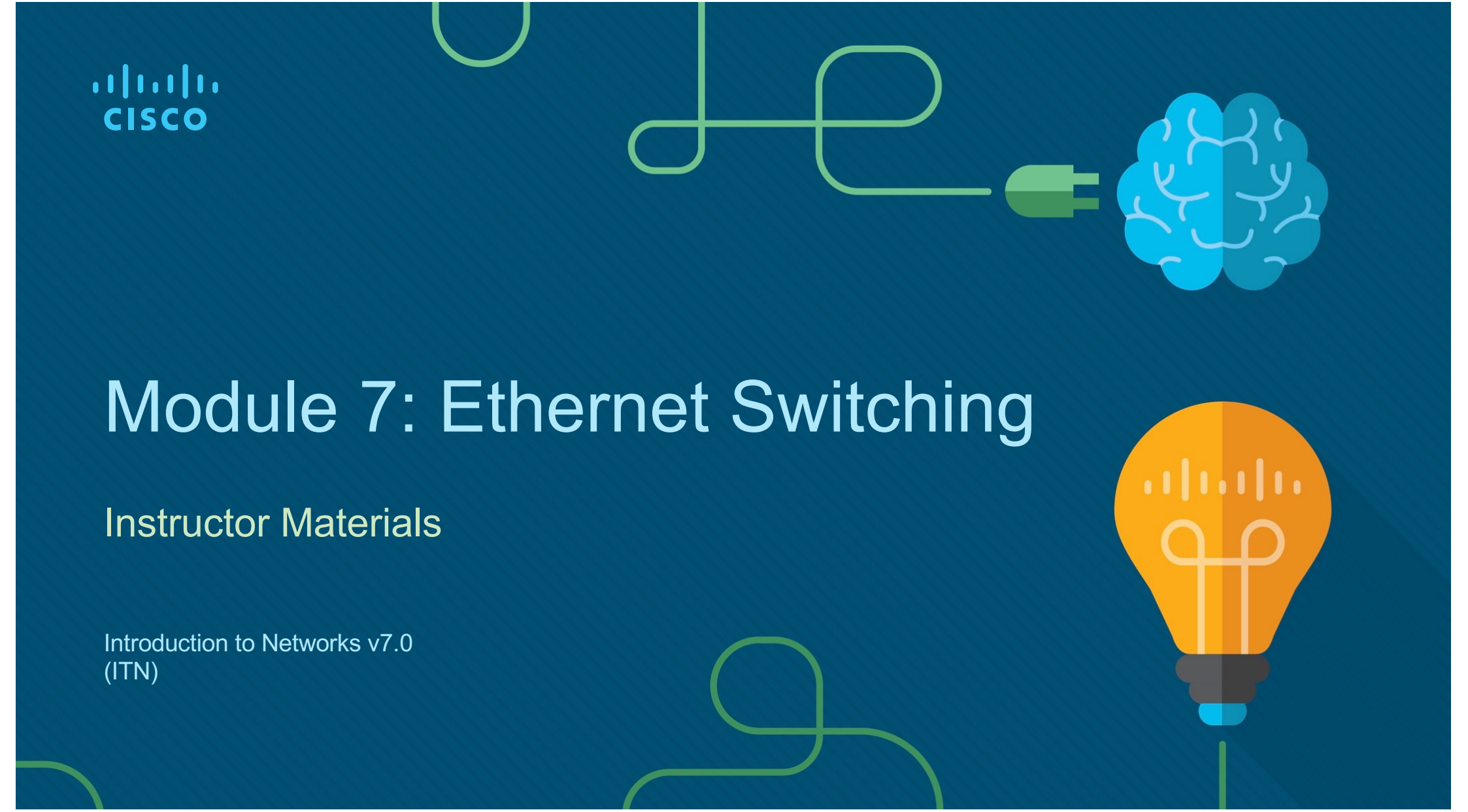


Module 7: Ethernet Switching

Instructor Materials

Introduction to Networks v7.0
(ITN)

Module Objectives

Module Title: Ethernet Switching

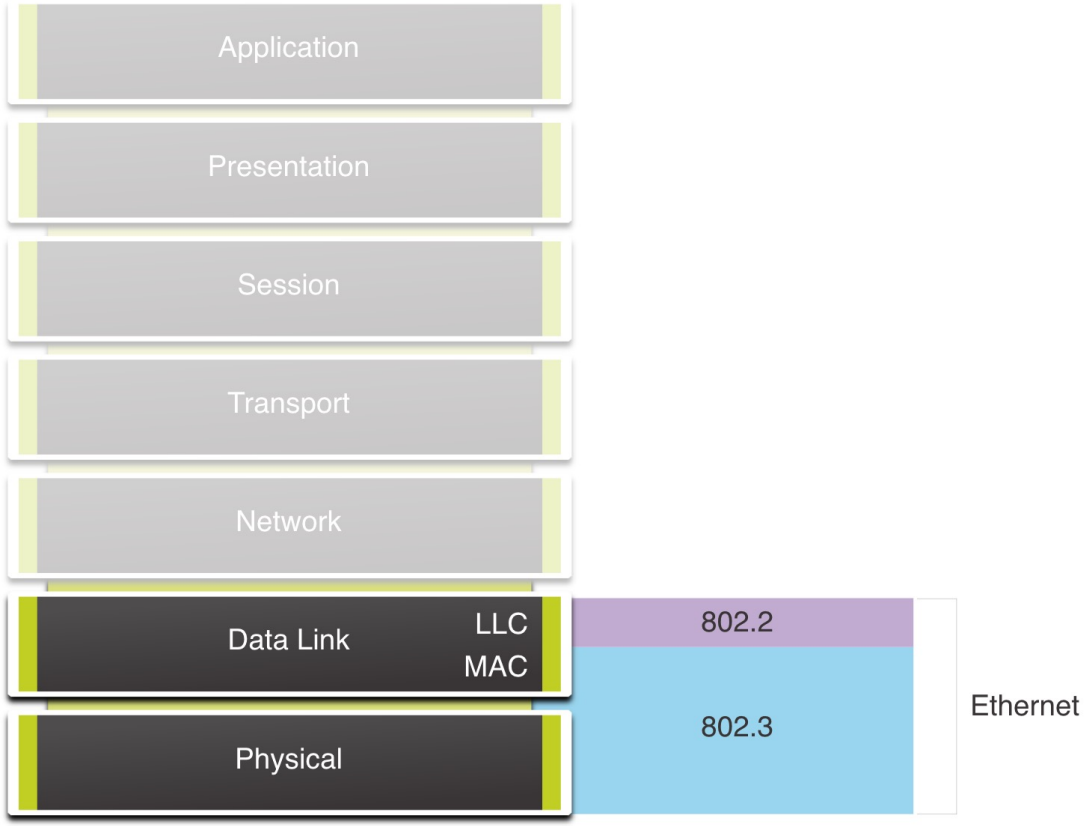
Module Objective: Explain how Ethernet works in a switched network.

Topic Title	Topic Objective
Ethernet Frame	Explain how the Ethernet sublayers are related to the frame fields.
Ethernet MAC Address	Describe the Ethernet MAC address.
The MAC Address Table	Explain how a switch builds its MAC address table and forwards frames.
Switch Speeds and Forwarding Methods	Describe switch forwarding methods and port settings available on Layer 2 switch ports.

Ethernet Frames

Ethernet Encapsulation

- Ethernet operates in the data link layer and the physical layer.
- It is a family of networking technologies defined in the IEEE 802.2 and 802.3 standards.

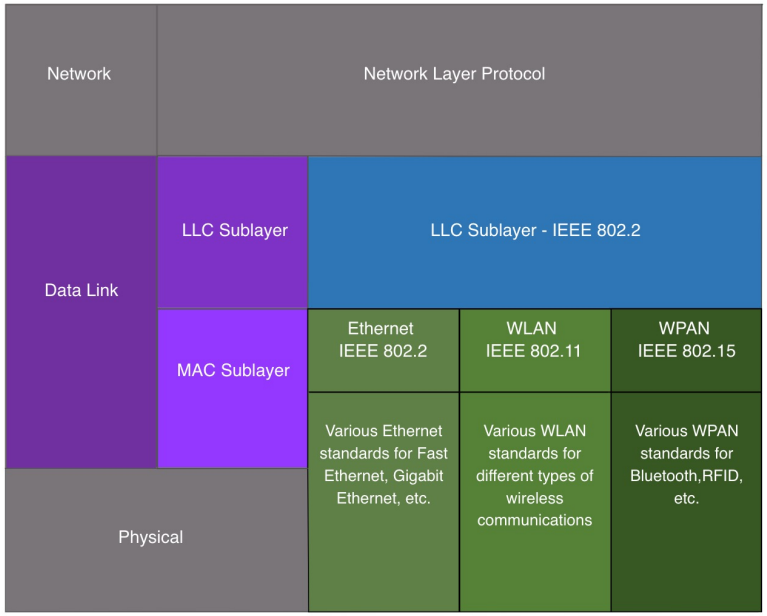


Ethernet Frames

Data Link Sublayers

The 802 LAN/MAN standards, including Ethernet, use two separate sublayers of the data link layer to operate:

- **LLC Sublayer**: (IEEE 802.2) Places information in the frame to identify which network layer protocol is used for the frame.
- **MAC Sublayer**: (IEEE 802.3, 802.11, or 802.15) Responsible for data encapsulation and media access control, and provides data link layer addressing.



Ethernet Frames

MAC Sublayer

The MAC sublayer is responsible for data encapsulation and accessing the media.

Data Encapsulation

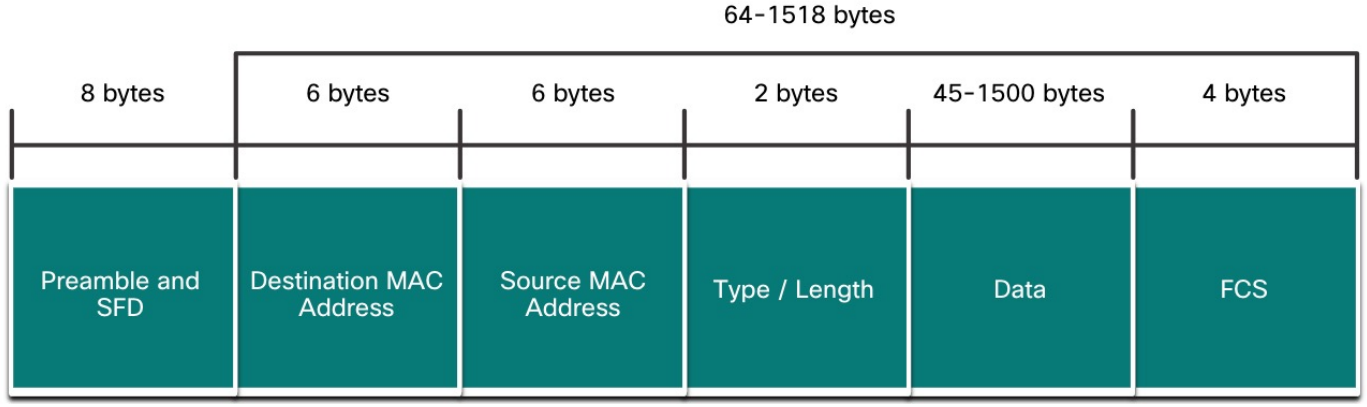
IEEE 802.3 data encapsulation includes the following:

1. **Ethernet frame** - This is the internal structure of the Ethernet frame.
2. **Ethernet Addressing** - The Ethernet frame includes both a source and destination MAC address to deliver the Ethernet frame from Ethernet NIC to Ethernet NIC on the same LAN.
3. **Ethernet Error detection** - The Ethernet frame includes a frame check sequence (FCS) trailer used for error detection.

Ethernet Frames

Ethernet Frame Fields

- The minimum Ethernet frame size is 64 bytes and the maximum is 1518 bytes. The preamble field is not included when describing the size of the frame.
- Any frame less than 64 bytes in length is considered a “collision fragment” or “runt frame” and is automatically discarded. Frames with more than 1500 bytes of data are considered “jumbo” or “baby giant frames”.
- 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. They are considered invalid. Jumbo frames are usually supported by most Fast Ethernet and Gigabit Ethernet switches and NICs.

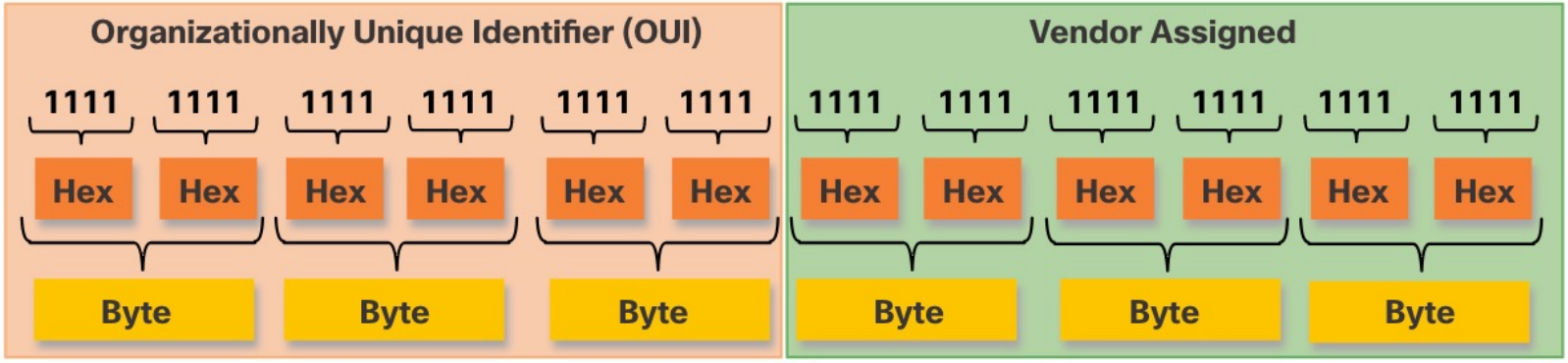


MAC Address and Hexadecimal

- An Ethernet MAC address consists of a 48-bit binary value, expressed using 12 hexadecimal values.
- Given that 8 bits (one byte) is a common binary grouping, binary 00000000 to 11111111 can be represented in hexadecimal as the range 00 to FF,
- When using hexadecimal, leading zeroes are always displayed to complete the 8-bit representation. For example the binary value 0000 1010 is represented in hexadecimal as 0A.
- Hexadecimal numbers are often represented by the value preceded by **0x** (e.g., 0x73) to distinguish between decimal and hexadecimal values in documentation.
- Hexadecimal may also be represented by a subscript 16, or the hex number followed by an H (e.g., 73H).

Ethernet MAC Address

- In an Ethernet LAN, every network device is connected to the same, shared media. MAC addressing provides a method for device identification at the data link layer of the OSI model.
- An Ethernet MAC address is a 48-bit address expressed using 12 hexadecimal digits. Because a byte equals 8 bits, we can also say that a MAC address is 6 bytes in length.
- All MAC addresses must be unique to the Ethernet device or Ethernet interface. To ensure this, all vendors that sell Ethernet devices must register with the IEEE to obtain a unique 6 hexadecimal (i.e., 24-bit or 3-byte) code called the organizationally unique identifier (OUI).
- An Ethernet MAC address consists of a 6 hexadecimal vendor OUI code followed by a 6 hexadecimal vendor-assigned value.



