet0/0

- On a Windows 7 PC, the arp -a command is used to display the ARP table, as shown in Figure 2.

```
C:\>arp -a

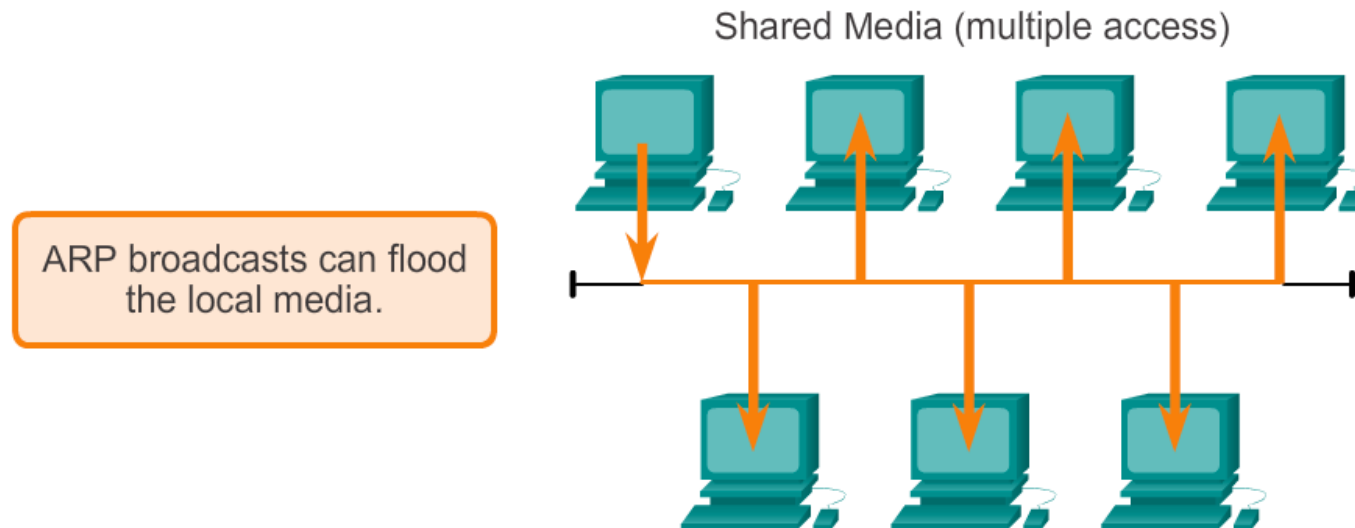
Interface: 192.168.1.67 --- 0xa
  Internet Address      Physical Address      Type
  192.168.1.254         64-0f-29-0d-36-91    dynamic
  192.168.1.255         ff-ff-ff-ff-ff-ff    static
  224.0.0.22            01-00-5e-00-00-16    static
  224.0.0.251          01-00-5e-00-00-fb    static
  224.0.0.252          01-00-5e-00-00-fc    static
  255.255.255.255      ff-ff-ff-ff-ff-ff    static

Interface: 10.82.253.91 --- 0x10
  Internet Address      Physical Address      Type
  10.82.253.92         64-0f-29-0d-36-91    dynamic
  224.0.0.22           01-00-5e-00-00-16    static
  224.0.0.251          01-00-5e-00-00-fb    static
  224.0.0.252          01-00-5e-00-00-fc    static
  255.255.255.255      ff-ff-ff-ff-ff-ff    static
```

5.2.2. ARP Issues

5.2.2.1. How ARP Can Create Problems

- The figure shows two potential issues with ARP.
- **Overhead on the Media**
 - As a broadcast frame, an ARP request is received and processed by every device on the local network. On a typical business network, these broadcasts would probably have minimal impact on network performance. However, if a large number of devices were to be powered up and all start accessing network services at the same time, there could be some reduction in performance for a short period of time. For example, if all students in a lab logged into classroom computers and attempted to access the Internet at the same time, there could be delays. However, after the devices send out the initial ARP broadcasts and have learned the necessary MAC addresses, any impact on the network will be minimized.
- **Security**
 - In some cases, the use of ARP can lead to a potential security risk. ARP spoofing, or ARP poisoning, is a technique used by an attacker to inject the wrong MAC address association into a network by issuing fake ARP replies. An attacker forges the MAC address of a device and then frames can be sent to the wrong destination.
 - Manually configuring static ARP associations is one way to prevent ARP spoofing. Authorized MAC addresses can be configured on some network devices to restrict network access to only those devices listed.



