Chapter 6: Network Layer

Introduction to Networks

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Chapter 6: Objectives

In this chapter, you will be able to:

- Explain how network layer protocols and services support communications across data networks.
- Explain how routers enable end-to-end connectivity in a small-to-medium-sized business network.
- Determine the appropriate device to route traffic in a small-to-medium-sized business network.
- Configure a router with basic configurations.

Chapter 6

6.1 Network Layer Protocols

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Network Layer in Communication
The Network Layer

The network layer, or OSI Layer 3, provides services to allow end devices to exchange data across the network. To accomplish this end-to-end transport, the network layer uses four basic processes:

- Addressing end devices
- Encapsulation
- Routing
- De-encapsulating

Network Layer Protocols

Common network layer protocols include:

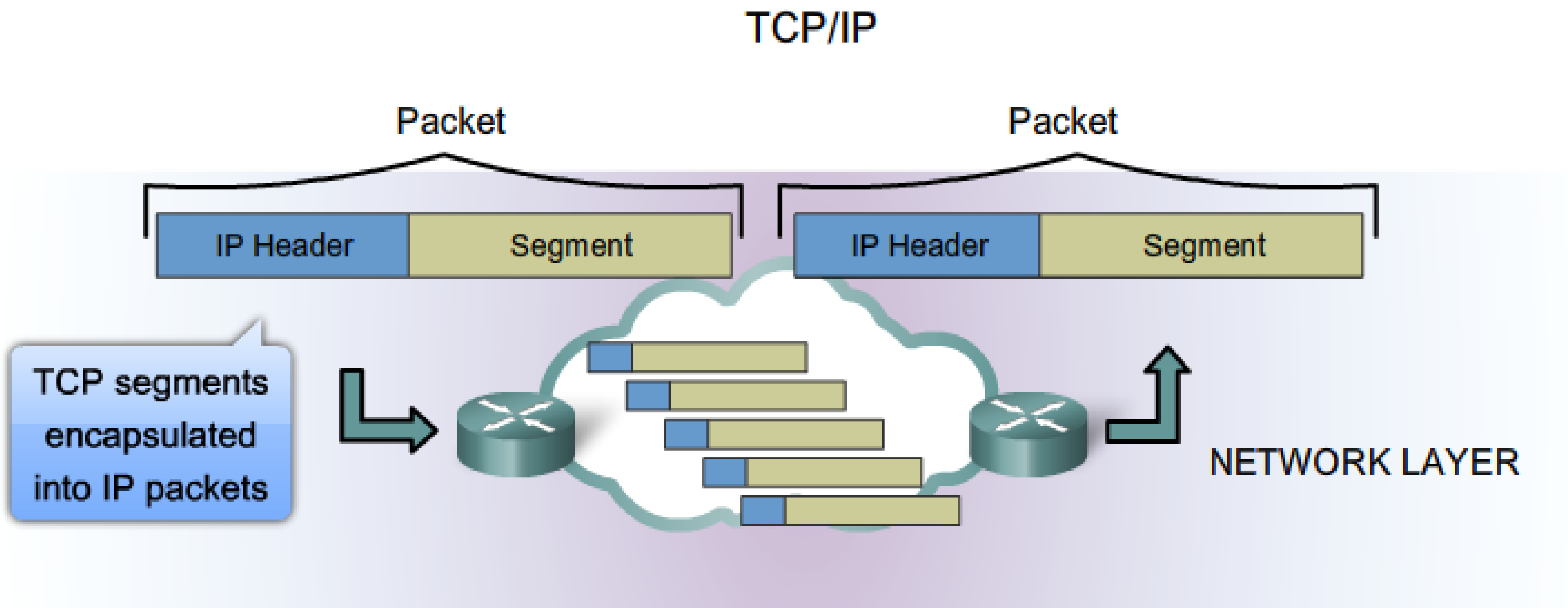
- IP version 4 (IPv4)
- IP version 6 (IPv6)

Legacy network layer protocols include:

- Novell Internetwork Packet Exchange (IPX)
- AppleTalk
- Connectionless Network Service (CLNS/DECNet)

IP Characteristics

IP Components



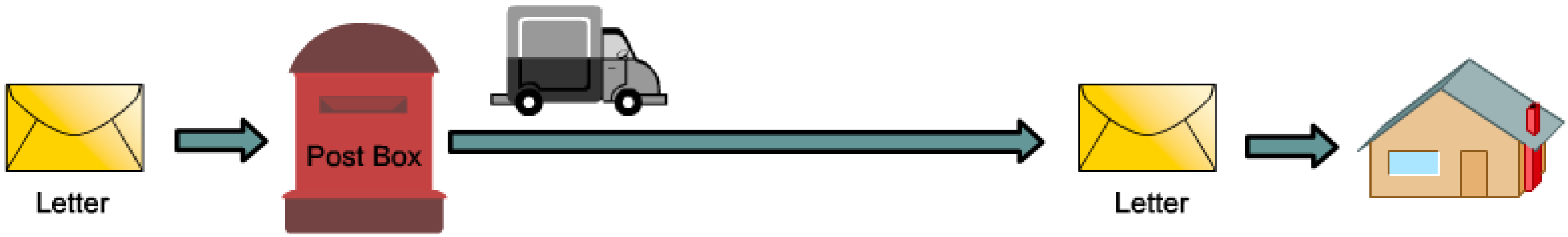
IP Packets flow through the internetwork.

- Connectionless - No connection is established before sending data packets.
- Best Effort (unreliable) - No overhead is used to guarantee packet delivery.
- Media Independent - Operates independently of the medium carrying the data.

Characteristics of the IP protocol

IP - Connectionless

Connectionless Communication



A letter is sent.