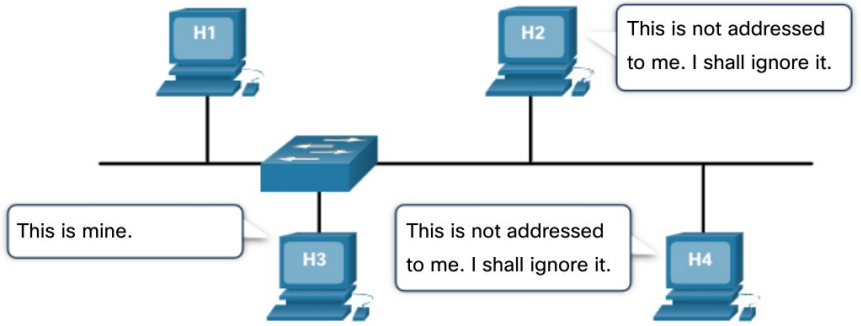
Ethernet MAC Addresses

Frame Processing

- When a device is forwarding a message to an Ethernet network, the Ethernet header include a Source MAC address and a Destination MAC address.
- When a NIC receives an Ethernet frame, it examines the destination MAC address to see if it matches the physical MAC address that is stored in RAM. If there is no match, the device discards the frame. If there is a match, it passes the frame up the OSI layers, where the de-encapsulation process takes place.

Note: Ethernet NICs will also accept frames if the destination MAC address is a broadcast or a multicast group of which the host is a member.

- Any device that is the source or destination of an Ethernet frame, will have an Ethernet NIC and therefore, a MAC address. This includes workstations, servers, printers, mobile devices, and routers.



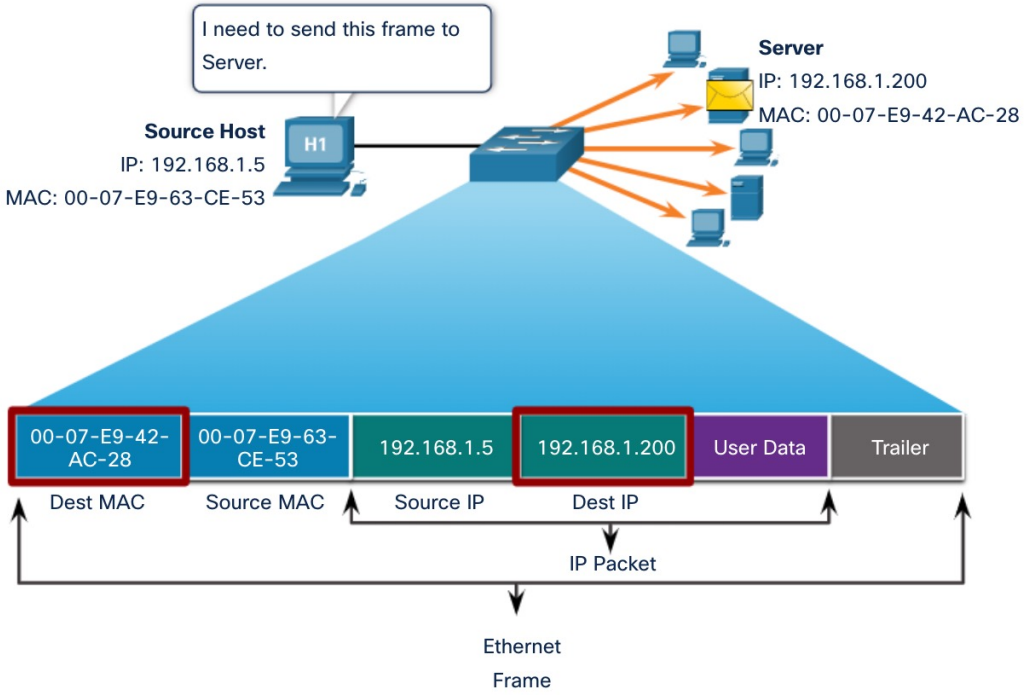
Ethernet MAC Addresses

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 that is used when a frame is sent from a single transmitting device to a single destination device.
- The process that a source host uses to determine the destination MAC address associated with an IPv4 address is known as Address Resolution Protocol (ARP). The process that a source host uses to determine the destination MAC address associated with an IPv6 address is known as Neighbor Discovery (ND).

Note: The source MAC address must always be a unicast.

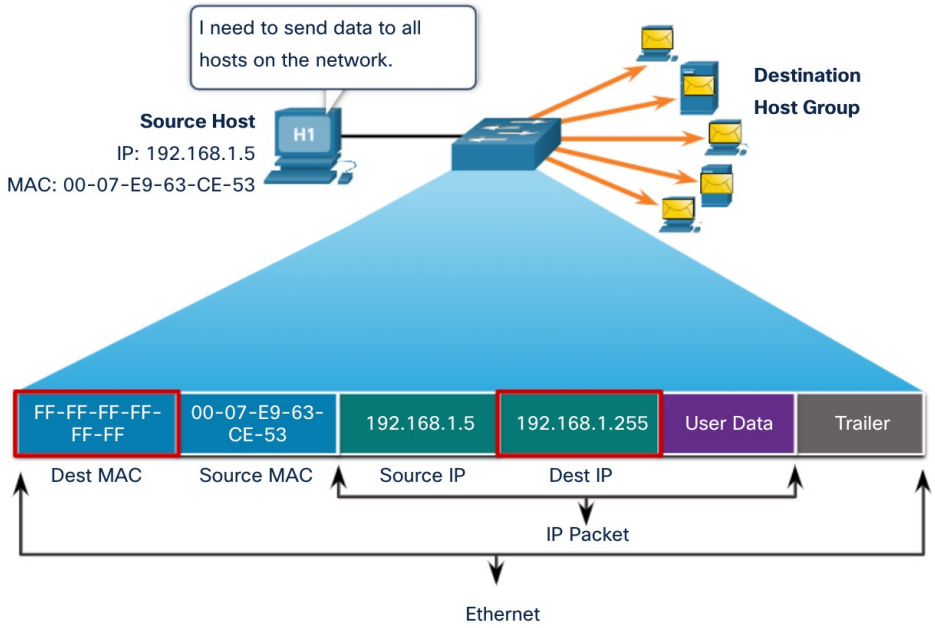


Ethernet MAC Addresses

Broadcast MAC Address

An Ethernet broadcast frame is received and processed by every device on the Ethernet LAN. The features of an Ethernet broadcast are as follows:

- It has a destination MAC address of FF-FF-FF-FF-FF-FF in hexadecimal (48 ones in binary).
- It is flooded out all Ethernet switch ports except the incoming port. It is not forwarded by a router.
- If the encapsulated data is an IPv4 broadcast packet, this means the packet contains a destination IPv4 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.

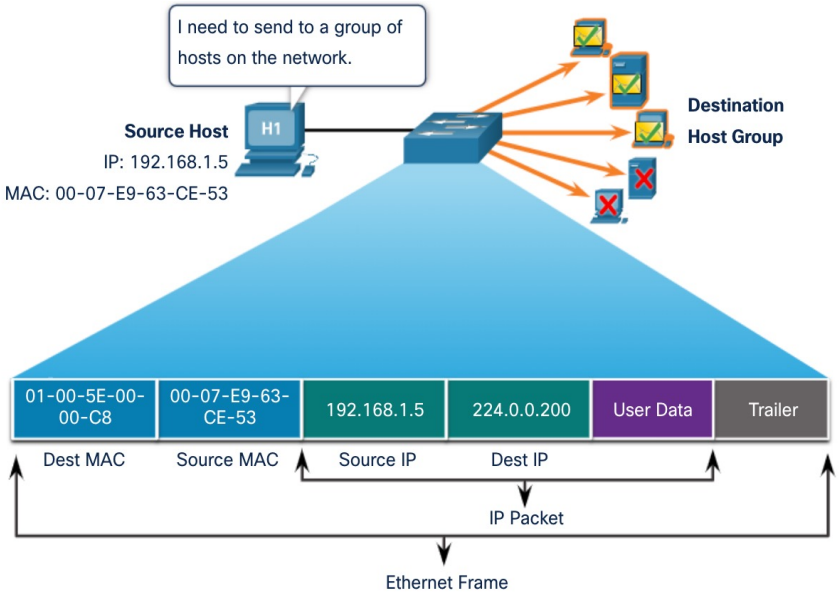


Ethernet MAC Addresses

Multicast MAC Address

An Ethernet multicast frame is received and processed by a group of devices that belong to the same multicast group.

- There is a destination MAC address of 01-00-5E when the encapsulated data is an IPv4 multicast packet and a destination MAC address of 33-33 when the encapsulated data is an IPv6 multicast packet.
- There are other reserved multicast destination MAC addresses for when the encapsulated data is not IP, such as Spanning Tree Protocol (STP).
- It is flooded out all Ethernet switch ports except the incoming port, unless the switch is configured for multicast snooping. It is not forwarded by a router, unless the router is configured to route multicast packets.
- 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 be a unicast address.
- As with the unicast and broadcast addresses, the multicast IP address requires a corresponding multicast MAC address.



Switch Fundamentals

- A Layer 2 Ethernet switch uses Layer 2 MAC addresses to make forwarding decisions. It is completely unaware of the data (protocol) being carried in the data portion of the frame, such as an IPv4 packet, an ARP message, or an IPv6 ND packet. The switch makes its forwarding decisions based solely on the Layer 2 Ethernet MAC addresses.
- An Ethernet switch examines its MAC address table to make a forwarding decision for each frame, unlike legacy Ethernet hubs that repeat bits out all ports except the incoming port.
- When a switch is turned on, the MAC address table is empty

Note: The MAC address table is sometimes referred to as a content addressable memory (CAM) table.

Switch Learning and Forwarding

Examine the Source MAC Address (Learn)

Every frame that enters a switch is checked for new information to learn. It does this by examining the source MAC address of the frame and the port number where the frame entered the switch. If the source MAC address does not exist, it is added to the table along with the incoming port number. If the source MAC address does exist, the switch updates the refresh timer for that entry. By default, most Ethernet switches keep an entry in the table for 5 minutes.

Note: If the source MAC address does exist in the table but on a different port, the switch treats this as a new entry. The entry is replaced using the same MAC address but with the more current port number.

Switch Learning and Forwarding (Contd.)

Find the Destination MAC Address (Forward)

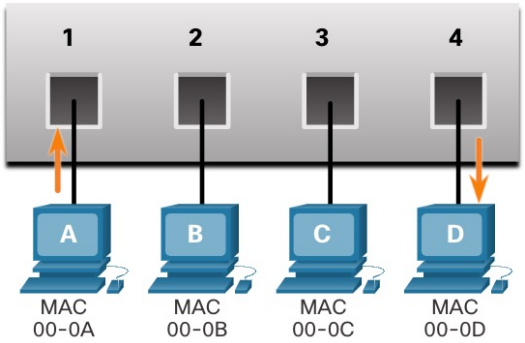
If the destination MAC address is a unicast address, the switch will look for a match between the destination MAC address of the frame and an entry in its MAC address table. If the destination MAC address is in the table, it will forward the frame out the specified port. If the destination MAC address is not in the table, the switch will forward the frame out all ports except the incoming port. This is called an unknown unicast.

Note: If the destination MAC address is a broadcast or a multicast, the frame is also flooded out all ports except the incoming port.

Filtering Frames

As a switch receives frames from different devices, it is able to populate its MAC address table by examining the source MAC address of every frame. When the MAC address table of the switch contains the destination MAC address, it is able to filter the frame and forward out a single port.

MAC Address Table	
Port	**MAC Address**
1	00-0A
4	00-0D



Frame Forwarding Methods on Cisco Switches

Switches use one of the following forwarding methods for switching data between network ports:

- **Store-and-forward switching** - This frame forwarding method 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. Then the frame is forwarded out of the correct port.
- **Cut-through switching** - This frame forwarding method 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.

- A big advantage of store-and-forward switching is that it determines if a frame has errors before propagating the frame. When an error is detected in a frame, the switch discards the frame. Discarding frames with errors reduces the amount of bandwidth consumed by corrupt data.
- Store-and-forward switching is required for quality of service (QoS) analysis on converged networks where frame classification for traffic prioritization is necessary. For example, voice over IP (VoIP) data streams need to have priority over web-browsing traffic.

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 it should forward out the data. The switch does not perform any error checking on the frame.

There are two variants of cut-through switching:

- **Fast-forward switching -** Offers the lowest level of latency by immediately forwarding 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. The destination NIC discards the faulty packet upon receipt. Fast-forward switching is the typical cut-through method of switching.
- **Fragment-free switching -** 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, the switch stores and performs an error check on the first 64 bytes of the frame before forwarding. Because most network errors and collisions occur during the first 64 bytes, this ensures that a collision has not occurred before forwarding the frame.

Memory Buffering on Switches

An Ethernet switch may use a buffering technique to store frames before forwarding them or when the destination port is busy because of congestion.

Method	Description
Port-based memory	•Frames are stored in queues that are linked to specific incoming and outgoing ports. •A frame is transmitted to the outgoing port only when all the frames ahead in the queue have been successfully transmitted. •It is possible for a single frame to delay the transmission of all the frames in memory because of a busy destination port. •This delay occurs even if the other frames could be transmitted to open destination ports.
Shared memory	•Deposits all frames into a common memory buffer shared by all switch ports and the amount of buffer memory required by a port is dynamically allocated. •The frames in the buffer are dynamically linked to the destination port enabling a packet to be received on one port and then transmitted on another port, without moving it to a different queue.

- Shared memory buffering also results in larger frames that can be transmitted with fewer dropped frames. This is important with asymmetric switching which allows for different data rates on different ports. Therefore, more bandwidth can be dedicated to certain ports (e.g., server port).

Duplex and Speed Settings

Two of the most basic settings on a switch are the bandwidth (“speed”) and duplex settings for each individual switch port. It is critical that the duplex and bandwidth settings match between the switch port and the connected devices.

There are two types of duplex settings used for communications on an Ethernet network:

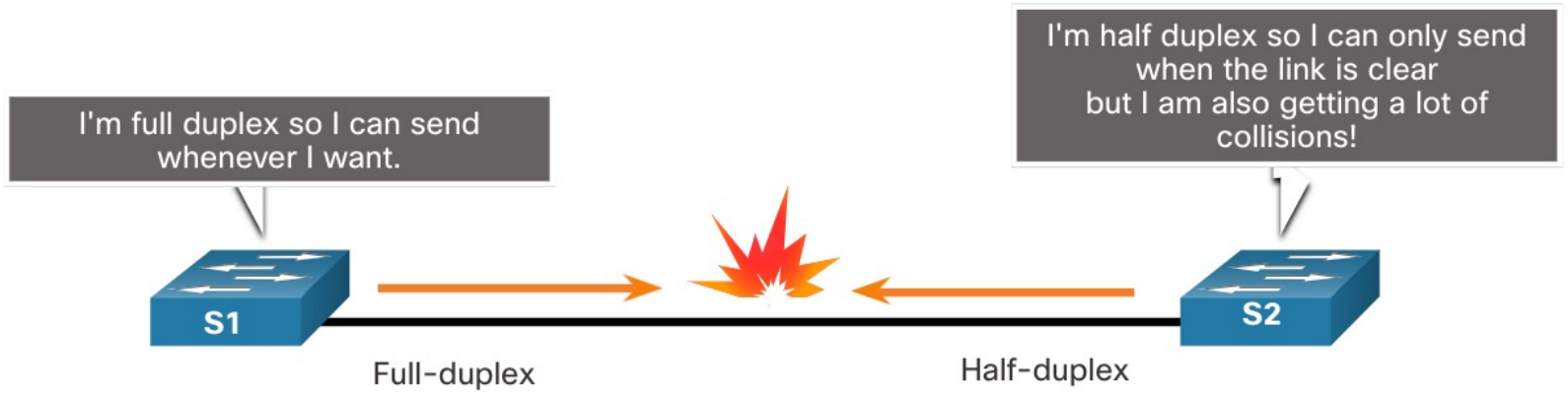
- **Full-duplex** - Both ends of the connection can send and receive simultaneously.
- **Half-duplex** - Only one end of the connection can send at a time.