ARP Issues:

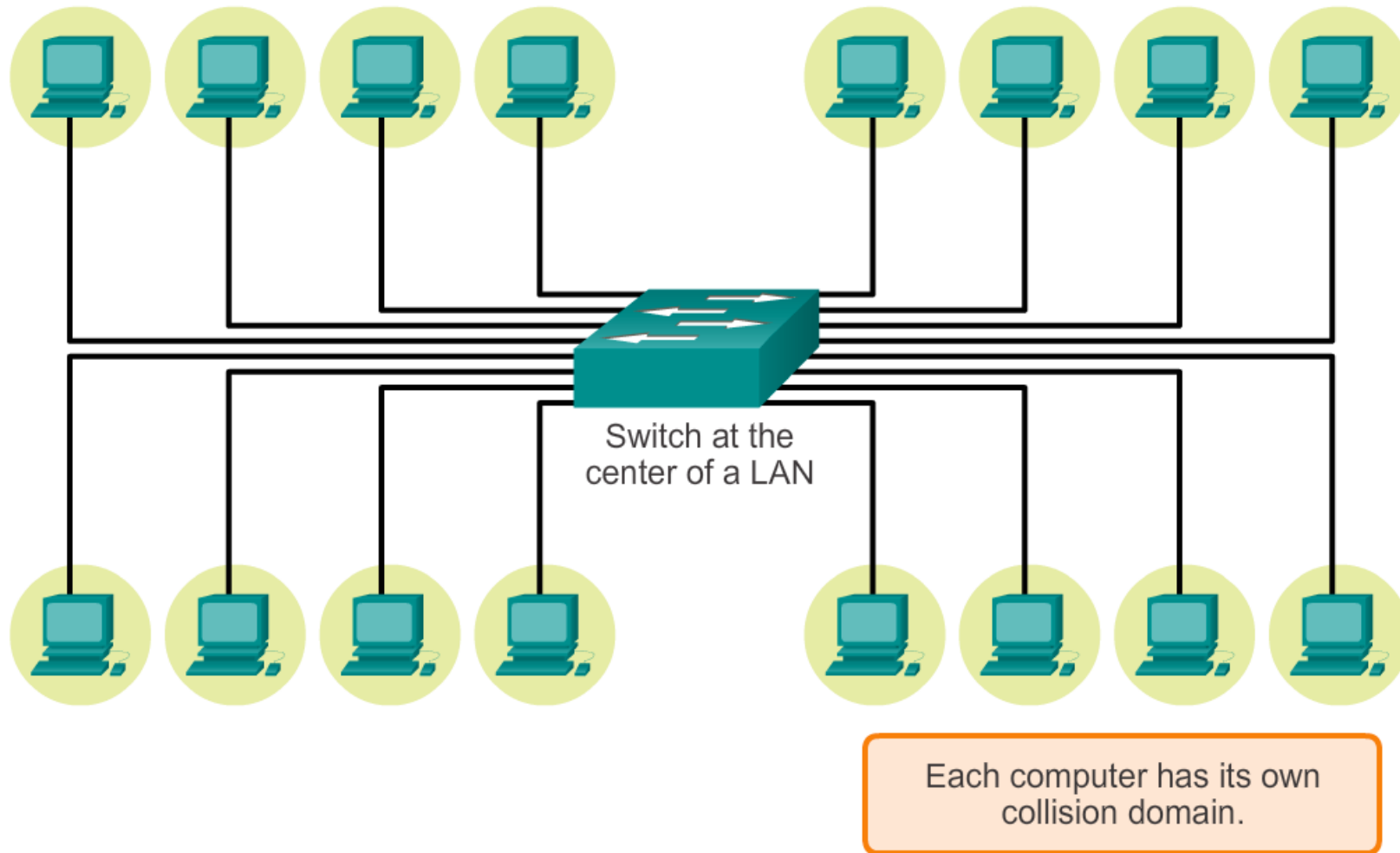
- Broadcasts, overhead on the media
- Security

A false ARP message can provide an incorrect MAC address that will then hijack frames using that address (called a spoof).

5.2.2.2. Mitigating ARP Problems

- Broadcast and security issues related to ARP can be mitigated with modern switches. Cisco switches support several security technologies specifically designed to mitigate Ethernet issues related to broadcasts, in general, and ARP, in particular.
- Switches provide segmentation of a LAN, dividing the LAN into independent collision domains. Each port on a switch represents a separate collision domain and provides the full media bandwidth to the node or nodes connected on that port. While switches do not by default prevent broadcasts from propagating to connected devices, they do isolate unicast Ethernet communications so that they are only "heard" by the source and destination devices. So if there are a large number of ARP requests, each ARP reply will only be between two devices.
- With regard to mitigating various types of broadcast attacks, to which Ethernet networks are prone, network engineers implement Cisco switch security technologies such as specialized access lists and port security.