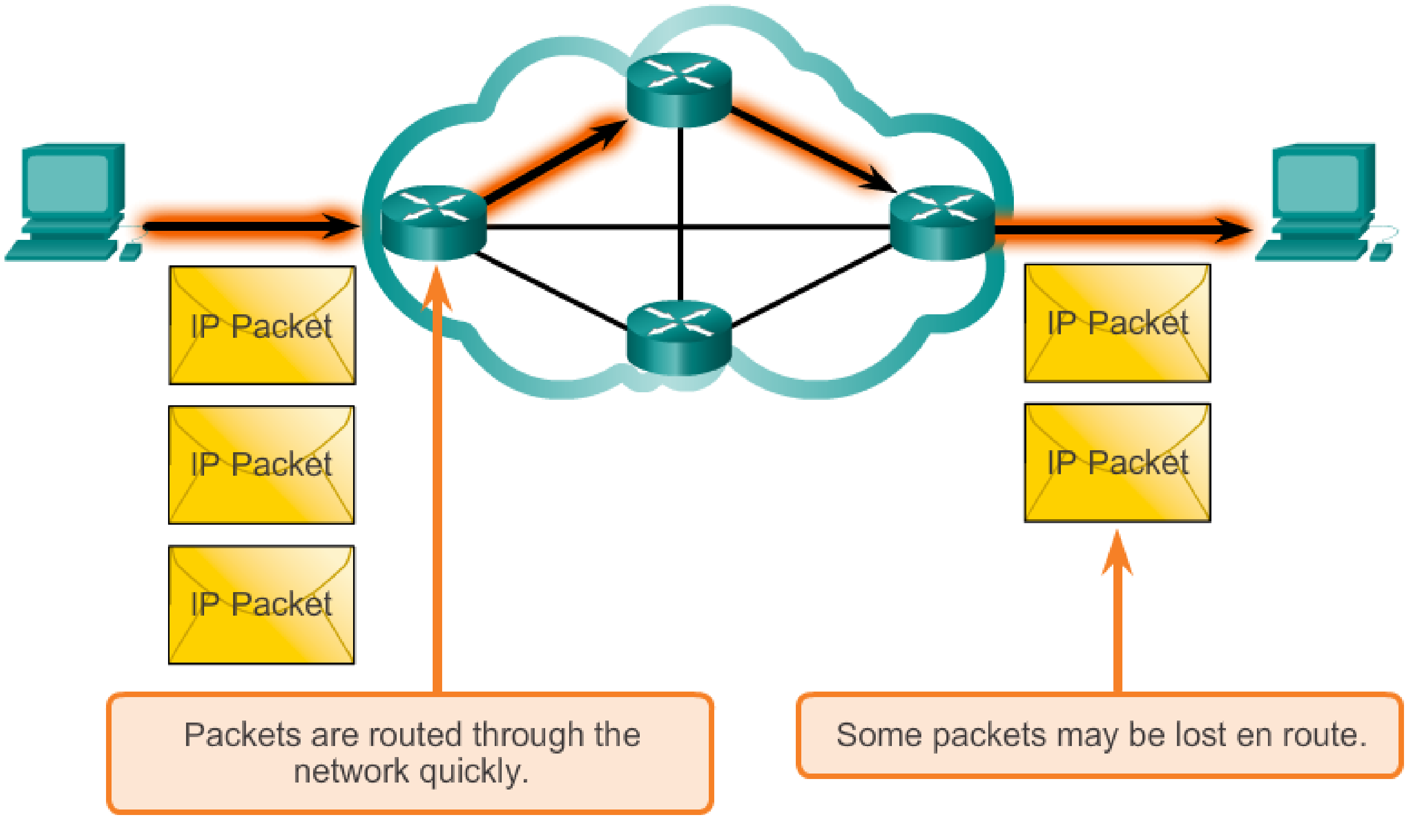
The sender doesn't know:

- if the receiver is present
- if the letter arrived
- if the receiver can read the letter

The receiver doesn't know:

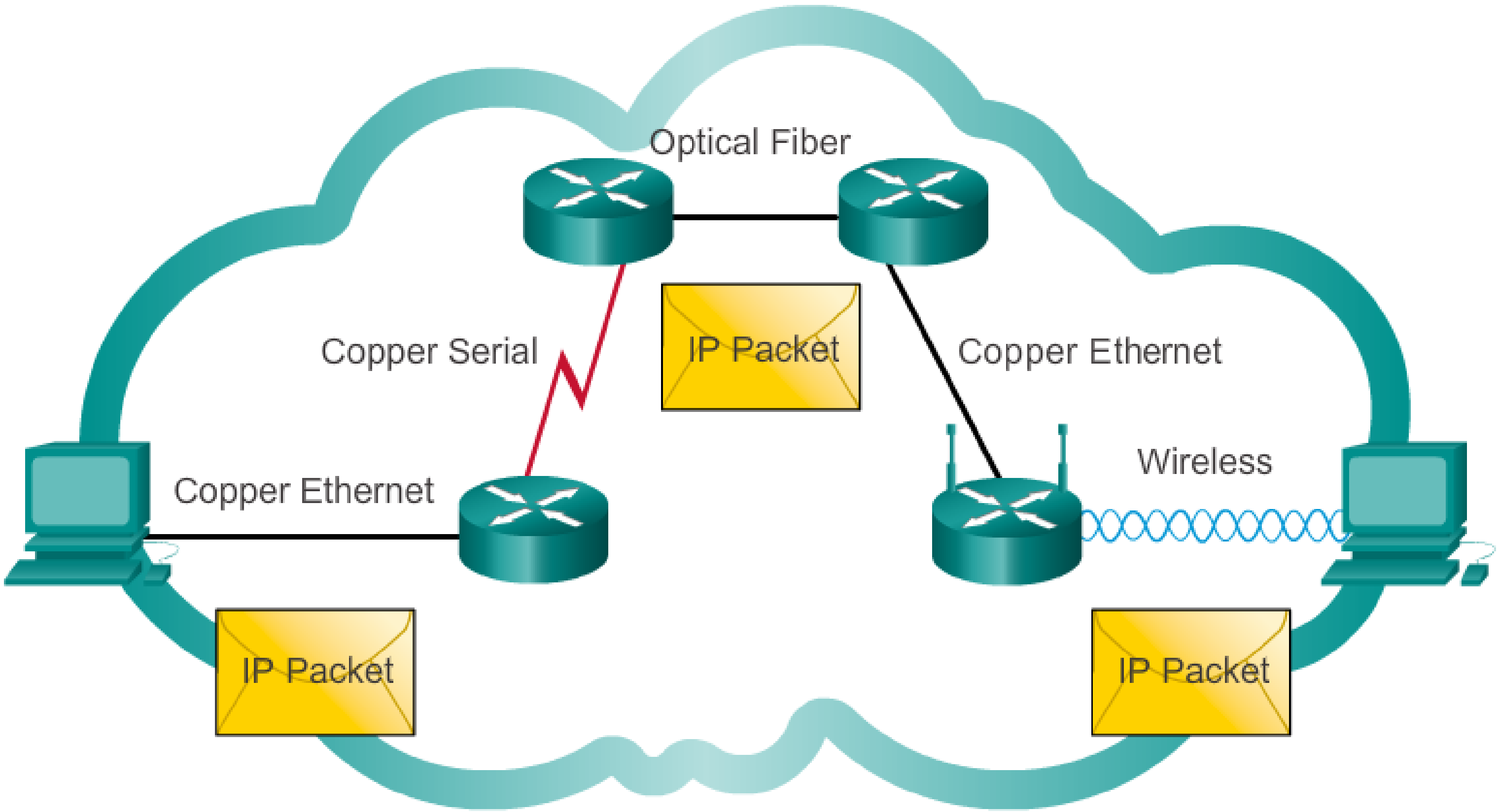
- when it is coming

Best Effort Delivery



As an unreliable network layer protocol, IP does not guarantee that all sent packets will be received. Other protocols manage the process of tracking packets and ensuring their delivery.

