Module 8: Network Layer

Introduction to Networks v7.0
(ITN)

Module 8: Topics

What will I learn to do in this module?

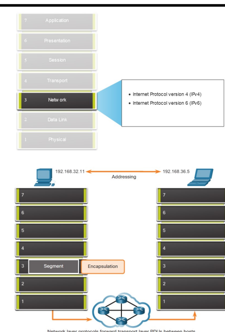
Topic Title	Topic Objective
Network Layer Characteristics	Explain how the network layer uses IP protocols for reliable communications.
IPv4 Packet	Explain the role of the major header fields in the IPv4 packet.
IPv6 Packet	Explain the role of the major header fields in the IPv6 packet.
How a Host Routes	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.

8.1 Network Layer Characteristics

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

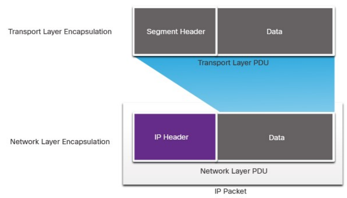


Network layer protocols forward transport layer PDUs between hosts.

Network Layer Characteristics
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.



Network Layer Characteristics
Characteristics of IP

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

- Connectionless
- Best Effort
- Media Independent

Network Layer Characteristics
Connectionless

IP is Connectionless

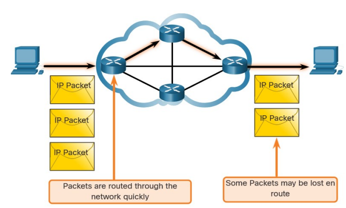
- IP does not establish a connection with the destination before sending the packet.
- There is no control information needed (synchronizations, acknowledgments, etc.).
- The destination will receive the packet when it arrives, but no pre-notifications are sent by IP.
- If there is a need for connection-oriented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

A letter is sent.

Network Layer Characteristics
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.



Network Layer Characteristics

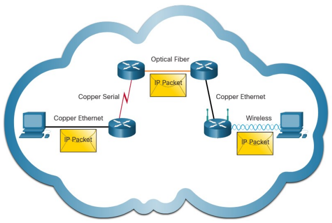
Media Independent

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.



Network Layer Characteristics

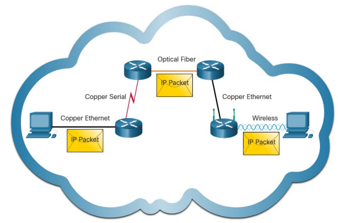
Media Independent (Contd.)

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



8.2 IPv4 Packet

IPv4 Packet

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

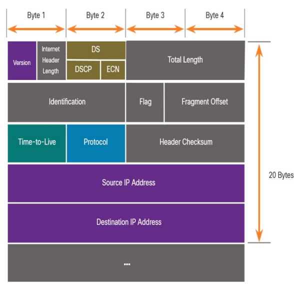
IPv4 Packet

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

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

IPv4 Packet

Video – Sample IPv4 Headers in Wireshark

This video will cover the following:

- IPv4 Ethernet packets in Wireshark
- The control information
- The difference between packets

8.3 IPv6 Packets

IPv6 Packets

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 Packets

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

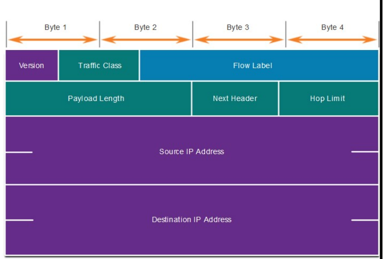
There are 4 billion IPv4 addresses

There are 340 undecillion IPv6 addresses

IPv6 Packets

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 IPv4 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 Packets

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.

IPv6 Packets

Video – Sample IPv6 Headers in Wireshark

This video will cover the following:

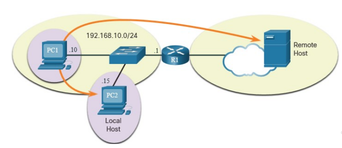
- IPv6 Ethernet packets in Wireshark
- The control information
- The difference between packets

8.4 How a Host Routes

How a Host Routes

Host Forwarding Decision

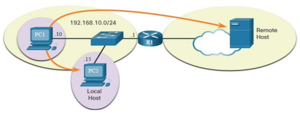
- Packets are always created at the source.
- Each host devices creates their own routing table.
- A host can send packets to the following:
  - Itself – 127.0.0.1 (IPv4), ::1 (IPv6)
  - Local Hosts – destination is on the same LAN
  - Remote Hosts – devices are not on the same LAN



How a Host Routes

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.



How a Host Routes

Default Gateway

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

Features of a default gateway (DGW):

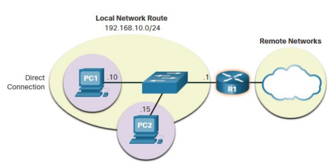
- It must have an IP address in the same range as the rest of the LAN.
- It can accept data from the LAN and is capable of forwarding traffic off of the LAN.
- It can route to other networks.

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

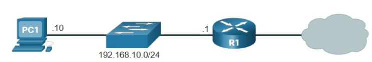
- The host will know the default gateway (DGW) either statically or through DHCP in IPv4.
- IPv6 sends the DGW through a router solicitation (RS) or can be configured manually.
- A DGW is static route which will be a last resort route in the routing table.
- All device on the LAN will need the DGW of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

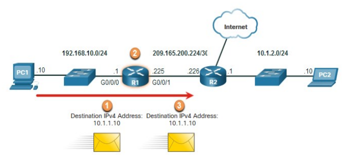
```
C:\Users\PC1> netstat -r

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
```

8.5 Introduction to Routing

Introduction to Routing

Router Packet Forwarding Decision

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



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

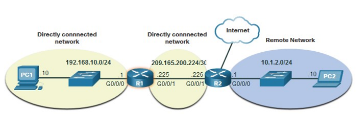
1. Packet arrives on the Gigabit Ethernet 0/0/0 interface of router R1. R1 de-encapsulates the Layer 2 Ethernet header and trailer.
2. Router R1 examines the destination IPv4 address of the packet and searches for the best match in its IPv4 routing table. The route entry indicates that this packet is 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.

Introduction to Routing

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

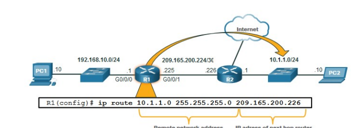


Introduction to Routing

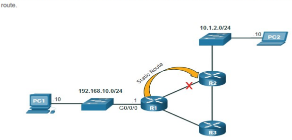
Static Routing

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.

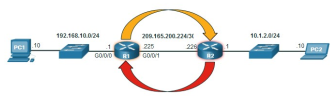
Introduction to Routing

Dynamic Routing

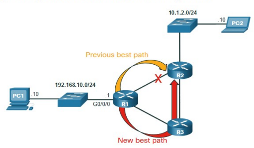
Dynamic Routes Automatically:

- 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 Routing

Video – IPv4 Router Routing Tables

This video will explain the information in the IPv4 router routing table.

Introduction to Routing

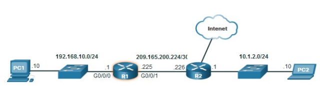
Introduction to an IPv4 Routing Table

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#
```


8.6 Module Practice and Quiz

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.

Network Layer

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

Network Layer

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