Autonegotiation is an optional function found on most Ethernet switches and NICs. It enables two devices to automatically negotiate the best speed and duplex capabilities.

Note: Gigabit Ethernet ports only operate in full-duplex.

Duplex and Speed Settings

- Duplex mismatch is one of the most common causes of performance issues on 10/100 Mbps Ethernet links. It occurs when one port on the link operates at half-duplex while the other port operates at full-duplex.
- This can occur when one or both ports on a link are reset, and the autonegotiation process does not result in both link partners having the same configuration.
- It also can occur when users reconfigure one side of a link and forget to reconfigure the other. Both sides of a link should have autonegotiation on, or both sides should have it off. Best practice is to configure both Ethernet switch ports as full-duplex.



Auto-MDIX

Connections between devices once required the use of either a crossover or straight-through cable. The type of cable required depended on the type of interconnecting devices.

Note: A direct connection between a router and a host requires a cross-over connection.

- Most switch devices now support the automatic medium-dependent interface crossover (auto-MDIX) feature. When enabled, the switch automatically detects the type of cable attached to the port and configures the interfaces accordingly.
- The auto-MDIX feature is enabled by default on switches running Cisco IOS Release 12.2(18)SE or later. However, the feature could be disabled. For this reason, you should always use the correct cable type and not rely on the auto-MDIX feature.
- Auto-MDIX can be re-enabled using the **mdix auto** interface configuration command.

Module Practice and Quiz

What did I learn in this module?

- Ethernet operates in the data link layer and the physical layer. Ethernet standards define both the Layer 2 protocols and the Layer 1 technologies.
- Ethernet uses the LLC and MAC sublayers of the data link layer to operate.
- The Ethernet frame fields are: preamble and start frame delimiter, destination MAC address, source MAC address, EtherType, data, and FCS.
- MAC addressing provides a method for device identification at the data link layer of the OSI model.
- An Ethernet MAC address is a 48-bit address expressed using 12 hexadecimal digits, or 6 bytes.
- When a device is forwarding a message to an Ethernet network, the Ethernet header includes the source and destination MAC addresses. In Ethernet, different MAC addresses are used for Layer 2 unicast, broadcast, and multicast communications.

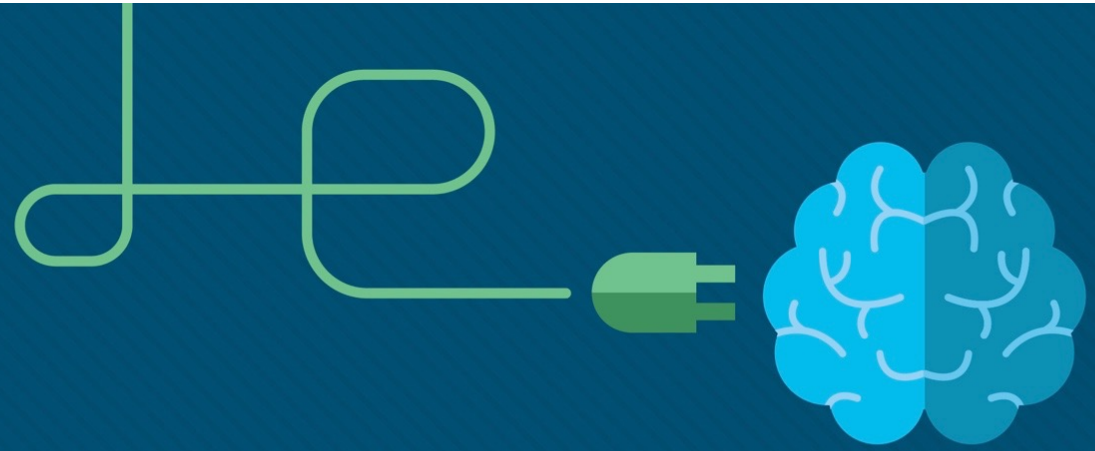
Module Practice and Quiz

What did I learn in this module? (Contd.)

- A Layer 2 Ethernet switch makes its forwarding decisions based solely on the Layer 2 Ethernet MAC addresses.
- The switch dynamically builds the MAC address table by examining the source MAC address of the frames received on a port.
- The switch forwards frames by searching for a match between the destination MAC address in the frame and an entry in the MAC address table.
- Switches use one of the following forwarding methods for switching data between network ports: store-and-forward switching or cut-through switching. Two variants of cut-through switching are fast-forward and fragment-free.
- Two methods of memory buffering are port-based memory and shared memory.
- There are two types of duplex settings used for communications on an Ethernet network: full-duplex and half-duplex.

New Terms and Commands

- Store-and-Forward Switching
- Cut-through Switching
- Fast-Forward Switching
- Fragment-free Switching
- OUI (Organizationally Unique Identifier)
- ARP (Address Resolution Protocol)
- ND (Neighbor Discovery)
- Port-based memory
- Shared memory
- Auto-MDIX



Module 8: Network Layer

Instructor Materials

Introduction to Networks v7.0
(ITN)

Module 8: Topics

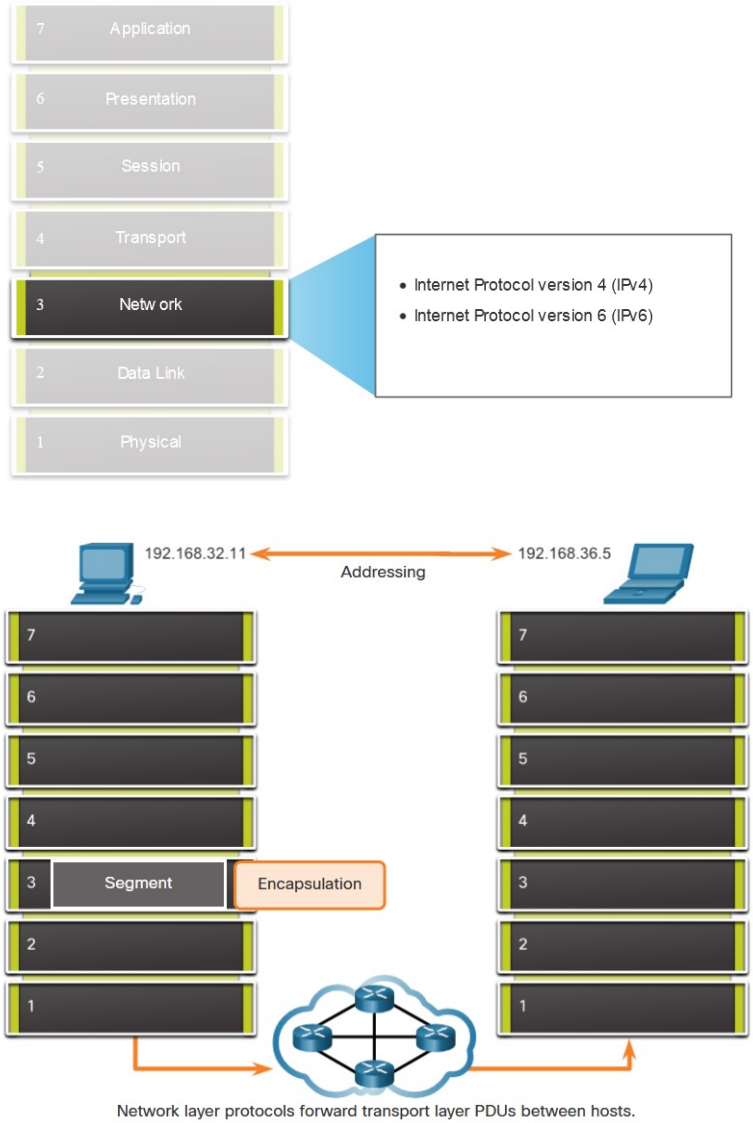
What will I learn to do in this module?

Topic Title	Topic Objective
Network Layer Characteristics	Explain how the network layer uses IP protocols for reliable communications.
IPv4 Packet	Explain the role of the major header fields in the IPv4 packet.
IPv6 Packet	Explain the role of the major header fields in the IPv6 packet.
How a Host Routes	Explain how network devices use routing tables to direct packets to a destination network.
Router Routing Tables	Explain the function of fields in the routing table of a router.

Network Layer Characteristics

The Network Layer

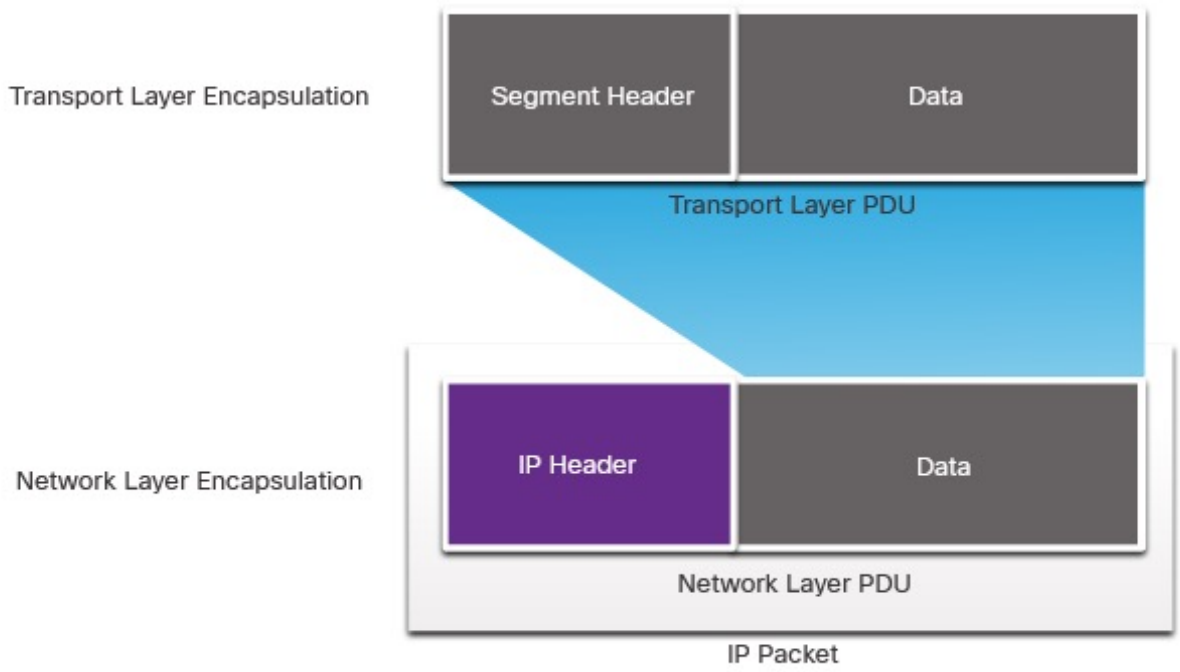
- Provides services to allow end devices to exchange data
- IP version 4 (IPv4) and IP version 6 (IPv6) are the principle network layer communication protocols.
- The network layer performs four basic operations:
  - Addressing end devices
  - Encapsulation
  - Routing
  - De-encapsulation



IP Encapsulation

- IP encapsulates the transport layer segment.
- IP can use either an IPv4 or IPv6 packet and not impact the layer 4 segment.
- IP packet will be examined by all layer 3 devices as it traverses the network.
- The IP addressing does not change from source to destination.

Note: NAT will change addressing, but will be discussed in a later module.



Characteristics of IP

IP is meant to have low overhead and may be described as:

- Connectionless
- Best Effort
- Media Independent

Connectionless

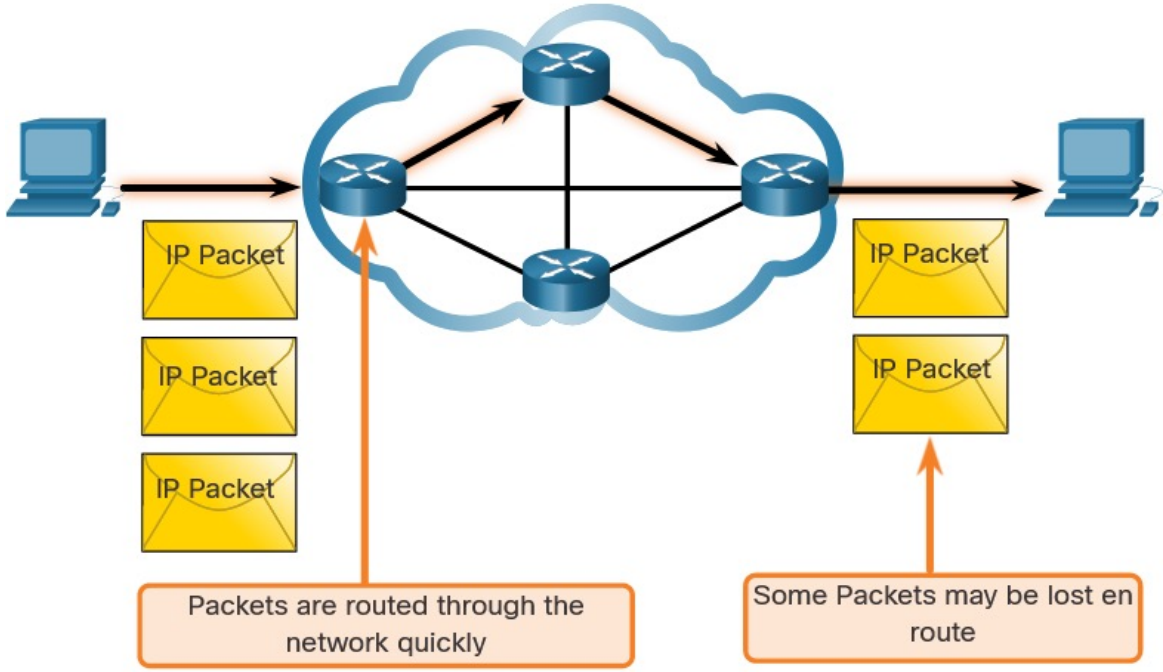
IP is Connectionless

- IP does not establish a connection with the destination before sending the packet.
- There is no control information needed (synchronizations, acknowledgments, etc.).
- The destination will receive the packet when it arrives, but no pre-notifications are sent by IP.
- If there is a need for connection-oriented traffic, then another protocol will handle this (typically TCP at the transport layer).

Best Effort

IP is Best Effort

- IP will not guarantee delivery of the packet.
- IP has reduced overhead since there is no mechanism to resend data that is not received.
- IP does not expect acknowledgments.
- IP does not know if the other device is operational or if it received the packet.