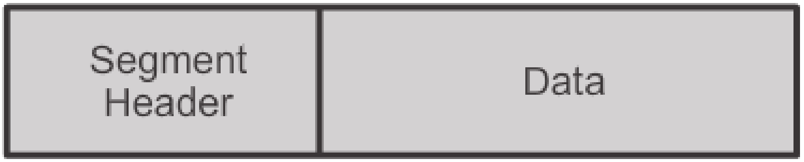
IP – Media Independent



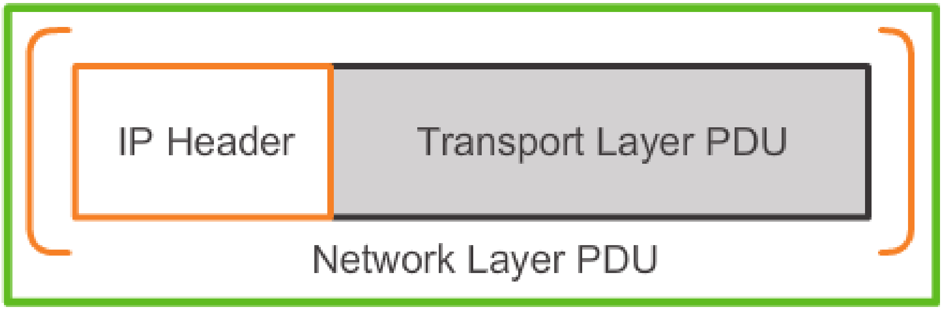
IP packets can travel over different media.

Encapsulating IP

Transport Layer Encapsulation



Network Layer Encapsulation

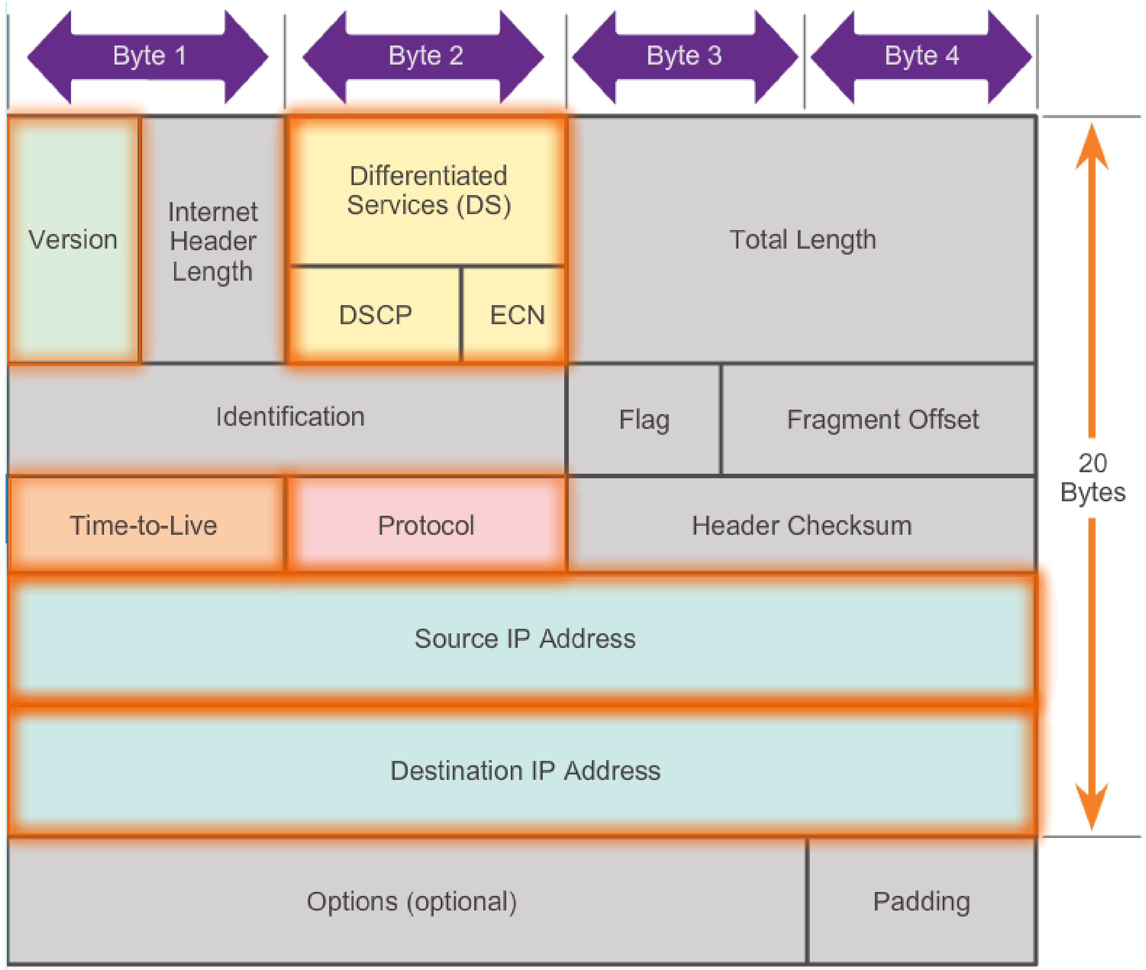


IP Packet

The network layer adds a header so packets can be routed through complex networks and reach their destination. In TCP/IP based networks, the network layer PDU is the IP packet.