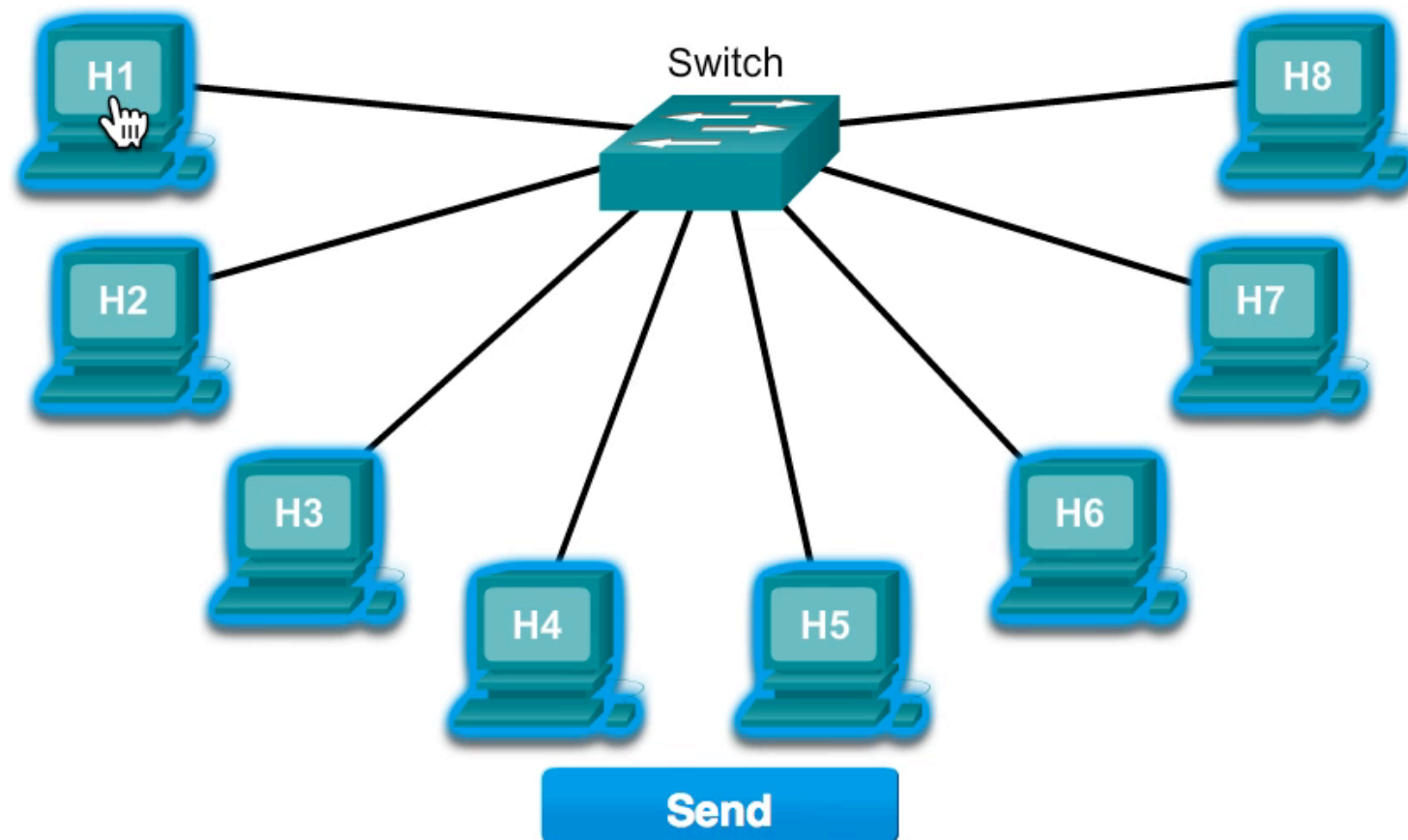
Segmentation



5.3. LAN Switches

5.3.1. Switching

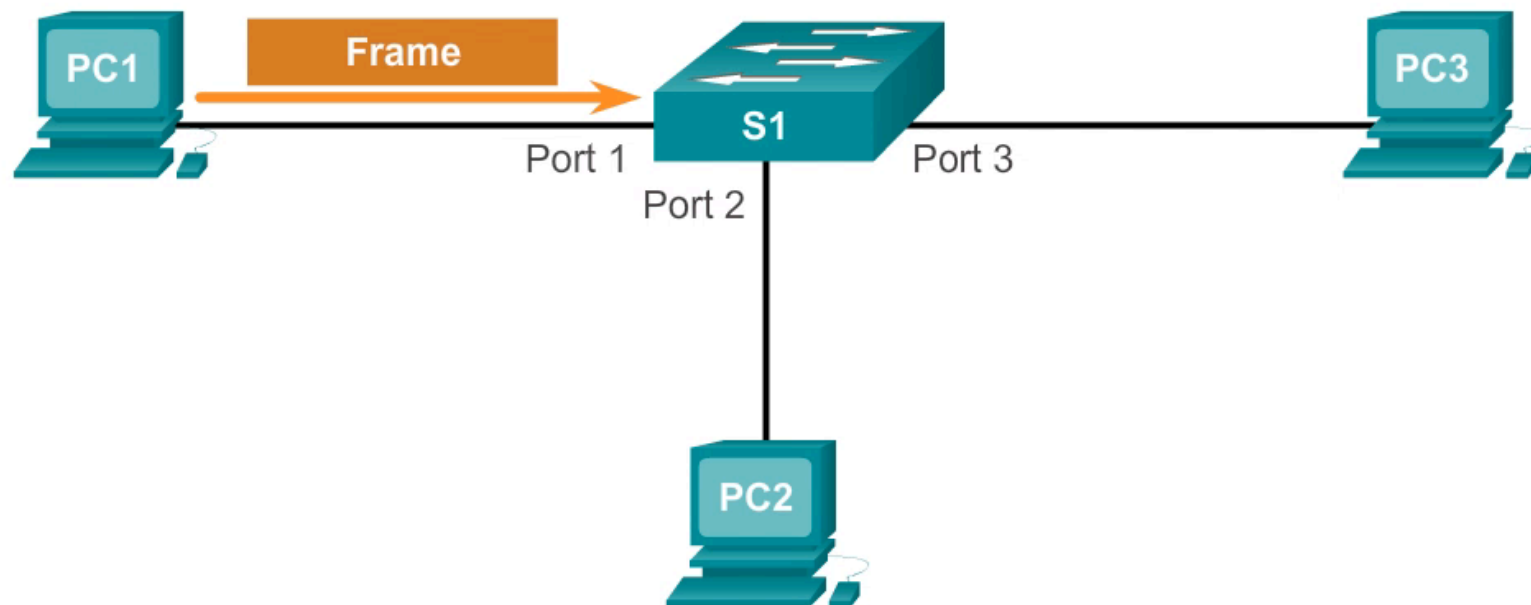
- The physical topology of most Ethernet networks today is that of a star or extended star. This means that on most Ethernet networks, end devices are typically connected, in a point-to-point basis, to a Layer 2 LAN switch.
- A Layer 2 LAN switch performs switching and filtering based only on the OSI data link layer (Layer 2) MAC address. A switch is completely transparent to network protocols and user applications. A Layer 2 switch builds a MAC address table that it uses to make forwarding decisions. Layer 2 switches depend on routers to pass data between independent IP subnetworks.



5.3.1.2. Switch MAC Address Table

- Switches use MAC addresses to direct network communications through their switch fabric to the appropriate port toward the destination node. The switch fabric is the integrated circuits and the accompanying machine programming that allows the data paths through the switch to be controlled. For a switch to know which port to use to transmit a unicast frame, it must first learn which nodes exist on each of its ports.
- The following describes this process:
 - Step 1. The switch receives a broadcast frame from PC1 on Port 1.
 - Step 2. The switch enters the source MAC address and the switch port that received the frame into the address table.
 - Step 3. Because the destination address is a broadcast, the switch floods the frame to all ports, except the port on which it received the frame.
 - Step 4. The destination device replies to the broadcast with a unicast frame addressed to PC1.
 - Step 5. The switch enters the source MAC address of PC3 and the port number of the switch port that received the frame into the address table. The destination address of the frame and its associated port is found in the MAC address table.
 - Step 6. The switch can now forward frames between source and destination devices without flooding, because it has entries in the address table that identify the associated ports.

MAC Addressing and Switch MAC Tables



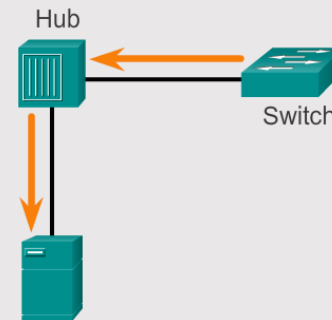
5.3.1.3. Duplex Setting

- There are two types of duplex settings used for communications on an Ethernet network: half duplex and full duplex.