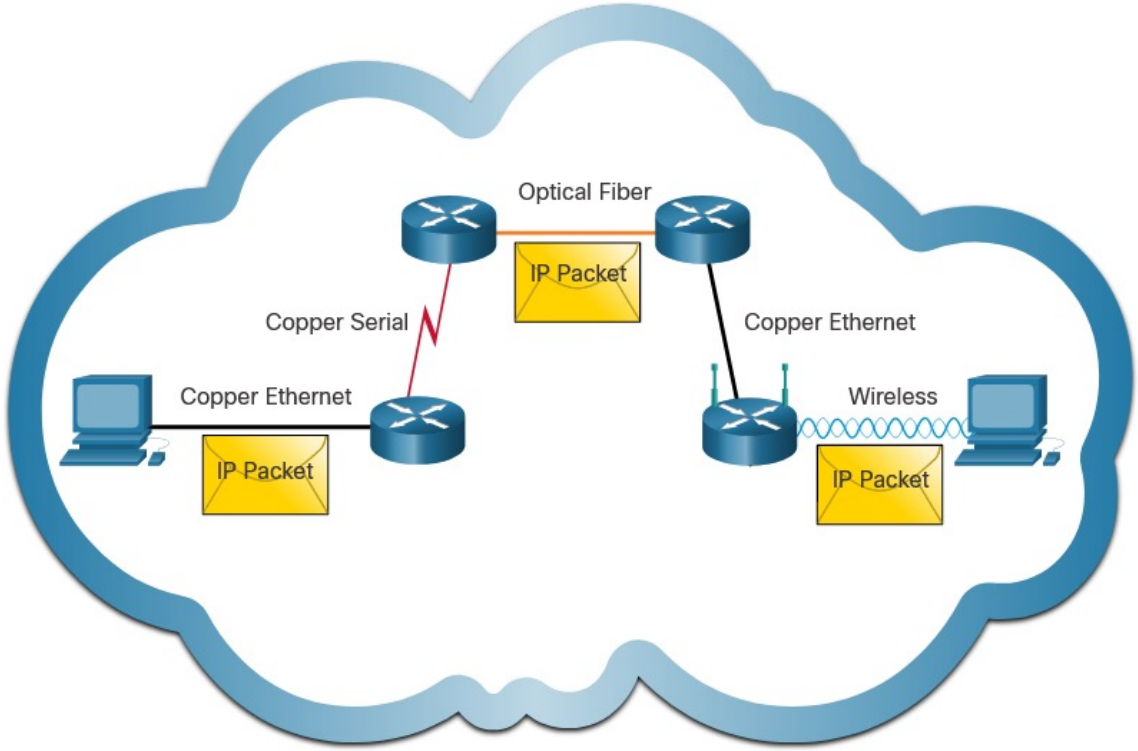
Media Independent

IP is unreliable:

- It cannot manage or fix undelivered or corrupt packets.
- IP cannot retransmit after an error.
- IP cannot realign out of sequence packets.
- IP must rely on other protocols for these functions.

IP is media Independent:

- IP does not concern itself with the type of frame required at the data link layer or the media type at the physical layer.
- IP can be sent over any media type: copper, fiber, or wireless.



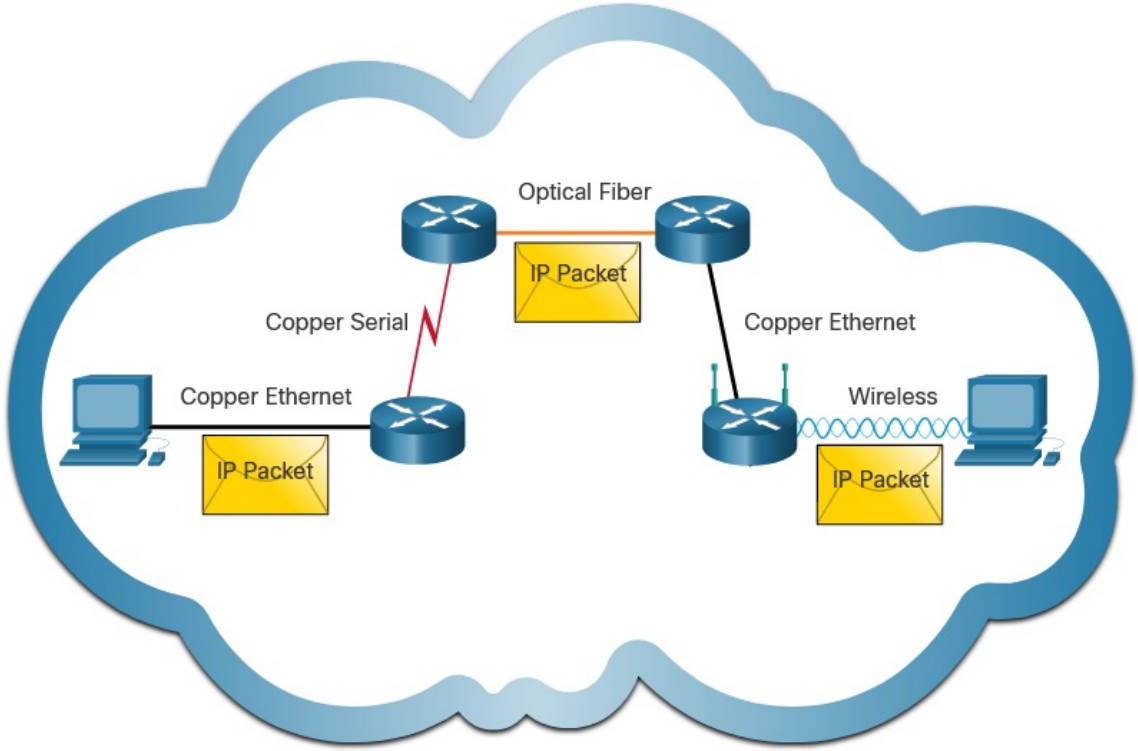
Media Independent (Contd.)

The network layer will establish the Maximum Transmission Unit (MTU).

- Network layer receives this from control information sent by the data link layer.
- The network then establishes the MTU size.

Fragmentation is when Layer 3 splits the IPv4 packet into smaller units.

- Fragmenting causes latency.
- IPv6 does not fragment packets.
- Example: Router goes from Ethernet to a slow WAN with a smaller MTU



IPv4 Packet Header

IPv4 is the primary communication protocol for the network layer.

The network header has many purposes:

- It ensures the packet is sent in the correct direction (to the destination).
- It contains information for network layer processing in various fields.
- The information in the header is used by all layer 3 devices that handle the packet

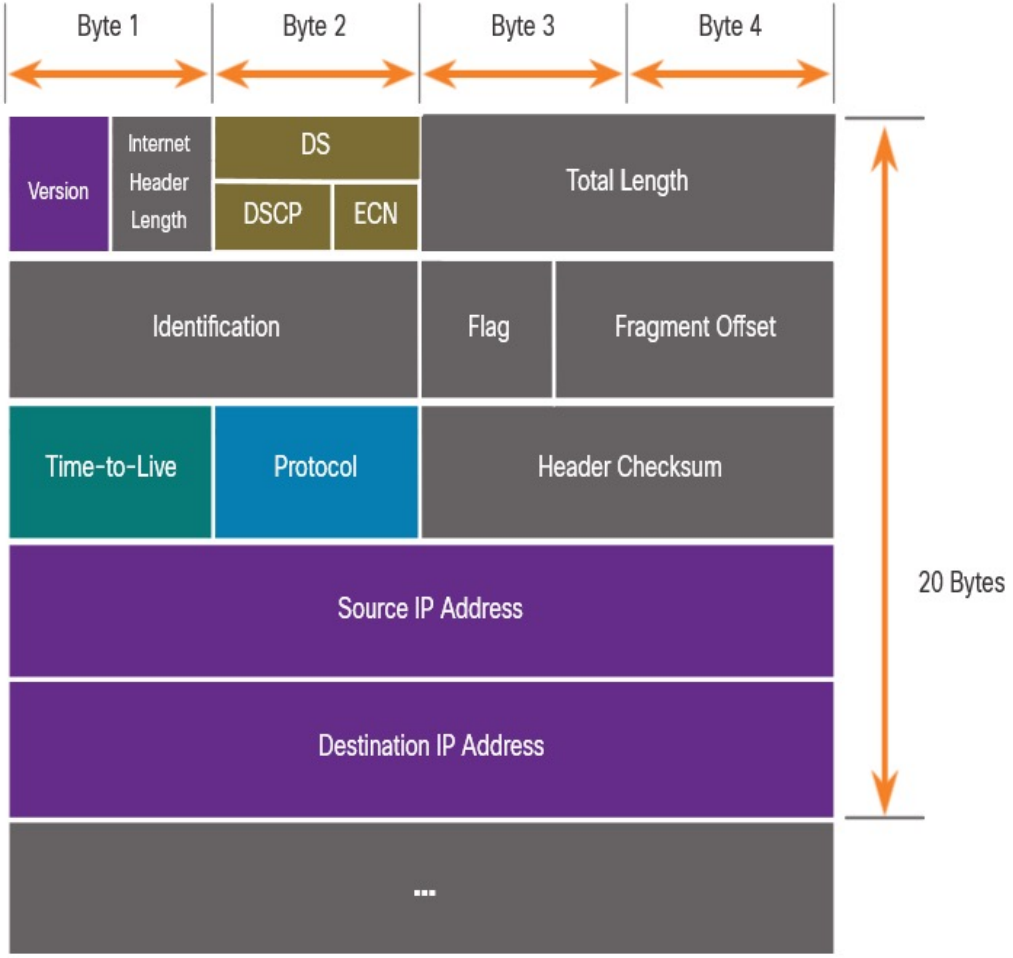
IPv4 Packet

IPv4 Packet Header Fields

The IPv4 network header characteristics:

- It is in binary.
- Contains several fields of information
- Diagram is read from left to right, 4 bytes per line
- The two most important fields are the source and destination.

Protocols may have may have one or more functions.



IPv4 Packet Header Fields

Significant fields in the IPv4 header:

Function	Description
Version	This will be for v4, as opposed to v6, a 4 bit field= 0100
Differentiated Services	Used for QoS: DiffServ – DS field or the older IntServ – ToS or Type of Service
Header Checksum	Detect corruption in the IPv4 header
Time to Live (TTL)	Layer 3 hop count. When it becomes zero the router will discard the packet.
Protocol	I.D.s next level protocol: ICMP, TCP, UDP, etc.
Source IPv4 Address	32 bit source address
Destination IPV4 Address	32 bit destination address

Limitations of IPv4

IPv4 has three major limitations:

- IPv4 address depletion – We have basically run out of IPv4 addressing.
- Lack of end-to-end connectivity – To make IPv4 survive this long, private addressing and NAT were created. This ended direct communications with public addressing.
- Increased network complexity – NAT was meant as temporary solution and creates issues on the network as a side effect of manipulating the network headers addressing. NAT causes latency and troubleshooting issues.

IPv6 Overview

- IPv6 was developed by Internet Engineering Task Force (IETF).
- IPv6 overcomes the limitations of IPv4.
- Improvements that IPv6 provides:
  - **Increased address space** – based on 128 bit address, not 32 bits
  - **Improved packet handling** – simplified header with fewer fields
  - **Eliminates the need for NAT** – since there is a huge amount of addressing, there is no need to use private addressing internally and be mapped to a shared public address

IPv4 and IPv6 Address Space Comparison

Number Name	Scientific Notation	Number of Zeros
1 Thousand	10^3	1,000
1 Million	10^6	1,000,000
1 Billion	10^9	1,000,000,000
1 Trillion	10^12	1,000,000,000,000
1 Quadrillion	10^15	1,000,000,000,000,000
1 Quintillion	10^18	1,000,000,000,000,000,000
1 Sextillion	10^21	1,000,000,000,000,000,000,000
1 Septillion	10^24	1,000,000,000,000,000,000,000,000
1 Octillion	10^27	1,000,000,000,000,000,000,000,000,000
1 Nonillion	10^30	1,000,000,000,000,000,000,000,000,000,000
1 Decillion	10^33	1,000,000,000,000,000,000,000,000,000,000,000
1 Undecillion	10^36	1,000,000,000,000,000,000,000,000,000,000,000,000

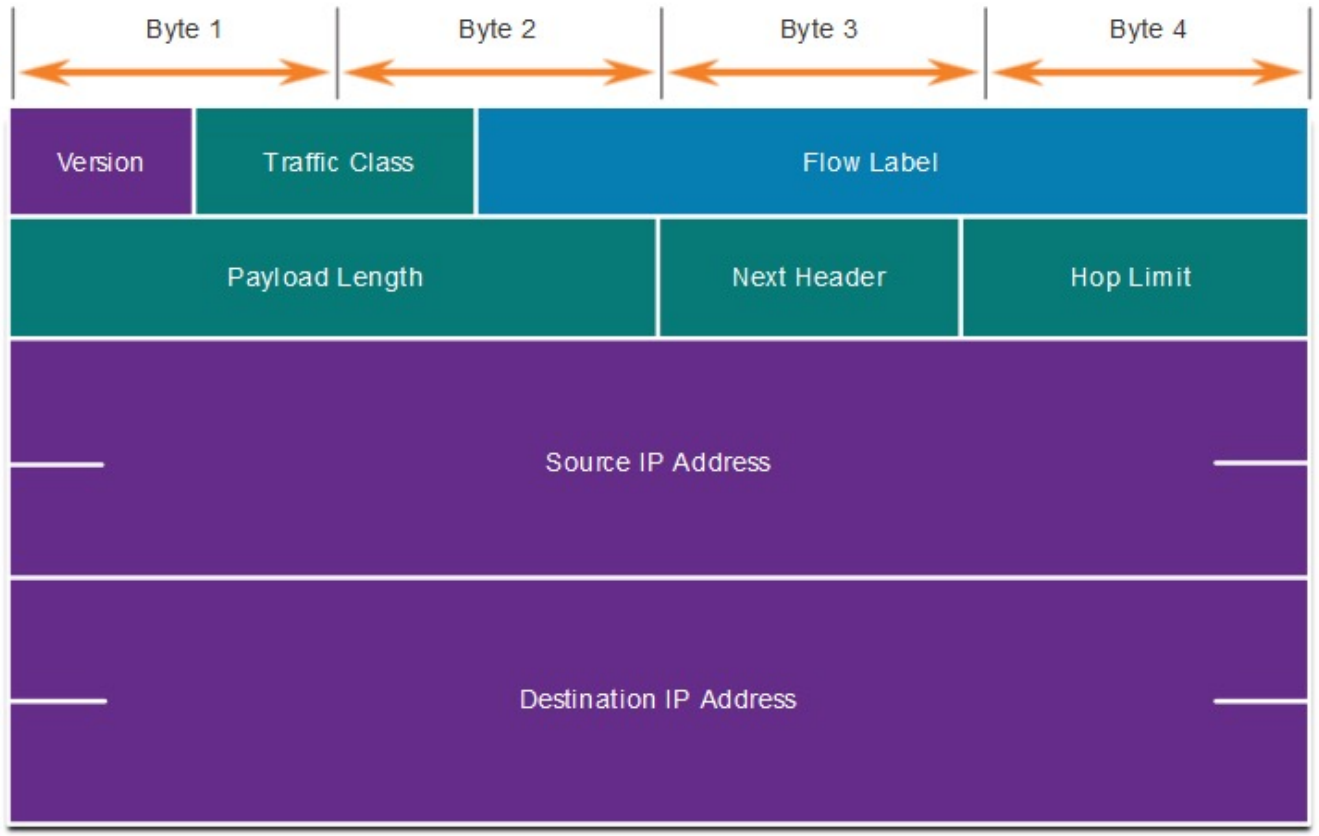
Legend

There are 4 billion IPv4 addresses

There are 340 undecillion IPv6 addresses

IPv4 Packet Header Fields in the IPv6 Packet Header

- The IPv6 header is simplified, but not smaller.
- The header is fixed at 40 Bytes or octets long.
- Several IPv4 fields were removed to improve performance.
- Some IPv4 fields were removed to improve performance:
  - Flag
  - Fragment Offset
  - Header Checksum



IPv6 Packets

IPv6 Packet Header

Significant fields in the IPv6 header:

Function	Description
Version	This will be for v6, as opposed to v4, a 4 bit field= 0110
Traffic Class	Used for QoS: Equivalent to DiffServ – DS field
Flow Label	Informs device to handle identical flow labels the same way, 20 bit field
Payload Length	This 16-bit field indicates the length of the data portion or payload of the IPv6 packet
Next Header	I.D.s next level protocol: ICMP, TCP, UDP, etc.
Hop Limit	Replaces TTL field Layer 3 hop count
Source IPv4 Address	128 bit source address
Destination IPV4 Address	128 bit destination address

IPv6 Packet Header (Cont.)