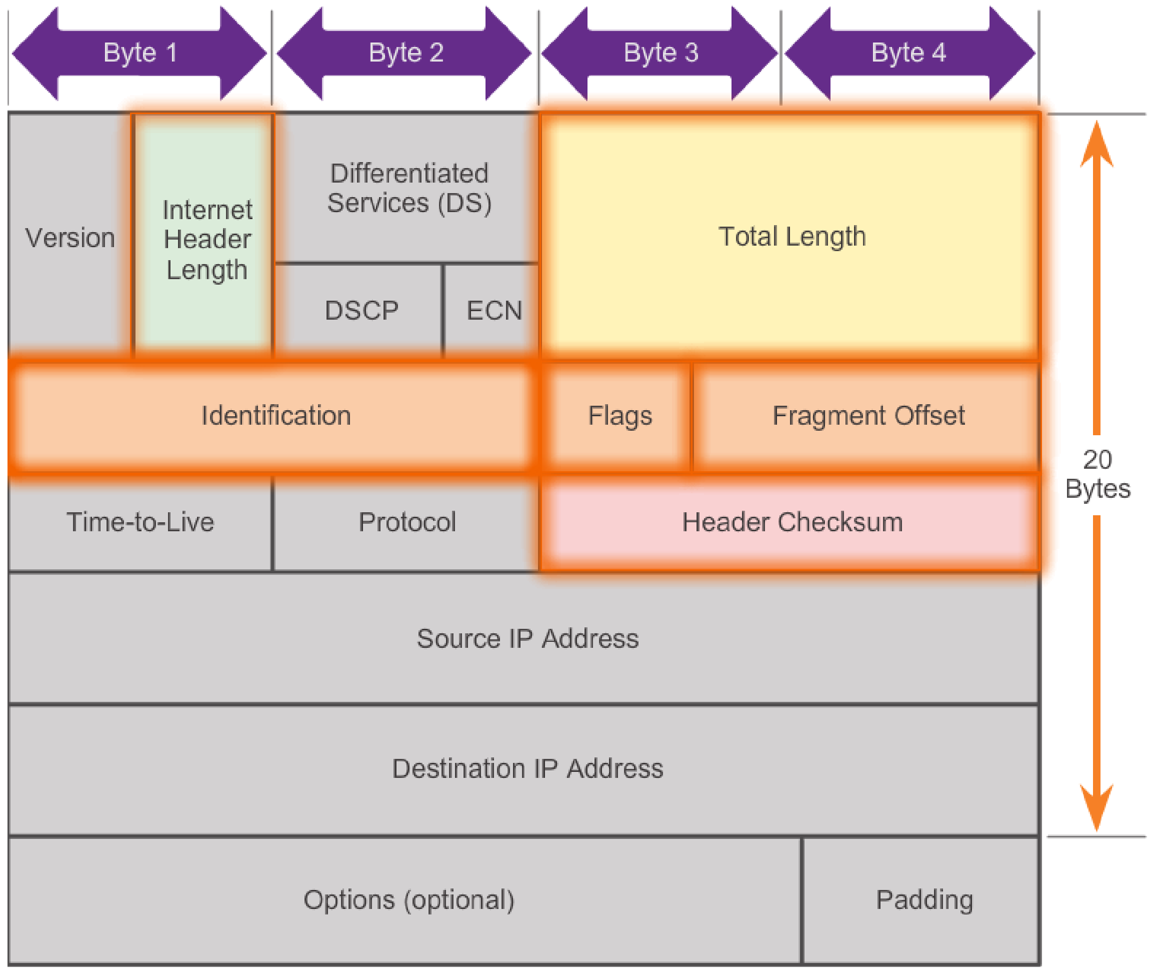
IPv4 Packet Header

Contents of the IPv4 packet header



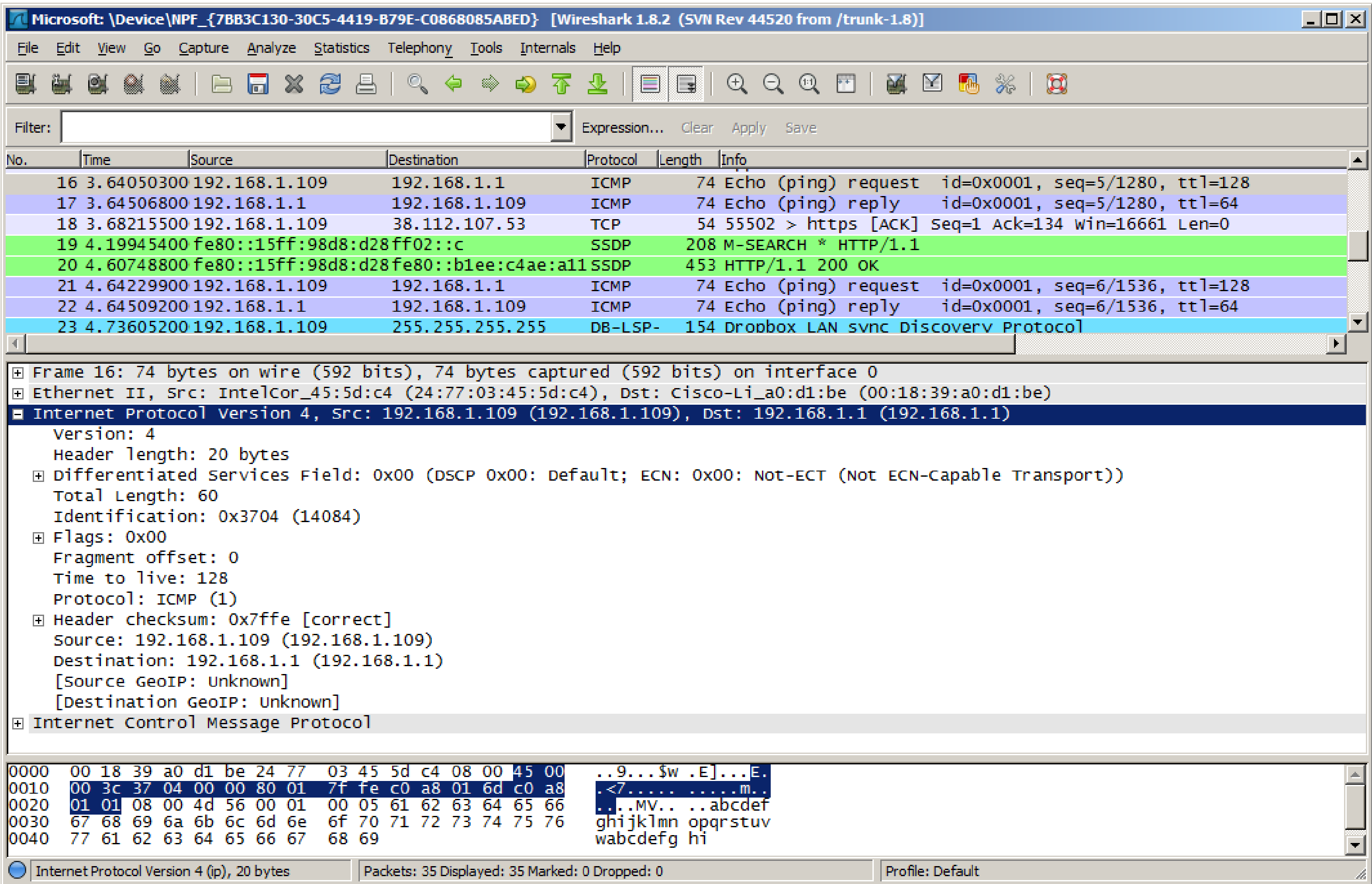
IPv4 Header Fields

Contents of the IPv4 header fields



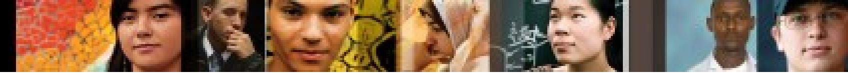
IPv4 Packet

Sample IPv4 Headers



Limitations of IPv4

- IP Address depletion
- Internet routing table expansion
- Lack of end-to-end connectivity