Duplex Settings

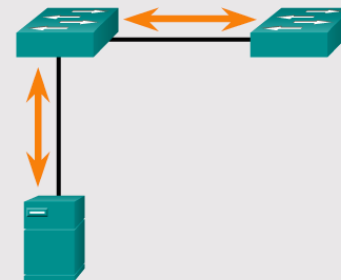
Half Duplex (CSMA/CD)

- Unidirectional data flow
- Higher potential for collision
- Hub connectivity



Full Duplex

- Point-to-point only
- Attached to dedicated switched port
- Requires full-duplex support on both ends
- Collision-free
- Collision detect circuit disabled



- **Half Duplex**

- Half-duplex communication relies on unidirectional data flow where sending and receiving data are not performed at the same time. This is similar to how walkie-talkies or two-way radios function in that only one person can talk at any one time. If someone talks while someone else is already speaking, a collision occurs. As a result, half-duplex communication implements CSMA/CD to help reduce the potential for collisions and detect them when they do happen. Half-duplex communications have performance issues due to the constant waiting, because data can only flow in one direction at a time. Half-duplex connections are typically seen in older hardware, such as hubs. Nodes that are attached to hubs that share their connection to a switch port must operate in half-duplex mode because the end computers must be able to detect collisions. Nodes can operate in a half-duplex mode if the NIC card cannot be configured for full duplex operations. In this case the port on the switch defaults to a half-duplex mode as well. Because of these limitations, full-duplex communication has replaced half duplex in more current hardware.

- **Full Duplex**

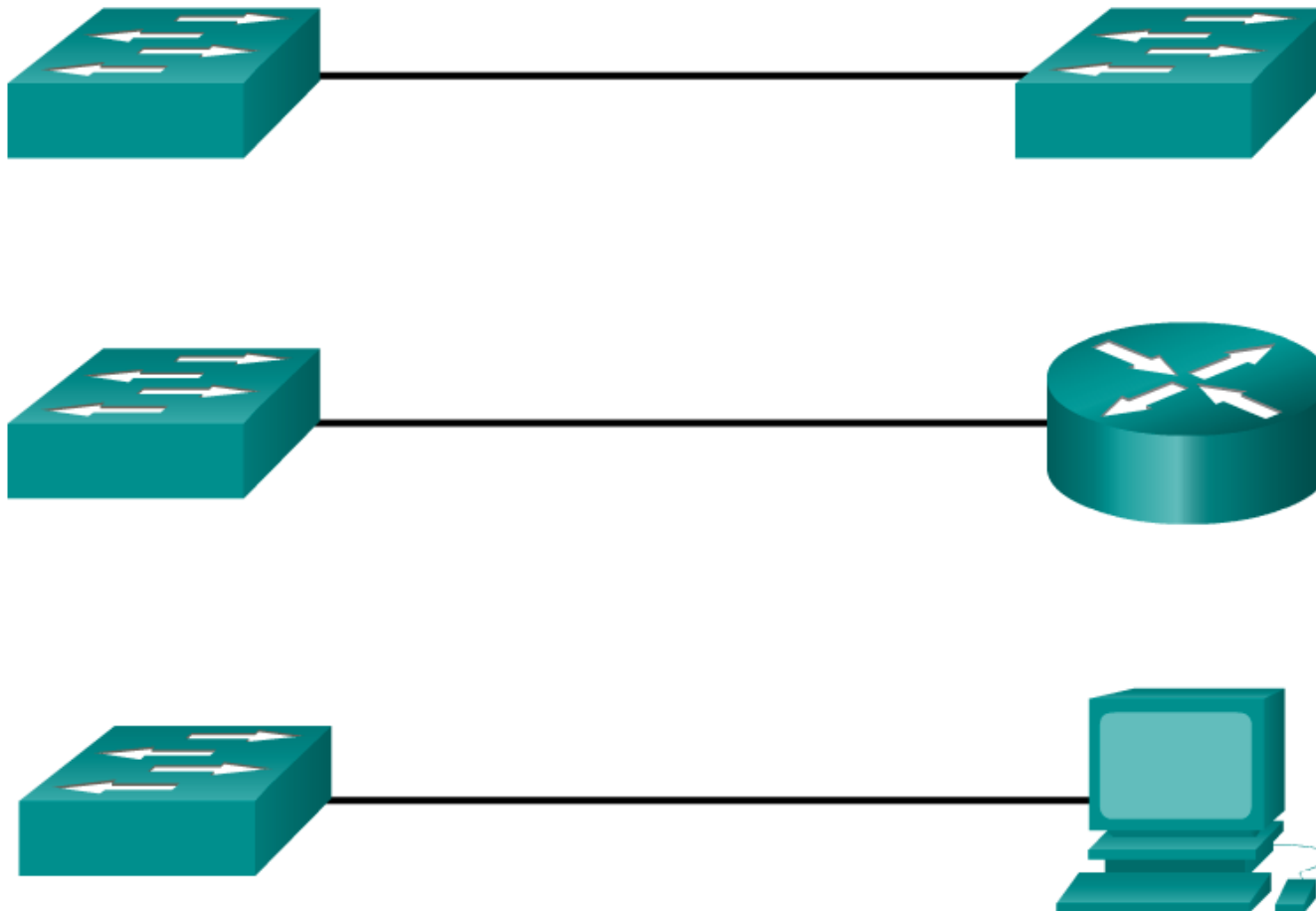
- In full-duplex communication, data flow is bidirectional, so data can be sent and received at the same time. The bidirectional support enhances performance by reducing the wait time between transmissions. Most Ethernet, Fast Ethernet, and Gigabit Ethernet NICs sold today offer full-duplex capability. In full-duplex mode, the collision detect circuit is disabled. Frames sent by the two connected end nodes cannot collide because the end nodes use two separate circuits in the network cable. Each full-duplex connection uses only one port. Full-duplex connections require a switch that supports full duplex or a direct connection between two nodes that each support full duplex. Nodes that are directly attached to a dedicated switch port with NICs that support full duplex should be connected to switch ports that are configured to operate in full-duplex mode.