IPv6 packet may also contain extension headers (EH).

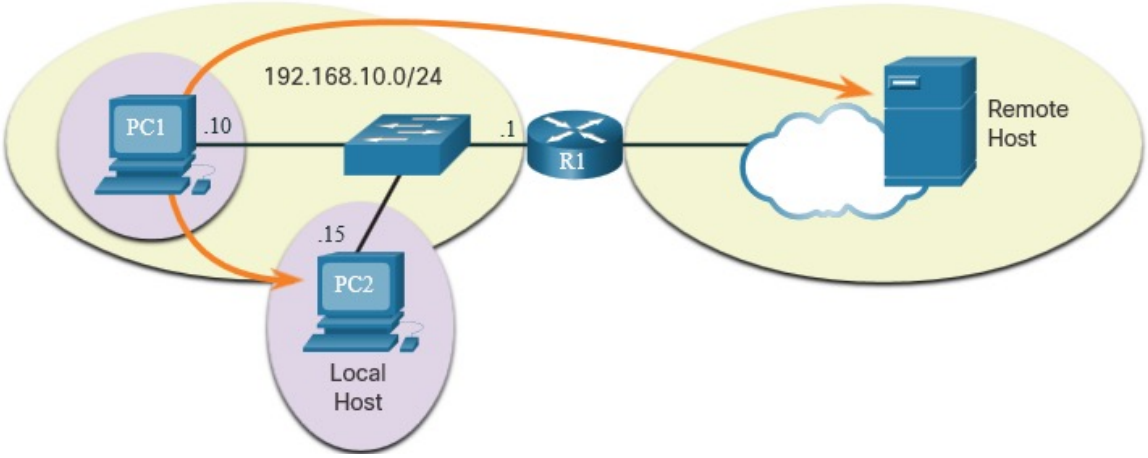
EH headers characteristics:

- provide optional network layer information
- are optional
- are placed between IPv6 header and the payload
- may be used for fragmentation, security, mobility support, etc.

Note: Unlike IPv4, routers do not fragment IPv6 packets.

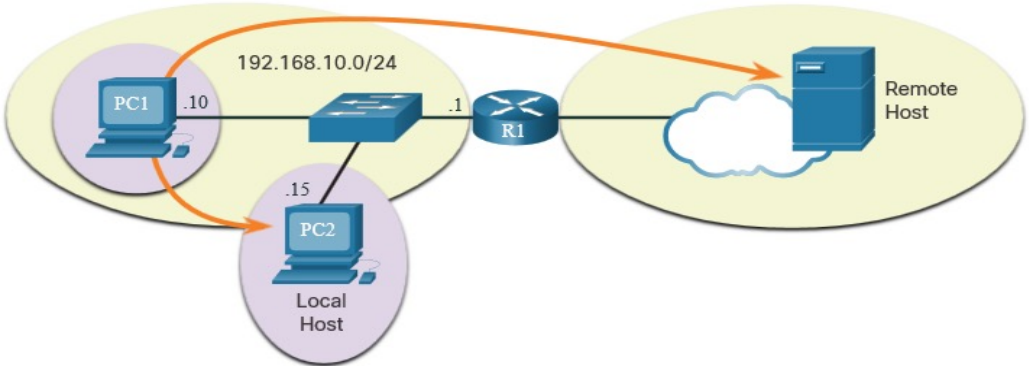
Host Forwarding Decision

- Packets are always created at the source.
- Each host devices creates their own routing table.
- A host can send packets to the following:
  - Itself – 127.0.0.1 (IPv4), ::1 (IPv6)
  - Local Hosts – destination is on the same LAN
  - Remote Hosts – devices are not on the same LAN



Host Forwarding Decision (Cont.)

- The Source device determines whether the destination is local or remote
- Method of determination:
  - IPv4 – Source uses its own IP address and Subnet mask, along with the destination IP address
  - IPv6 – Source uses the network address and prefix advertised by the local router
- Local traffic is dumped out the host interface to be handled by an intermediary device.
- Remote traffic is forwarded directly to the default gateway on the LAN.



Default Gateway

A router or layer 3 switch can be a default-gateway.

Features of a default gateway (DGW):

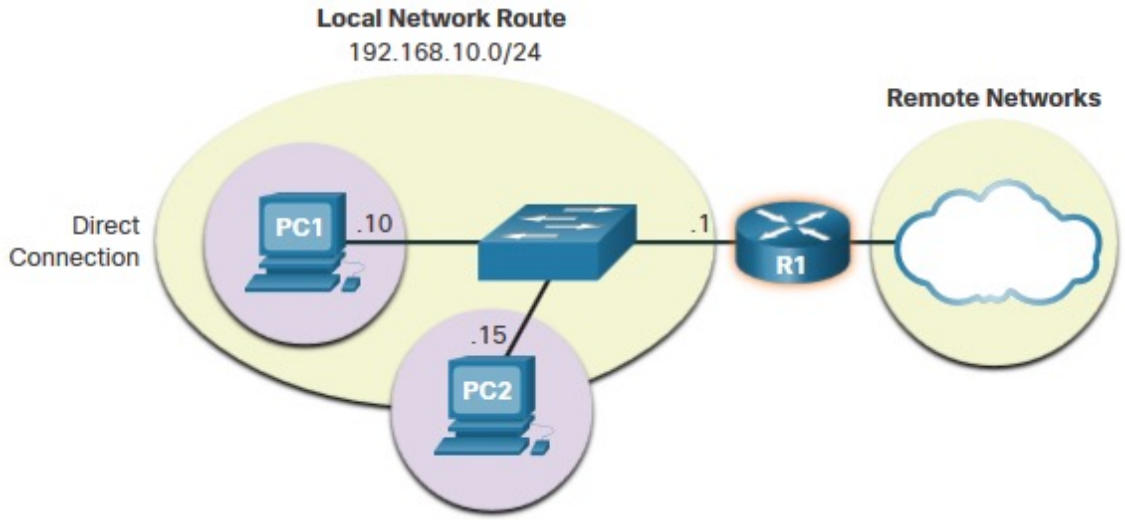
- It must have an IP address in the same range as the rest of the LAN.
- It can accept data from the LAN and is capable of forwarding traffic off of the LAN.
- It can route to other networks.

If a device has no default gateway or a bad default gateway, its traffic will not be able to leave the LAN.

How a Host Routes

A Host Routes to the Default Gateway

- The host will know the default gateway (DGW) either statically or through DHCP in IPv4.
- IPv6 sends the DGW through a router solicitation (RS) or can be configured manually.
- A DGW is static route which will be a last resort route in the routing table.
- All device on the LAN will need the DGW of the router if they intend to send traffic remotely.



How a Host Routes

Host Routing Tables

- On Windows, route print or netstat -r to display the PC routing table
- Three sections displayed by these two commands:
  - Interface List – all potential interfaces and MAC addressing
  - IPv4 Routing Table
  - IPv6 Routing Table

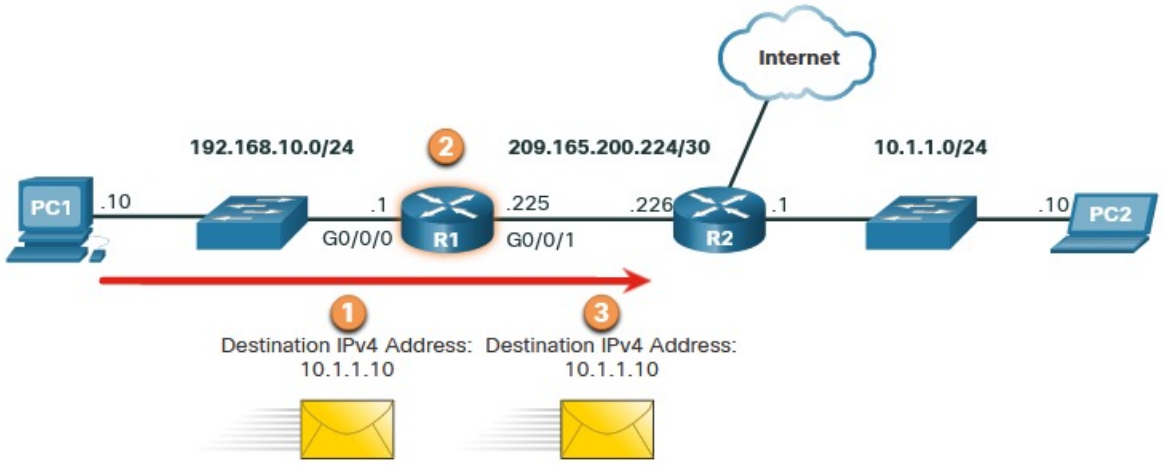
IPv4 Routing Table for PC1

```
C:\Users\PC1> netstat -r

IPv4 Route Table
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0    192.168.10.1    192.168.10.10      25
        127.0.0.0        255.0.0.0         On-link         127.0.0.1     306
        127.0.0.1  255.255.255.255         On-link         127.0.0.1     306
  127.255.255.255  255.255.255.255         On-link         127.0.0.1     306
    192.168.10.0    255.255.255.0         On-link    192.168.10.10     281
   192.168.10.10  255.255.255.255         On-link    192.168.10.10     281
  192.168.10.255  255.255.255.255         On-link    192.168.10.10     281
        224.0.0.0        240.0.0.0         On-link         127.0.0.1     306
        224.0.0.0        240.0.0.0         On-link    192.168.10.10     281
  255.255.255.255  255.255.255.255         On-link         127.0.0.1     306
  255.255.255.255  255.255.255.255         On-link    192.168.10.10     281
```

Router Packet Forwarding Decision

What happens when the router receives the frame from the host device?



1. Packet arrives on the Gigabit Ethernet 0/0/0 interface of router R1. R1 de-encapsulates the Layer 2 Ethernet header and trailer.
2. Router R1 examines the destination IPv4 address of the packet and searches for the best match in its IPv4 routing table. The route entry indicates that this packet is to be forwarded to router R2.
3. Router R1 encapsulates the packet into a new Ethernet header and trailer, and forwards the packet to the next hop router R2.

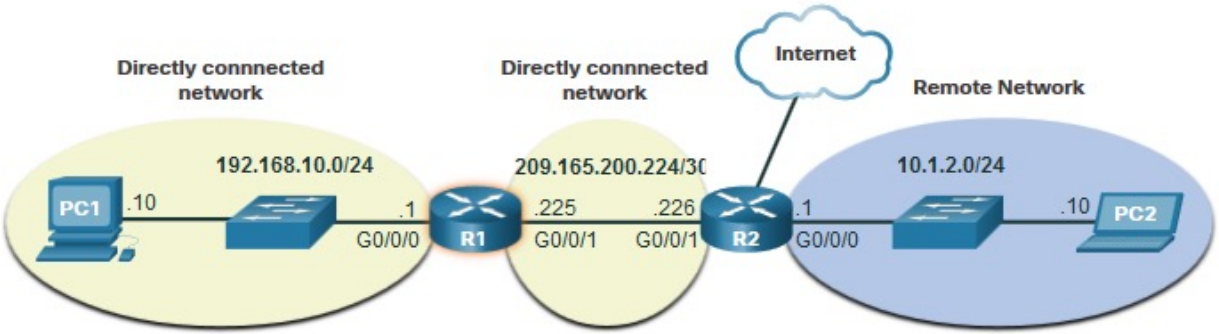
R1 Routing Table

Route	Next Hop or Exit Interface
192.168.10.0 /24	G0/0/0
209.165.200.224/30	G0/0/1
10.1.1.0/24	**via R2**
Default Route 0.0.0.0/0	via R2

IP Router Routing Table

There three types of routes in a router's routing table:

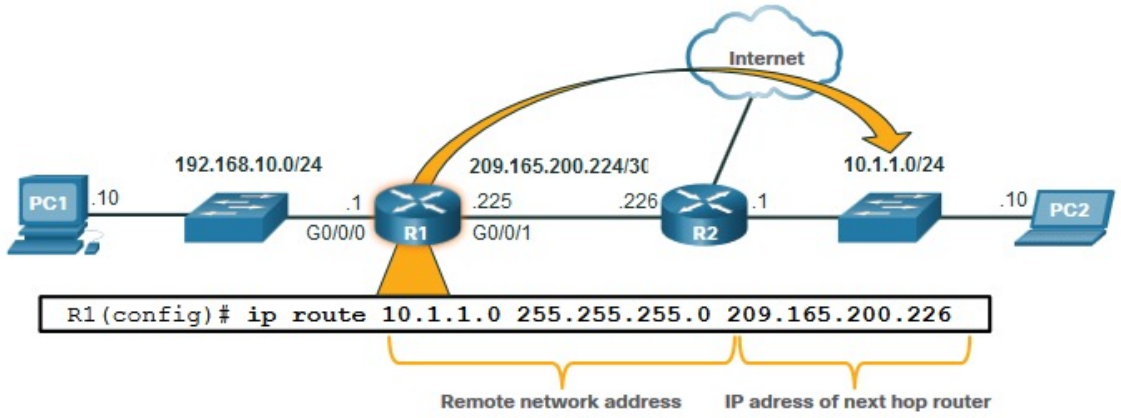
- **Directly Connected** – These routes are automatically added by the router, provided the interface is active and has addressing.
- **Remote** – These are the routes the router does not have a direct connection and may be learned:
  - Manually – with a static route
  - Dynamically – by using a routing protocol to have the routers share their information with each other
- **Default Route** – this forwards all traffic to a specific direction when there is not a match in the routing table



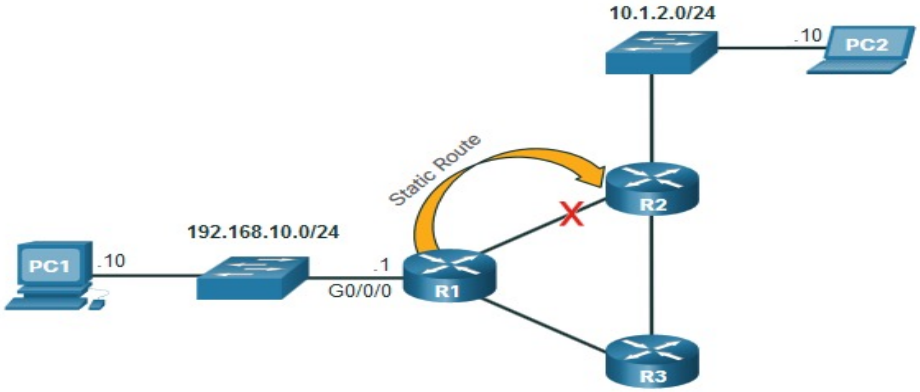
Static Routing

Static Route Characteristics:

- Must be configured manually
- Must be adjusted manually by the administrator when there is a change in the topology
- Good for small non-redundant networks
- Often used in conjunction with a dynamic routing protocol for configuring a default route



R1 is manually configured with a static route to reach the 10.1.1.0/24 network. If this path changes, R1 will require a new static route.