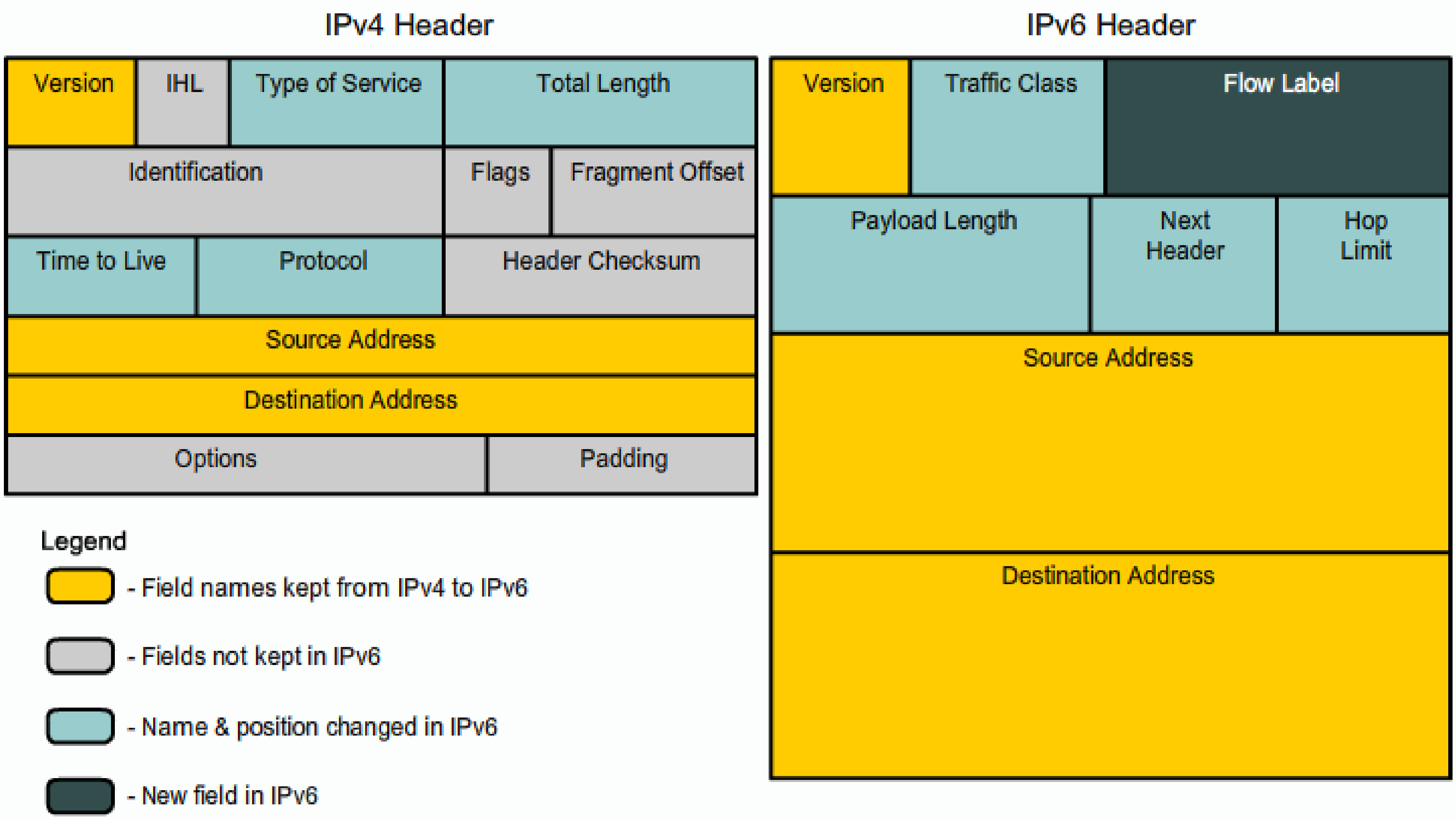
Network Layer in Communication

Introducing IPv6

- Increased address space
- Improved packet handling
- Eliminates the need for NAT
- Integrated security
- 4 billion IPv4 addresses
  4,000,000,000
- 340 undecillion IPv6 addresses
  340,000,000,000,000,000,000,000,000,000,000,000,000