5.3.1.4. Auto-MDIX

- In addition to having the correct duplex setting, it is also necessary to have the correct cable type defined for each port. Connections between specific devices, such as switch-to-switch, switch-to-router, switch-to-host, and router-to-host device, once required the use of a specific cable types (crossover or straight-through). Instead, most switch devices now support the `mdix auto` interface configuration command in the CLI to enable the automatic medium-dependent interface crossover (auto-MDIX) feature.
- When the auto-MDIX feature is enabled, the switch detects the required cable type for copper Ethernet connections and configures the interfaces accordingly. Therefore, you can use either a crossover or a straight-through cable for connections to a copper 10/100/1000 port on the switch, regardless of the type of device on the other end of the connection.
- The auto-MDIX feature is enabled by default on switches running Cisco IOS Release 12.2(18)SE or later. For releases between Cisco IOS Release 12.1(14)EA1 and 12.2(18)SE, the auto-MDIX feature is disabled by default.

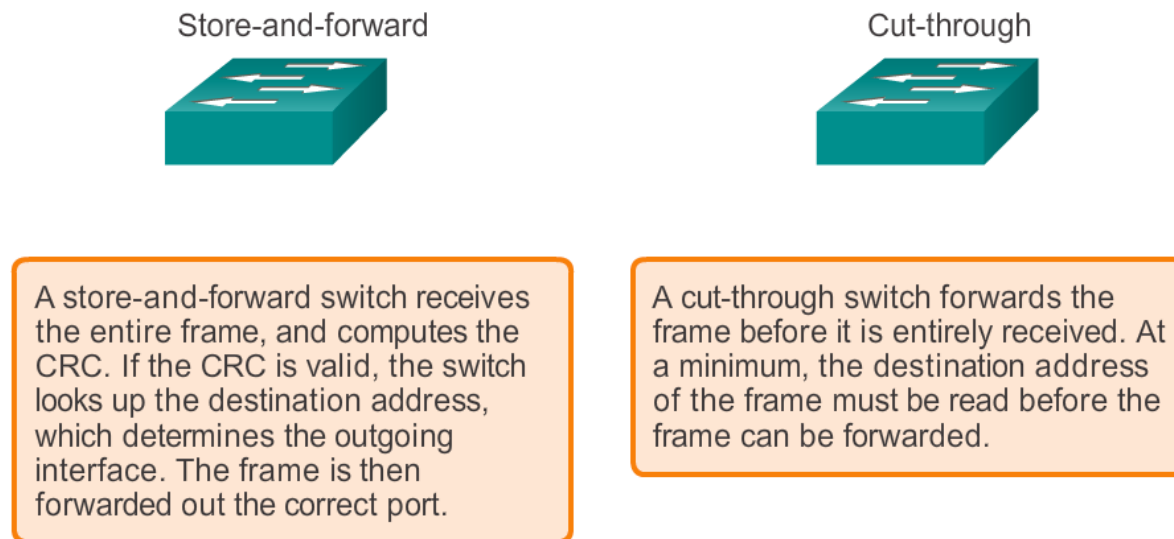
Auto-MDIX

MDIX auto detects the type of connection required and configures the interface accordingly.