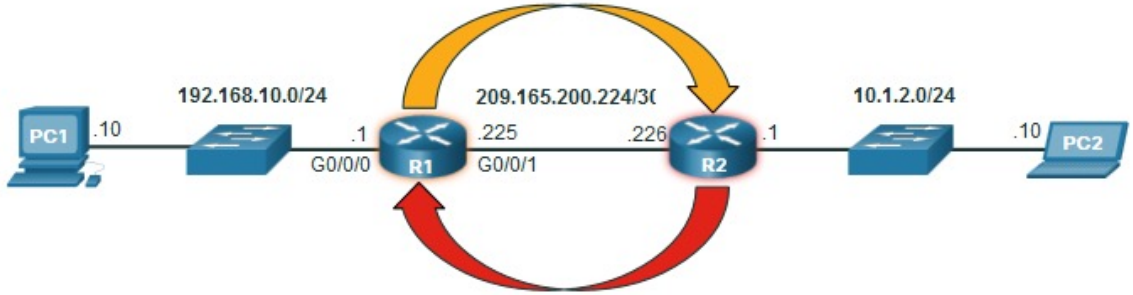
If the route from R1 via R2 is no longer available, a new static route via R3 would need to be configured. A static route does not automatically adjust for topology changes.

Dynamic Routing

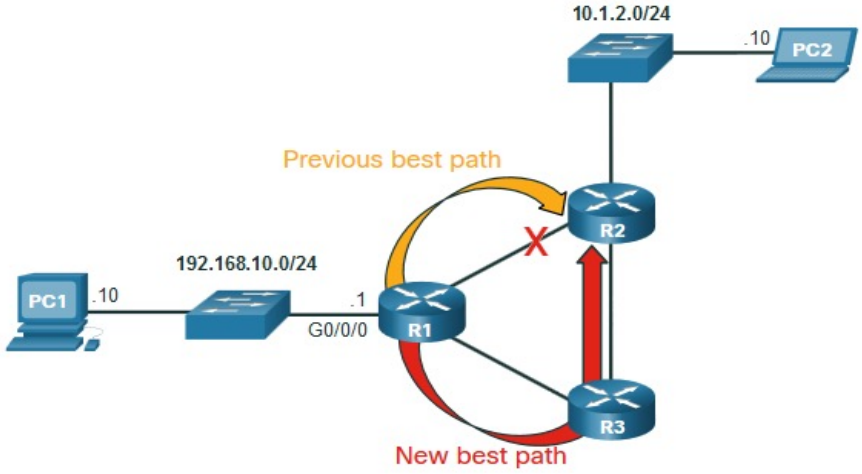
Dynamic Routes Automatically:

- Discover remote networks
- Maintain up-to-date information
- Choose the best path to the destination
- Find new best paths when there is a topology change

Dynamic routing can also share static default routes with the other routers.



- R1 is using the routing protocol OSPF to let R2 know about the 192.168.10.0/24 network.
- R2 is using the routing protocol OSPF to let R1 know about the 10.1.1.0/24 network.



R1, R2, and R3 are using the dynamic routing protocol OSPF. If there is a network topology change, they can automatically adjust to find a new best path.

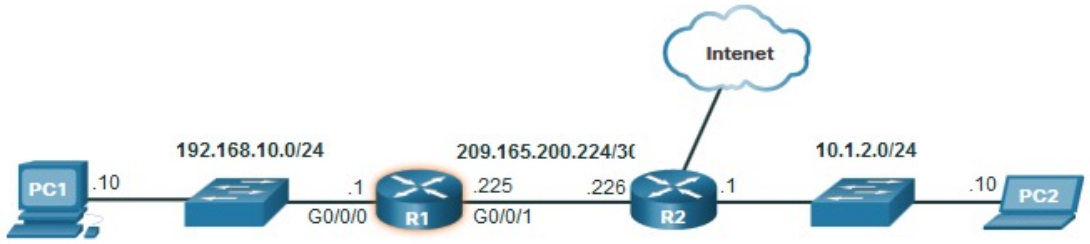
Introduction to an IPv4 Routing Table

The **show ip route** command shows the following route sources:

- **L** - Directly connected local interface IP address
- **C** – Directly connected network
- **S** – Static route was manually configured by an administrator
- **O** – OSPF
- **D** – EIGRP

This command shows types of routes:

- Directly Connected – C and L
- Remote Routes – O, D, etc.
- Default Routes – S*




```
R1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR
Gateway of last resort is 209.165.200.226 to network 0.0.0.0
S*    0.0.0.0/0 [1/0] via 209.165.200.226, GigabitEthernet0/0/1
      10.0.0.0/24 is subnetted, 1 subnets
O        10.1.1.0 [110/2] via 209.165.200.226, 00:02:45, GigabitEthernet0/0/1
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, GigabitEthernet0/0/0
L        192.168.10.1/32 is directly connected, GigabitEthernet0/0/0
      209.165.200.0/24 is variably subnetted, 2 subnets, 2 masks
C        209.165.200.224/30 is directly connected, GigabitEthernet0/0/1
L        209.165.200.225/32 is directly connected, GigabitEthernet0/0/1
R1#
```

Module Practice and Quiz

What did I learn in this module?

- IP is connectionless, best effort, and media independent.
- IP does not guarantee packet delivery.
- IPv4 packet header consists of fields containing information about the packet.
- IPv6 overcomes IPv4 lack of end-to-end connectivity and increased network complexity.
- A device will determine if a destination is itself, another local host, and a remote host.
- A default gateway is router that is part of the LAN and will be used as a door to other networks.
- The routing table contains a list of all known network addresses (prefixes) and where to forward the packet.
- The router uses longest subnet mask or prefix match.
- The routing table has three types of route entries: directly connected networks, remote networks, and a default route.

New Terms and Commands

- Encapsulation
- Routing
- De-encapsulation
- Data payload
- Packet
- Internet Protocol Version 4 (IPv4)
- Internet Protocol Version 6 (IPv6)
- Network Layer PDU = IP Packet
- IP Header

- Best effort delivery
- Media independent
- Connectionless
- Unreliable
- Maximum Transmission Unit (MTU)
- Version
- Differentiated Services (DS)
- Time-to-Live (TTL)
- Internet Control Message Protocol (ICMP)

- Identification, Flags, Fragment Offset fields
- Network Address Translation (NAT)
- Traffic Class
- Flow Label
- Payload Length
- Next Header
- Hop Limit
- Extension Headers
- Local host
- Remote host
- Default Gateway

New Terms and Commands

- netstat –r
- route print
- interface list
- IPv4 Route Table
- IPv6 Route Table
- directly-connected routes
- remote routes
- default route
- **show ip route**
- route source
- destination network
- outgoing interface
- administrative distance
- metric
- next-hop
- route timestamp

Module 9: Address Resolution

Instructor Materials

Introduction to Networks v7.0
(ITN)

Module Objectives

Module Title: Address Resolution

Module Objective: Explain how ARP and ND enable communication on a network.

Topic Title	Topic Objective
MAC and IP	Compare the roles of the MAC address and the IP address.
ARP	Describe the purpose of ARP.
Neighbor Discovery	Describe the operation of IPv6 neighbor discovery.

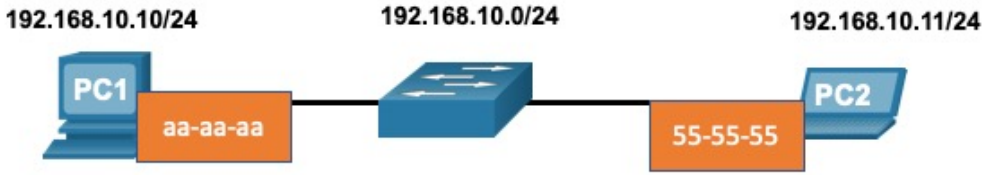
MAC and IP

Destination on Same Network

There are two primary addresses assigned to a device on an Ethernet LAN:

- **Layer 2 physical address (the MAC address)** – Used for NIC to NIC communications on the same Ethernet network.
- **Layer 3 logical address (the IP address)** – Used to send the packet from the source device to the destination device.

Layer 2 addresses are used to deliver frames from one NIC to another NIC on the same network. If a destination IP address is on the same network, the destination MAC address will be that of the destination device.



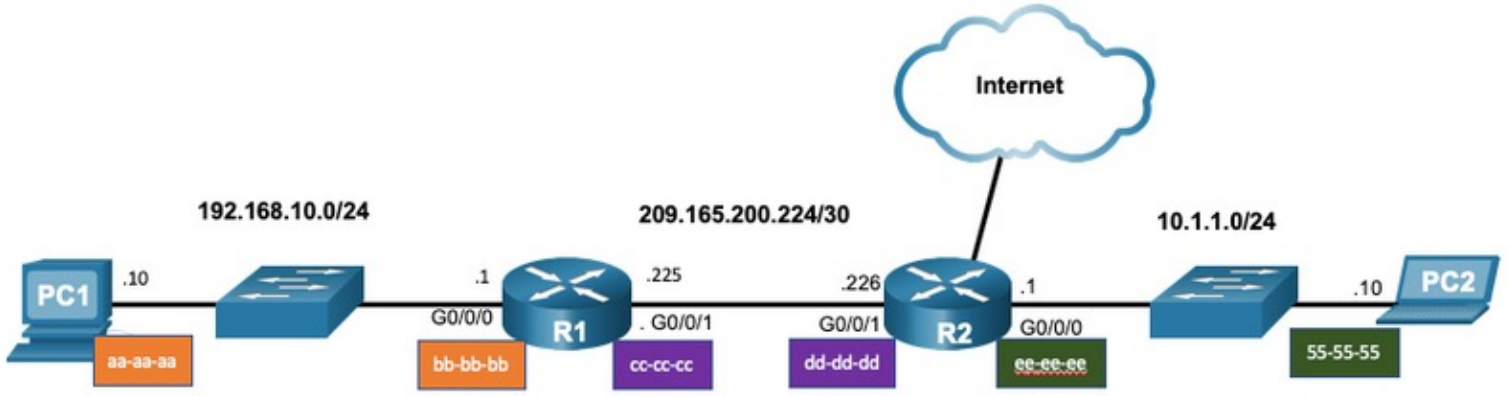
Destination MAC	Source MAC	Source IPv4	Destination IPv4
55-55-55	aa-aa-aa	192.168.10.10	192.168.10.11

MAC and IP

Destination on Remote Network

When the destination IP address is on a remote network, the destination MAC address is that of the default gateway.

- ARP is used by IPv4 to associate the IPv4 address of a device with the MAC address of the device NIC.
- ICMPv6 is used by IPv6 to associate the IPv6 address of a device with the MAC address of the device NIC.



Destination MAC	Source MAC	Source IPv4	Destination IPv4
bb-bb-bb	aa-aa-aa	192.168.10.10	10.1.1.10

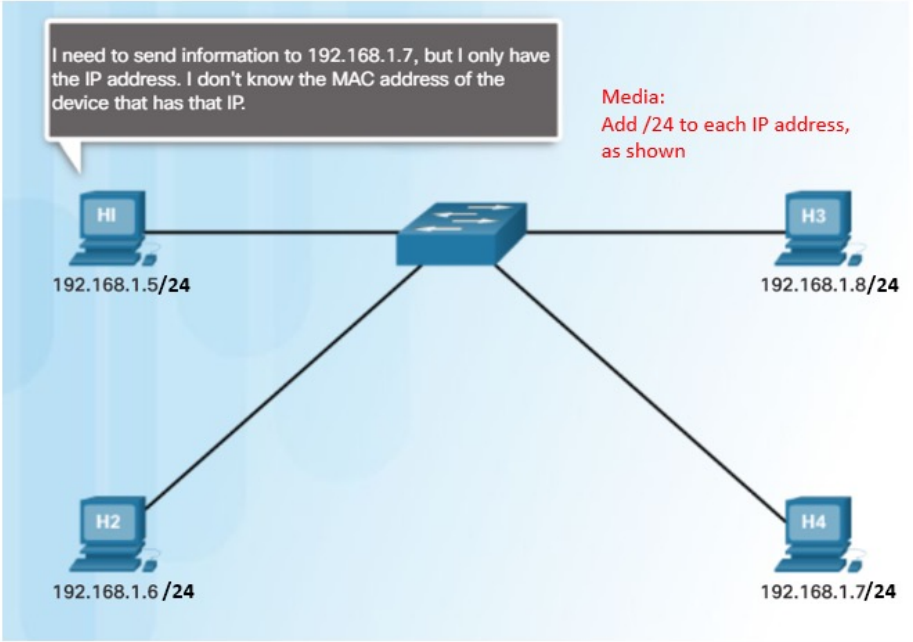
ARP

ARP Overview

A device uses ARP to determine the destination MAC address of a local device when it knows its IPv4 address.

ARP provides two basic functions:

- Resolving IPv4 addresses to MAC addresses
- Maintaining an ARP table of IPv4 to MAC address mappings



ARP Functions

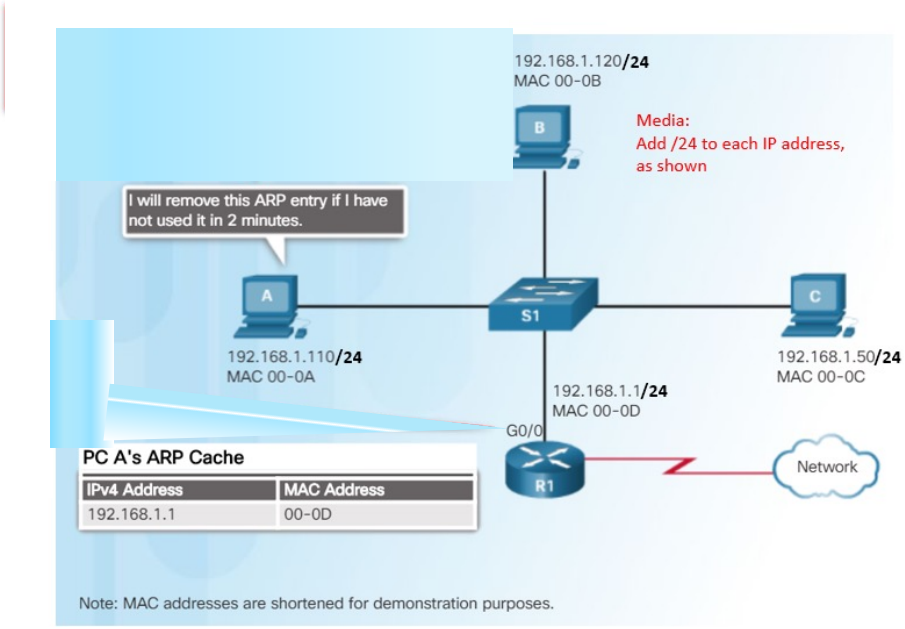
To send a frame, a device will search its ARP table for a destination IPv4 address and a corresponding MAC address.