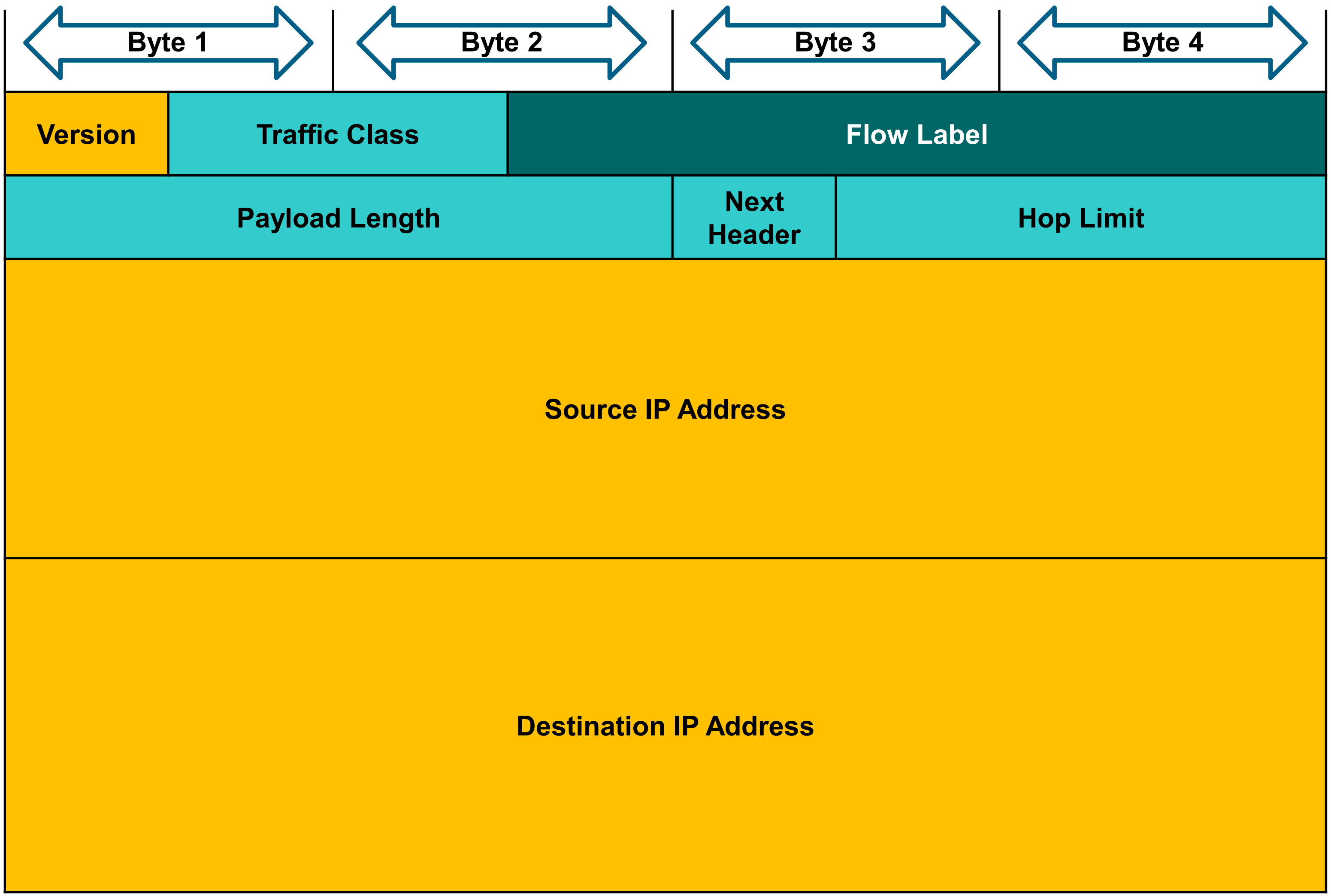
IPv6 Packet
Encapsulating IPv6

IPv4 and IPv6 Headers



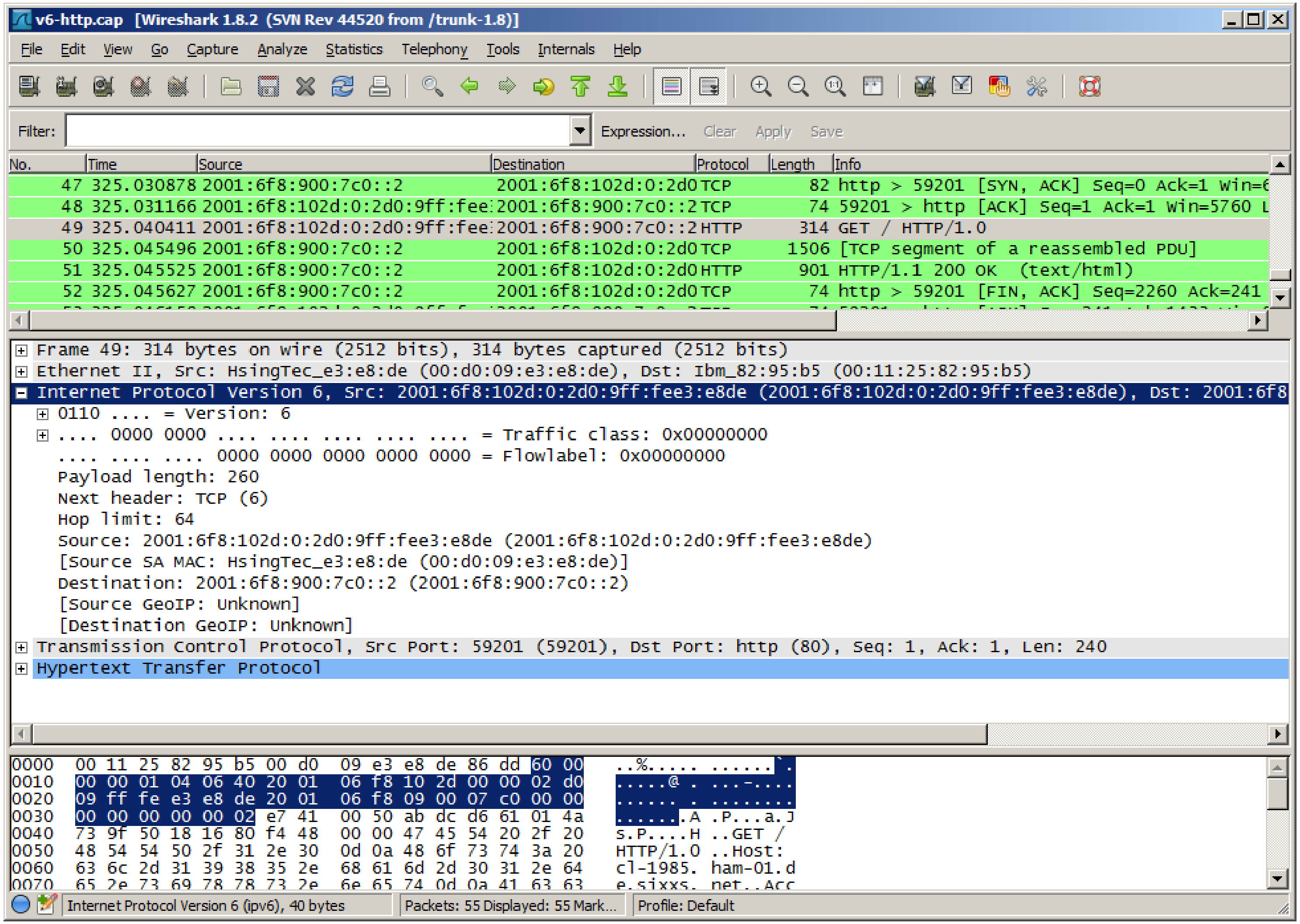
IPv6 Packet

IPv6 Packet Header



IPv6 Packet

Sample IPv6 Header



6.2 Routing

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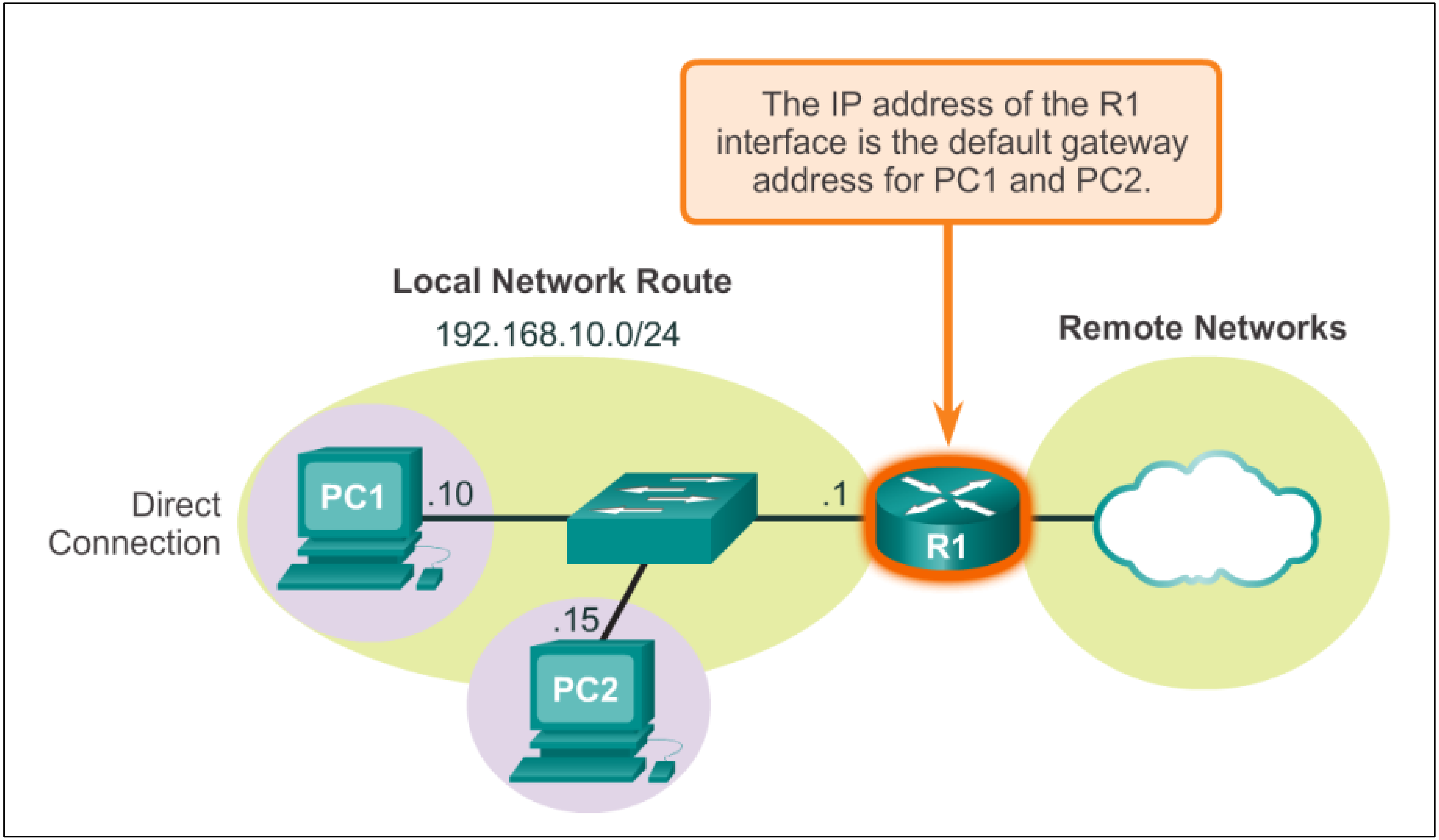
Host Packet Forwarding Decision