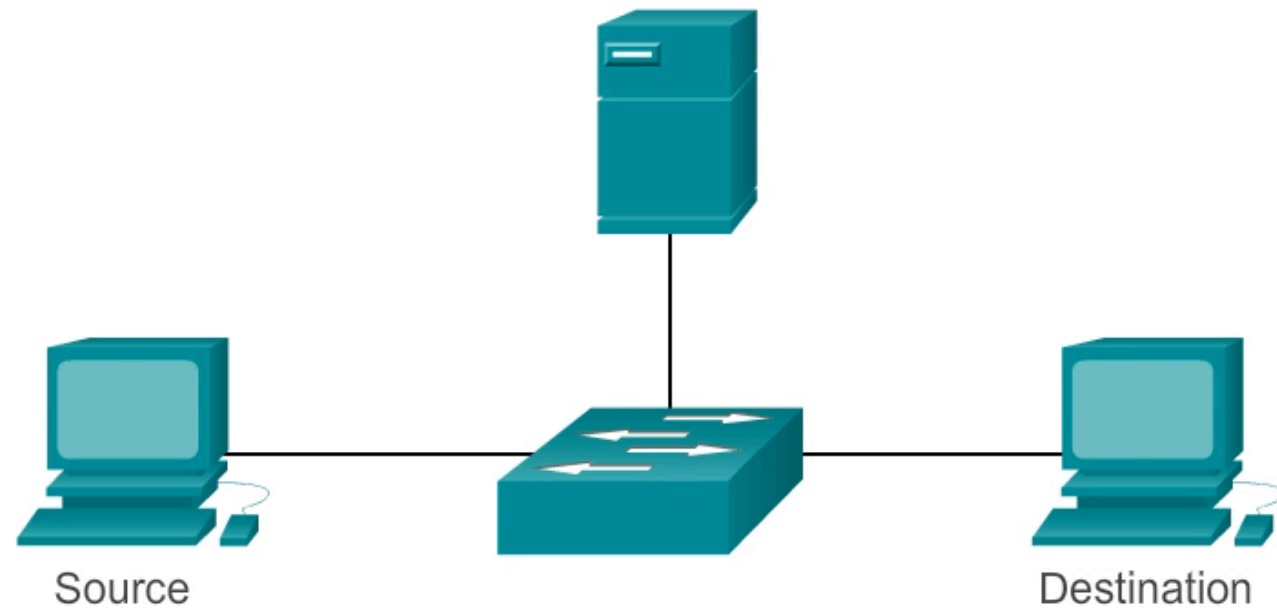
5.3.1.5. Frame Forwarding Methods on Cisco Switches

- In the past, switches used one of the following forwarding methods for switching data between network ports:
 - Store-and-forward switching
 - Cut-through switching
- Figure 1 highlights differences between these two methods.



- In store-and-forward switching, when the switch receives the frame, it stores the data in buffers until the complete frame has been received. During the storage process, the switch analyzes the frame for information about its destination. In this process, the switch also performs an error check using the Cyclic Redundancy Check (CRC) trailer portion of the Ethernet frame.

Store-and-Forward Switching



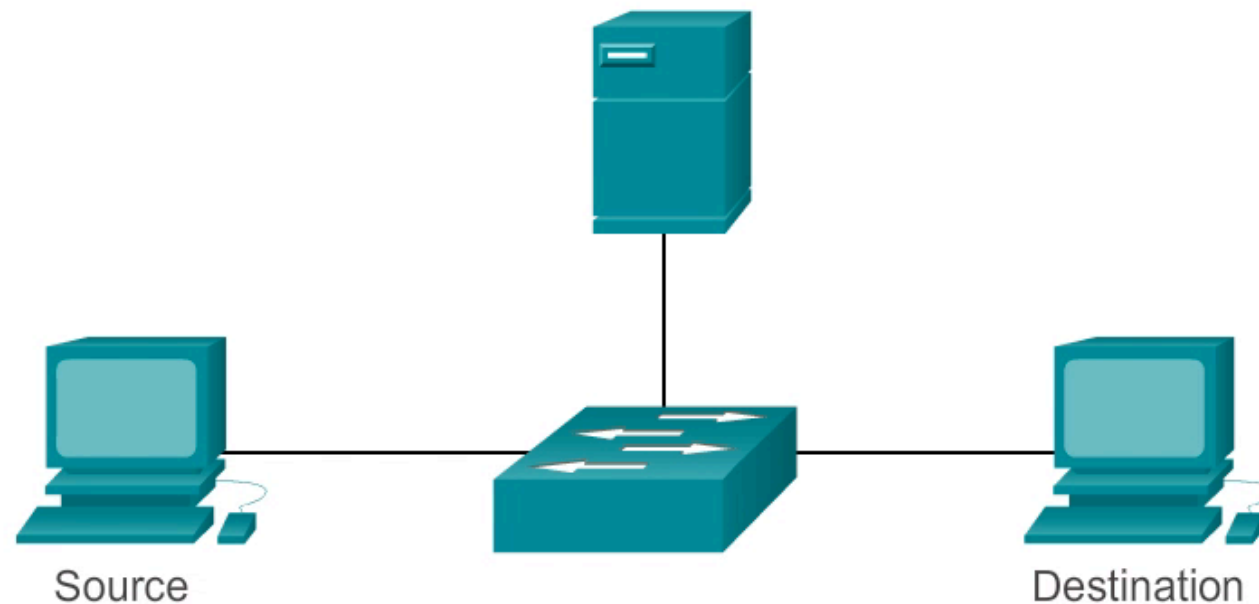
A store-and-forward switch receives the entire frame, and computes the CRC. If the CRC is valid, the switch looks up the destination address, which determines the outgoing interface. The frame is then forwarded out the correct port.