- If the packet's destination IPv4 address is on the same network, the device will search the ARP table for the destination IPv4 address.
- If the destination IPv4 address is on a different network, the device will search the ARP table for the IPv4 address of the default gateway.
- If the device locates the IPv4 address, its corresponding MAC address is used as the destination MAC address in the frame.
- If there is no ARP table entry is found, then the device sends an ARP request.

ARP

Removing Entries from an ARP Table

- Entries in the ARP table are not permanent and are removed when an ARP cache timer expires after a specified period of time.
- The duration of the ARP cache timer differs depending on the operating system.
- ARP table entries can also be removed manually by the administrator.



ARP Tables on Networking Devices

- The **show ip arp** command displays the ARP table on a Cisco router.
- The **arp –a** command displays the ARP table on a Windows 10 PC.

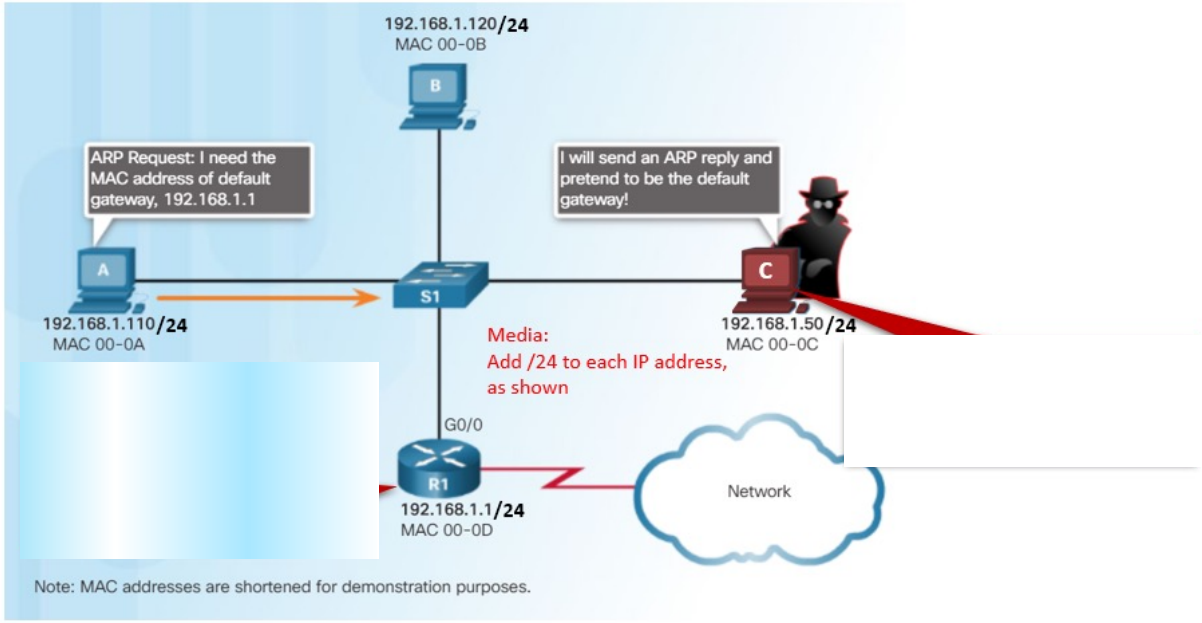
```
R1# show ip arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  192.168.10.1            -   a0e0.af0d.e140  ARPA   GigabitEthernet0/0/0
```

```
C:\Users\PC> arp -a

Interface: 192.168.1.124 --- 0x10
  Internet Address      Physical Address      Type
  192.168.1.1           c8-d7-19-cc-a0-86     dynamic
  192.168.1.101         08-3e-0c-f5-f7-77     dynamic
```

ARP Issues – ARP Broadcasting and ARP Spoofing

- ARP requests are received and processed by every device on the local network.
- Excessive ARP broadcasts can cause some reduction in performance.
- ARP replies can be spoofed by a threat actor to perform an ARP poisoning attack.
- Enterprise level switches include mitigation techniques to protect against ARP attacks.



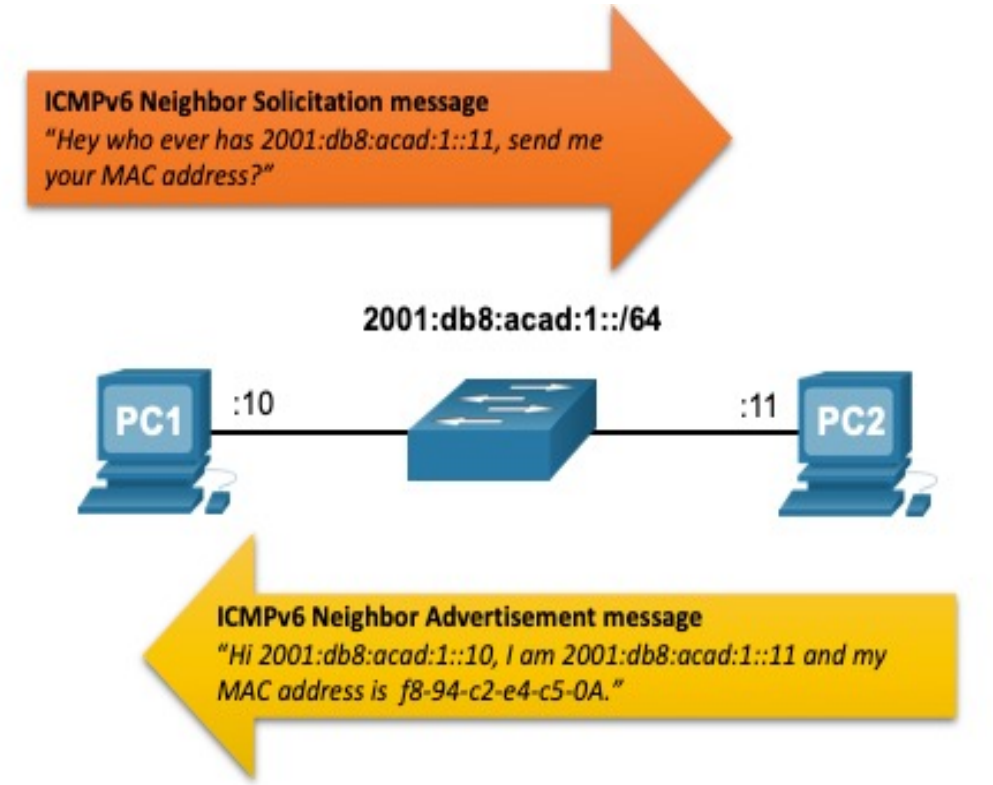
IPv6 Neighbor Discovery Messages

IPv6 Neighbor Discovery (ND) protocol provides:

- Address resolution
- Router discovery
- Redirection services

- ICMPv6 Neighbor Solicitation (NS) and Neighbor Advertisement (NA) messages are used for device-to-device messaging such as address resolution.
- ICMTPv6 Router Solicitation (RS) and Router Advertisement (RA) messages are used for messaging between devices and routers for router discovery.
- ICMPv6 redirect messages are used by routers for better next-hop selection.

IPv6 Neighbor Discovery – Address Resolution



- IPv6 devices use ND to resolve the MAC address of a known IPv6 address.
- ICMPv6 Neighbor Solicitation messages are sent using special Ethernet and IPv6 multicast addresses.

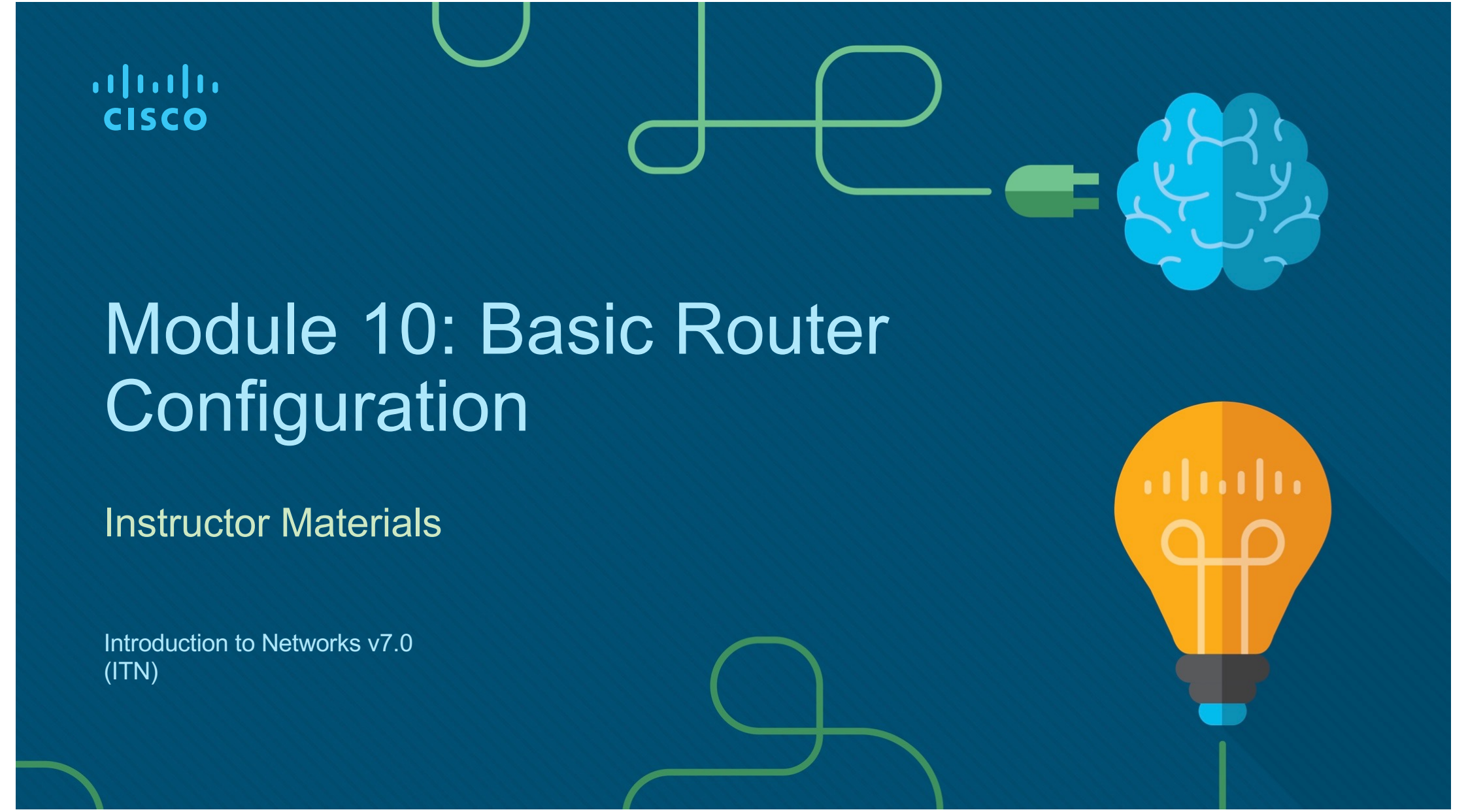
Module Practice and Quiz

What did I learn in this module?

- Layer 2 physical addresses (i.e., Ethernet MAC addresses) are used to deliver the data link frame with the encapsulated IP packet from one NIC to another NIC on the same network.
- If the destination IP address is on the same network, the destination MAC address will be that of the destination device.
- When the destination IP address (IPv4 or IPv6) is on a remote network, the destination MAC address will be the address of the host default gateway (i.e., the router interface).
- An IPv4 device uses ARP to determine the destination MAC address of a local device when it knows its IPv4 address.
- ARP provides two basic functions: resolving IPv4 addresses to MAC addresses and maintaining a table of IPv4 to MAC address mappings.
- After the ARP reply is received, the device will add the IPv4 address and the corresponding MAC address to its ARP table.
- For each device, an ARP cache timer removes ARP entries that have not been used for a specified period of time.
- IPv6 does not use ARP, it uses the ND protocol to resolve MAC addresses.
- An IPv6 device uses ICMPv6 Neighbor Discovery to determine the destination MAC address of a local device when it knows its IPv6 address.

New Terms and Commands

• Address Resolution Protocol (ARP) • ARP table • show ip arp • arpr -a • ICMPv6 Neighbor Discovery protocol (ND) • ICMPv6 Neighbor Solicitation (NS) message • ICMPv6 Neighbor Advertisement (NA) message • ICMPv6 Router Solicitation (RS) message • ICMPv6 Router Advertisement (RA) message • ICMPv6 Redirect Message	



Module 10: Basic Router Configuration

Instructor Materials

Introduction to Networks v7.0
(ITN)

Module Objectives

Module Title: Basic Router Configuration

Module Objective: Implement initial settings on a router and end devices.

Topic Title	Topic Objective
Configure Initial Router Settings	Configure initial settings on an IOS Cisco router.
Configure Interfaces	Configure two active interfaces on a Cisco IOS router.
Configure the Default Gateway	Configure devices to use the default gateway.

Configure Initial Router Settings

Basic Router Configuration Steps

- Configure the device name.
- Secure privileged EXEC mode.
- Secure user EXEC mode.
- Secure remote Telnet / SSH access.
- Encrypt all plaintext passwords.
- Provide legal notification and save the configuration.

```
Router(config)# hostname hostname
```

```
Router(config)# enable secret password
```

```
Router(config)# line console 0
Router(config-line)# password password
Router(config-line)# login
```

```
Router(config)# line vty 0 4
Router(config-line)# password password
Router(config-line)# login
Router(config-line)# transport input {ssh | telnet}
```

```
Router(config)# service password encryption
```

```
Router(config)# banner motd # message #
Router(config)# end
Router# copy running-config startup-config
```

Configure Initial Router Settings

Basic Router Configuration Example

- Commands for basic router configuration on R1.
- Configuration is saved to NVRAM.

```
R1(config)# hostname R1
R1(config)# enable secret class
R1(config)# line console 0
R1(config-line)# password cisco
R1(config-line)# login
R1(config-line)# line vty 0 4
R1(config-line)# password cisco
R1(config-line)# login
R1(config-line)# transport input ssh telnet
R1(config-line)# exit
R1(config)# service password encryption
R1(config)# banner motd #
Enter TEXT message. End with a new line and the #
**********************************************
WARNING: Unauthorized access is prohibited!
**********************************************
R1(config)# exit
R1# copy running-config startup-config
```

Configure Router Interfaces

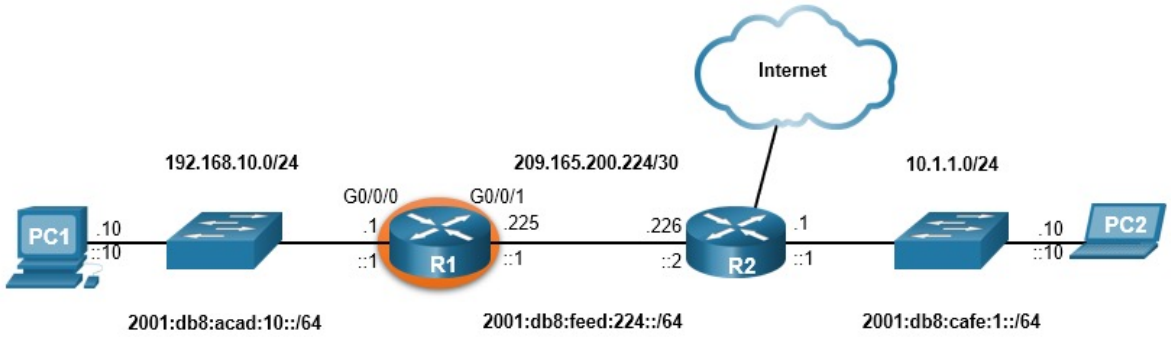
Configuring a router interface includes issuing the following commands:

```
Router(config)# interface type-and-number
Router(config-if)# description description-text
Router(config-if)# ip address ipv4-address subnet-mask
Router(config-if)# ipv6 address ipv6-address/prefix-length
Router(config-if)# no shutdown
```

- It is a good practice to use the **description** command to add information about the network connected to the interface.
- The **no shutdown** command activates the interface.