Host Routing Tables

Default Gateway

Hosts must maintain their own, local, routing table to ensure that network layer packets are directed to the correct destination network. The local table of the host typically contains:

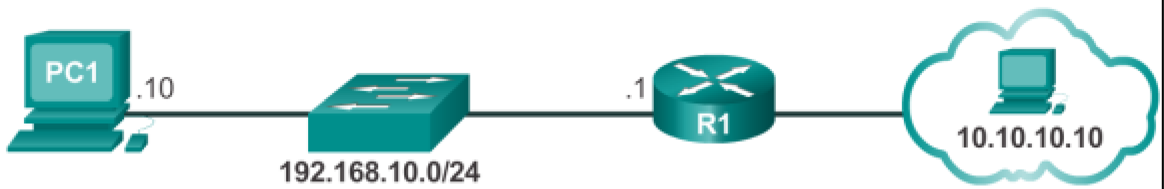
- Direct connection
- Local network route
- Local default route

IPv4 Host Routing Table


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

<Output omitted>

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
===========================================================================

<Output omitted>
```

Host Routing Tables

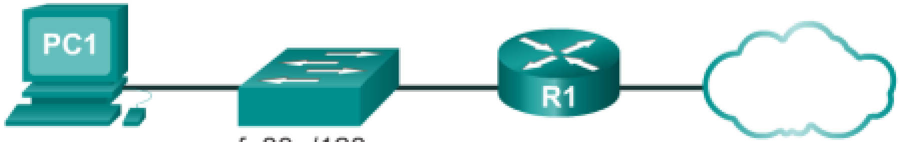
Sample IPv4 Host Routing Table




```
C:\Users\PC1> netstat -r
<Output omitted>
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
===========================================================================
<Output omitted>
```

Host Routing Tables

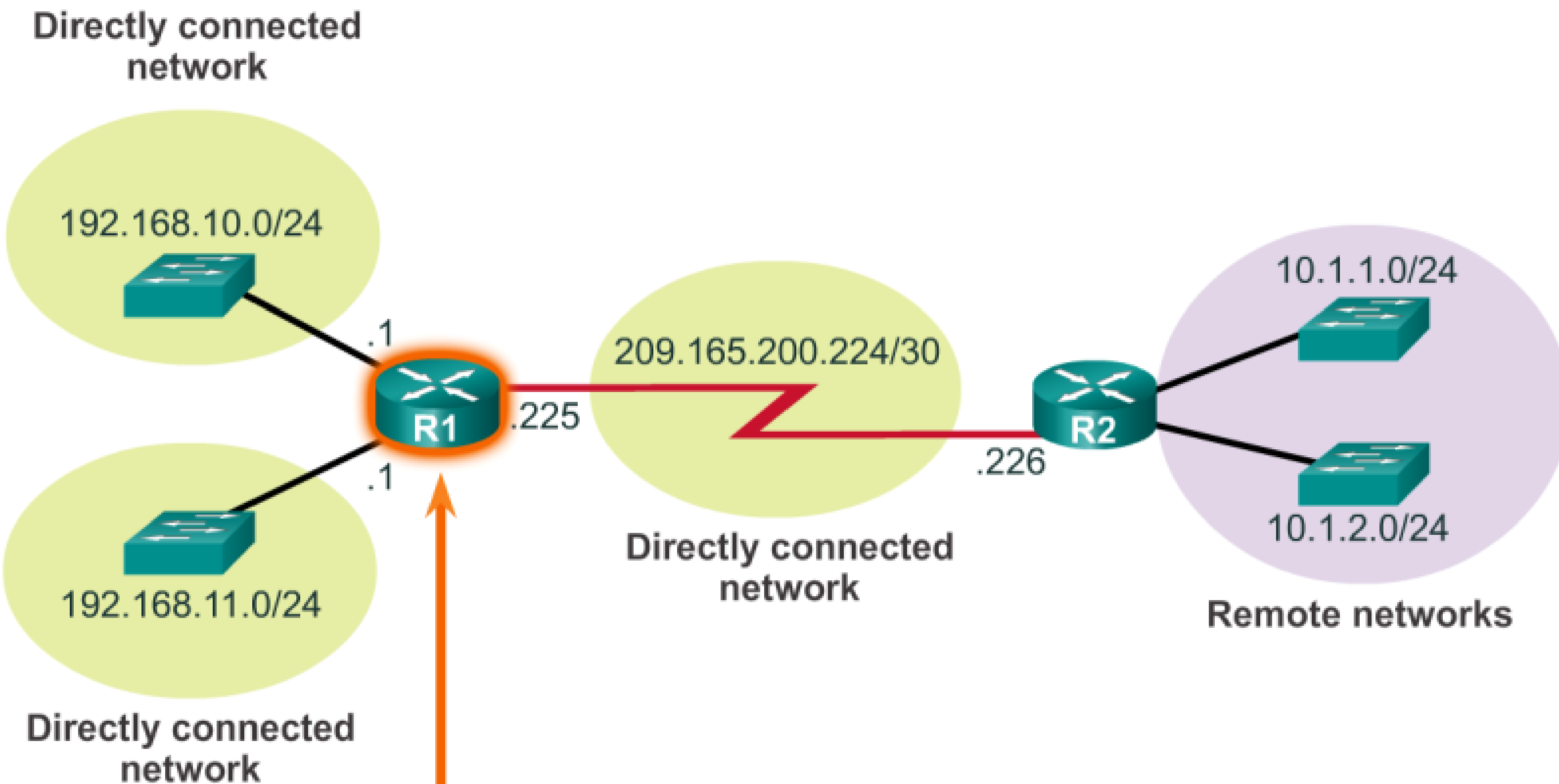
Sample IPv6 Host Routing Table




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

<Output omitted>

IPv6 Route Table
===========================================================================
Active Routes:
 If Metric Network Destination      Gateway
 16     58 ::/0                     On-link
  1    306 ::1/128                  On-link
 16     58 2001::/32                On-link
 16    306 2001:0:9d38:953c:2c30:3071:e718:a926/128
                                    On-link
 15    281 fe80::/64                On-link
 16    306 fe80::/64                On-link
 16    306 fe80::2c30:3071:e718:a926/128
                                    On-link
 15    281 fe80::b1ee:c4ae:a117:271f/128
                                    On-link
  1    306 ff00::/8                 On-link
 16    306 ff00::/8                 On-link
 15    281 ff00::/8                 On-link
===========================================================================
<Output omitted>
```