- Store-and-forward is the sole forwarding method used on current models of Cisco Catalyst switches.

5.3.1.6. Cut-Through Switching

- In cut-through switching, the switch acts upon the data as soon as it is received, even if the transmission is not complete. The switch buffers just enough of the frame to read the destination MAC address so that it can determine to which port to forward the data. The destination MAC address is located in the first 6 bytes of the frame following the preamble. The switch looks up the destination MAC address in its switching table, determines the outgoing interface port, and forwards the frame onto its destination through the designated switch port. The switch does not perform any error checking on the frame. Because the switch does not have to wait for the entire frame to be completely buffered, and because the switch does not perform any error checking, cut-through switching is faster than store-and-forward switching. However, because the switch does not perform any error checking, it forwards corrupt frames throughout the network. The corrupt frames consume bandwidth while they are being forwarded. The destination NIC eventually discards the corrupt frames.

Cut-Through Switching



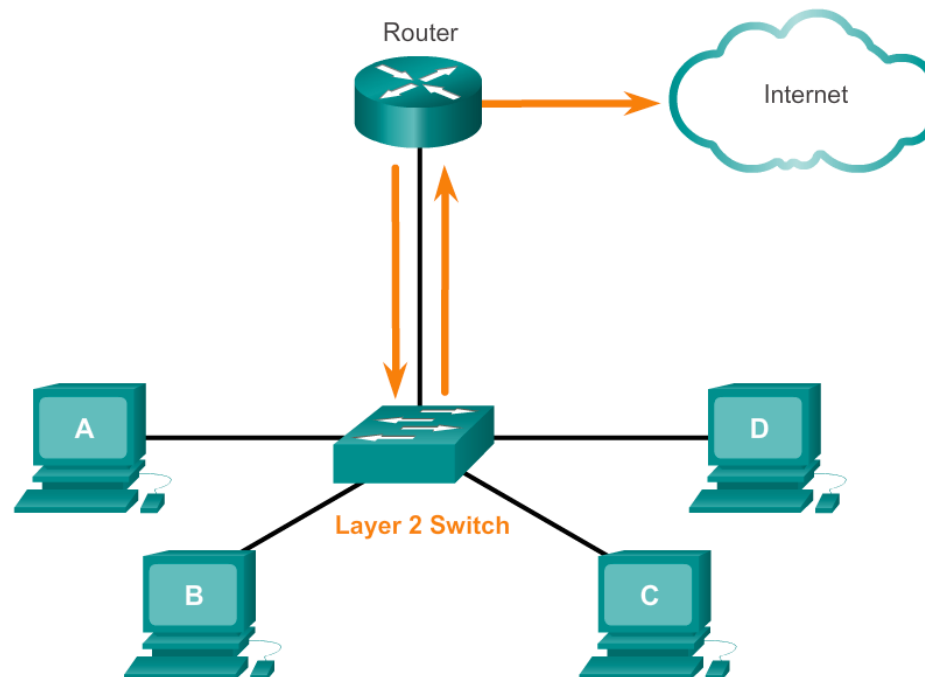
A cut-through switch forwards the frame before it is entirely received. At a minimum, the destination address of the frame must be read before the frame can be forwarded.

- There are two variants of cut-through switching:
 - Fast-forward switching: Fast-forward switching offers the lowest level of latency. Fast-forward switching immediately forwards a packet after reading the destination address. Because fast-forward switching starts forwarding before the entire packet has been received, there may be times when packets are relayed with errors. This occurs infrequently, and the destination network adapter discards the faulty packet upon receipt. In fast-forward mode, latency is measured from the first bit received to the first bit transmitted. Fast-forward switching is the typical cut-through method of switching.
 - Fragment-free switching: In fragment-free switching, the switch stores the first 64 bytes of the frame before forwarding. Fragment-free switching can be viewed as a compromise between store-and-forward switching and fast-forward switching. The reason fragment-free switching stores only the first 64 bytes of the frame is that most network errors and collisions occur during the first 64 bytes. Fragment-free switching tries to enhance fast-forward switching by performing a small error check on the first 64 bytes of the frame to ensure that a collision has not occurred before forwarding the frame. Fragment-free switching is a compromise between the high latency and high integrity of store-and-forward switching, and the low latency and reduced integrity of fast-forward switching.

5.3.3. Layer 3 Switching

- Layer 3 switches are also capable of performing Layer 3 routing functions, reducing the need for dedicated routers on a LAN. Because Layer 3 switches have specialized switching hardware, they can typically route data as quickly as they can switch.

Layer 2 Switching



Layer 3 Switching