Configure Router Interfaces Example

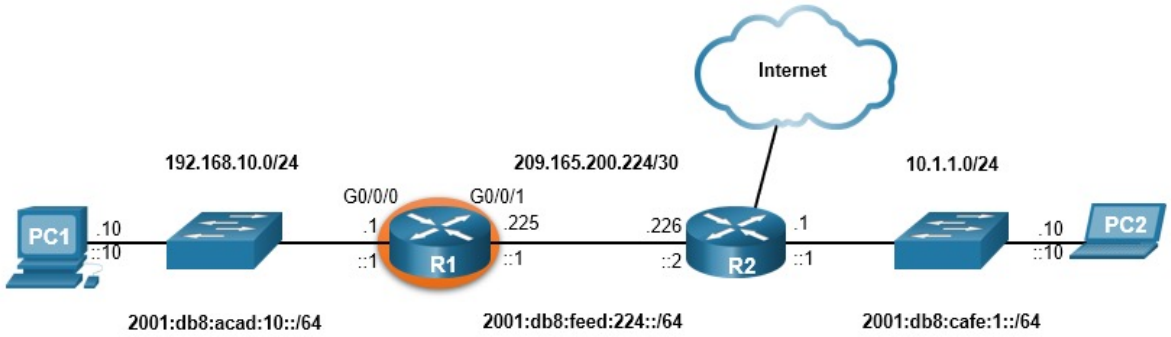
The commands to configure interface G0/0/0 on R1 are shown here:




```
R1(config)# interface gigabitEthernet 0/0/0
R1(config-if)# description Link to LAN
R1(config-if)# ip address 192.168.10.1 255.255.255.0
R1(config-if)# ipv6 address 2001:db8:acad:10::1/64
R1(config-if)# no shutdown
R1(config-if)# exit
R1(config)#
*Aug  1 01:43:53.435: %LINK-3-UPDOWN: Interface GigabitEthernet0/0/0, changed state to down
*Aug  1 01:43:56.447: %LINK-3-UPDOWN: Interface GigabitEthernet0/0/0, changed state to up
*Aug  1 01:43:57.447: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/0/0,
changed state to up
```

Configure Router Interfaces Example (Cont.)

The commands to configure interface G0/0/1 on R1 are shown here:




```
R1(config)# interface gigabitEthernet 0/0/1
R1(config-if)# description Link to R2
R1(config-if)# ip address 209.165.200.225 255.255.255.252
R1(config-if)# ipv6 address 2001:db8:feed:224::1/64
R1(config-if)# no shutdown
R1(config-if)# exit
R1(config)#
*Aug  1 01:46:29.170: %LINK-3-UPDOWN: Interface GigabitEthernet0/0/1, changed state to down
*Aug  1 01:46:32.171: %LINK-3-UPDOWN: Interface GigabitEthernet0/0/1, changed state to up
*Aug  1 01:46:33.171: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/0/1,
changed state to up
```

Verify Interface Configuration

To verify interface configuration use the **show ip interface brief** and **show ipv6 interface brief** commands shown here:

```
R1#  show ip interface brief
Interface              IP-Address      OK? Method Status                Protocol
GigabitEthernet0/0/0   192.168.10.1    YES manual up                    up
GigabitEthernet0/0/1   209.165.200.225 YES manual up                    up
Vlan1                  unassigned      YES unset  administratively down down
```

```
R1#  show ipv6 interface brief
GigabitEthernet0/0/0       [up/up]
    FE80::201:C9FF:FE89:4501
    2001:DB8:ACAD:10::1
GigabitEthernet0/0/1       [up/up]
    FE80::201:C9FF:FE89:4502
    2001:DB8:FEED:224::1
Vlan1                      [administratively down/down]
    unassigned
R1#
```

Configure Verification Commands

The table summarizes show commands used to verify interface configuration.

Commands	Description
`show ip interface brief` `show ipv6 interface brief`	Displays all interfaces, their IP addresses, and their current status.
`show ip route` `show ipv6 route`	Displays the contents of the IP routing tables stored in RAM.
`show interfaces`	Displays statistics for all interfaces on the device. Only displays the IPv4 addressing information.
`show ip interfaces`	Displays the IPv4 statistics for all interfaces on a router.
`show ipv6 interfaces`	Displays the IPv6 statistics for all interfaces on a router.

Configure Interfaces

Configure Verification Commands (Cont.)

View status of all interfaces with the **show ip interface brief** and **show ipv6 interface brief** commands, shown here:

```
R1# show ip interface brief
Interface              IP-Address      OK? Method Status                Protocol
GigabitEthernet0/0/0   192.168.10.1    YES manual up                    up
GigabitEthernet0/0/1   209.165.200.225 YES manual up                    up
Vlan1                  unassigned      YES unset  administratively down down
R1#
```

```
R1# show ipv6 interface brief
GigabitEthernet0/0/0       [up/up]
    FE80::201:C9FF:FE89:4501
    2001:DB8:ACAD:10::1
GigabitEthernet0/0/1       [up/up]
    FE80::201:C9FF:FE89:4502
    2001:DB8:FEED:224::1
Vlan1                      [administratively down/down]
    unassigned
R1#
```

Configure Interfaces

Configure Verification Commands (Cont.)

Display the contents of the IP routing tables with the **show ip route** and **show ipv6 route** commands as shown here:

```
R1# show ip route
< output omitted>
Gateway of last resort is not set
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, GigabitEthernet0/0/0
L        192.168.10.1/32 is directly connected, GigabitEthernet0/0/0
      209.165.200.0/24 is variably subnetted, 2 subnets, 2 masks
C        209.165.200.224/30 is directly connected, GigabitEthernet0/0/1
L        209.165.200.225/32 is directly connected, GigabitEthernet0/0/1
R1#
```

```
R1# show ipv6 route
<output omitted>
C   2001:DB8:ACAD:10::/64 [0/0]
     via GigabitEthernet0/0/0, directly connected
L   2001:DB8:ACAD:10::1/128 [0/0]
     via GigabitEthernet0/0/0, receive
C   2001:DB8:FEED:224::/64 [0/0]
     via GigabitEthernet0/0/1, directly connected
L   2001:DB8:FEED:224::1/128 [0/0]
     via GigabitEthernet0/0/1, receive
L   FF00::/8 [0/0]
     via Null0, receive
R1#
```

Configure Interfaces

Configure Verification Commands (Cont.)

Display statistics for all interfaces with the **show interfaces** command, as shown here:

```
R1# show interfaces gig0/0/0
GigabitEthernet0/0/0 is up, line protocol is up
  Hardware is ISR4321-2x1GE, address is a0e0.af0d.e140 (bia  a0e0.af0d.e140)
  Description: Link to LAN
  Internet address is 192.168.10.1/24
  MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive not supported
  Full Duplex, 100Mbps, link type is auto, media type is RJ45
  output flow-control is off, input flow-control is off
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 00:00:01, output 00:00:35, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/375/0/0 (size/max/drops/flushes); Total output     drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     1180 packets input, 109486 bytes, 0 no buffer
     Received 84 broadcasts (0 IP multicasts)
     0 runts, 0 giants, 0 throttles

<output omitted>

R1#
```

Configure Verification Commands (Cont.)

Display IPv4 statistics for router interfaces with the **show ip interface** command, as shown here:

```
R1# show ip interface g0/0/0
GigabitEthernet0/0/0 is up, line protocol is up
  Internet address is 192.168.10.1/24
  Broadcast address is 255.255.255.255
  Address determined by setup command
  MTU is 1500 bytes
  Helper address is not set
  Directed broadcast forwarding is disabled
  Outgoing Common access list is not set
  Outgoing access list is not set
  Inbound Common access list is not set
  Inbound  access list is not set
  Proxy ARP is enabled
  Local Proxy ARP is disabled
  Security level is default
  Split horizon is enabled
  ICMP redirects are always sent
  ICMP unreachables are always sent
  ICMP mask replies are never sent
  IP fast switching is enabled
  IP Flow switching is disabled

<output omitted>

R1#
```

Configure Interfaces

Configure Verification Commands (Cont.)

Display IPv6 statistics for router interfaces with the **show ipv6 interface** command shown here:

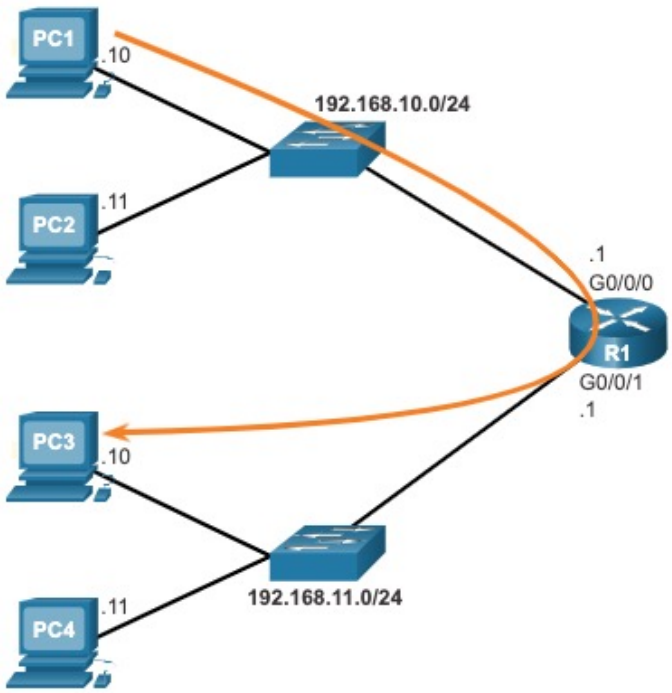
```
R1# show ipv6 interface g0/0/0
GigabitEthernet0/0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is
FE80::868A:8DFF:FE44:49B0
  No Virtual link-local address(es):
  Description: Link to LAN
  Global unicast address(es):
    2001:DB8:ACAD:10::1, subnet is 2001:DB8:ACAD:10::/64
  Joined group address(es):
    FF02::1
    FF02::1:FF00:1
    FF02::1:FF44:49B0
  MTU is 1500 bytes
  ICMP error messages limited to one every 100 milliseconds
  ICMP redirects are enabled
  ICMP unreachables are sent
  ND DAD is enabled, number of DAD attempts: 1
  ND reachable time is 30000 milliseconds (using 30000)
  ND NS retransmit interval is 1000 milliseconds

R1#
```

Configure the Default Gateway

Default Gateway on a Host

- The default gateway is used when a host sends a packet to a device on another network.
- The default gateway address is generally the router interface address attached to the local network of the host.
- To reach PC3, PC1 addresses a packet with the IPv4 address of PC3, but forwards the packet to its default gateway, the G0/0/0 interface of R1.

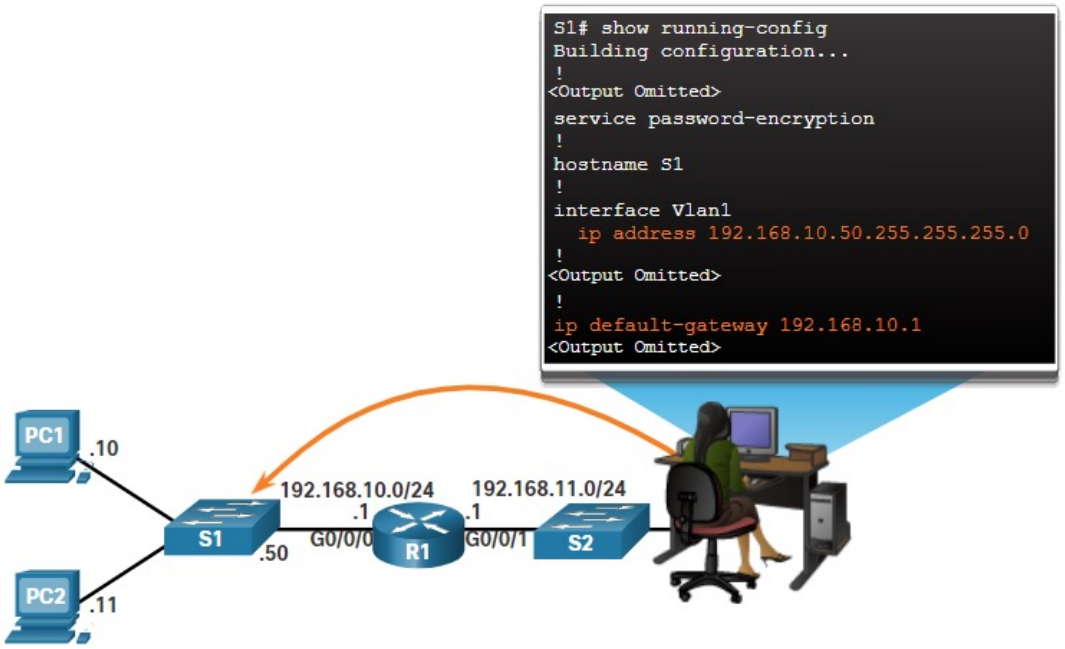


Note: The IP address of the host and the router interface must be in the same network.

Configure the Default Gateway

Default Gateway on a Switch

- A switch must have a default gateway address configured to remotely manage the switch from another network.
- To configure an IPv4 default gateway on a switch, use the **ip default-gateway** *ip-address* global configuration command.



Module Practice and Quiz

What did I learn in this module?

- The tasks that should be completed when configuring initial settings on a router.
  - Configure the device name.
  - Secure privileged EXEC mode.
  - Secure user EXEC mode.
  - Secure remote Telnet / SSH access.
  - Secure all passwords in the config file.
  - Provide legal notification.
  - Save the configuration.
- For routers to be reachable, the router interfaces must be configured.
  - Using the **no shutdown** command activates the interface. The interface must also be connected to another device, such as a switch or a router, for the physical layer to be active. There are several commands that can be used to verify interface configuration including the **show ip interface brief** and **show ipv6 interface brief**, the **show ip route** and **show ipv6 route**, as well as **show interfaces**, **show ip interface** and **show ipv6 interface.**

What did I learn in this module (Cont.)?

- For an end device to reach other networks, a default gateway must be configured.
  - The IP address of the host device and the router interface address must be in the same network.
- A switch must have a default gateway address configured to remotely manage the switch from another network.
  - To configure an IPv4 default gateway on a switch, use the **ip default-gateway** *ip-address* global configuration command.

New Terms and Commands

- **show ip interface brief**
- **show ipv6 interface brief**
- **show ip route**
- **show ipv6 route**
- **show interfaces**
- **show ip interface**
- **show ipv6 interface**
- **ip default-gateway**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