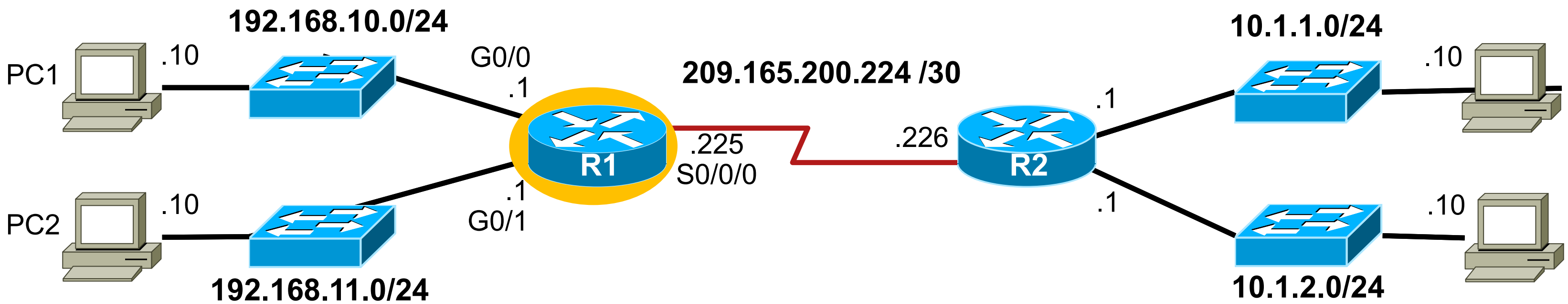
Router Routing Tables

Router Packet Forwarding Decision



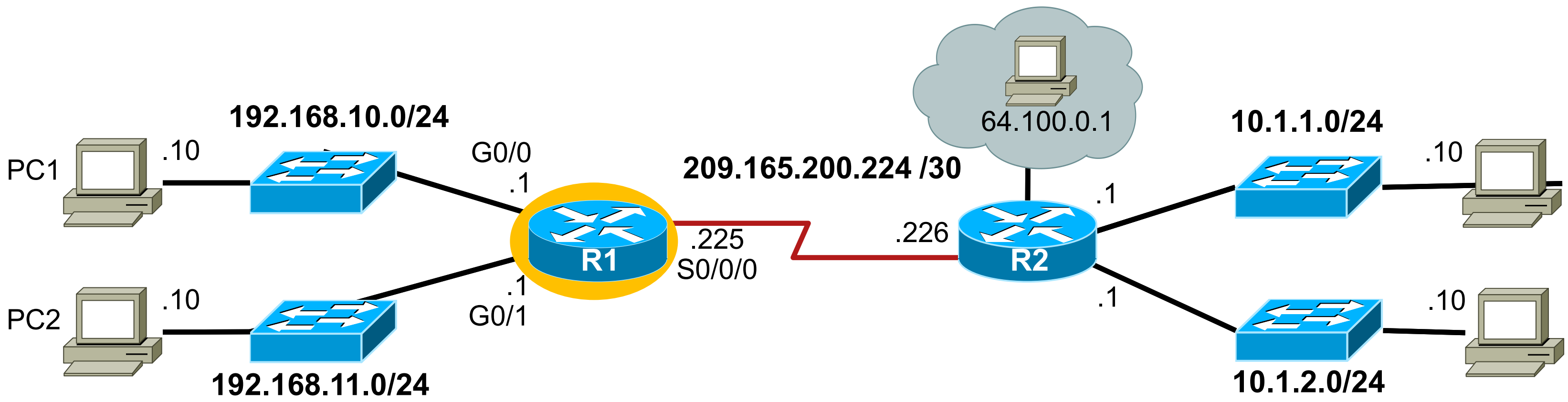
R1 has three directly connected networks: 192.168.10.0/24, 192.168.11.0/24, and 209.165.200.224/30. R1 also has two remote networks that it can learn about from R2: 10.1.1.0/24 and 10.1.2.0/24.

IPv4 Router Routing Table




```
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, E - EGP
       i - IS-IS, 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

Gateway of last resort is not set

     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
D       10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
D       10.1.2.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
     192.168.10.0/24 is variably subnetted, 2 subnets, 3 masks
C       192.168.10.0/24 is directly connected, GigabitEthernet0/0
L       192.168.10.1/32 is directly connected, GigabitEthernet0/0
     192.168.11.0/24 is variably subnetted, 2 subnets, 3 masks
C       192.168.11.0/24 is directly connected, GigabitEthernet0/1
L       192.168.11.1/32 is directly connected, GigabitEthernet0/1
     209.165.200.0/24 is variably subnetted, 2 subnets, 3 masks
C       209.165.200.224/30 is directly connected, Serial0/0/0
L       209.165.200.225/32 is directly connected, Serial0/0/0
R1#
```

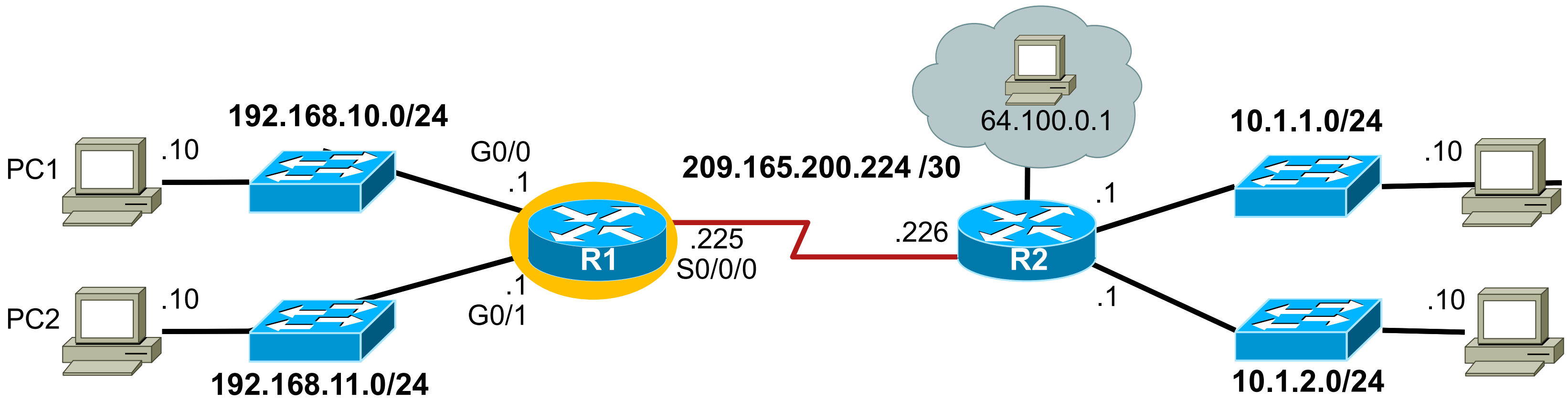
Directly Connected Routing Table Entries



A		B	C
C		192.168.10.0/24 is directly connected,	GigabitEthernet0/0
L		192.168.10.1/32 is directly connected,	GigabitEthernet0/0

A	Identifies how the network was learned by the router.
B	Identifies the destination network and how it is connected.
C	Identifies the interface on the router connected to the destination network.

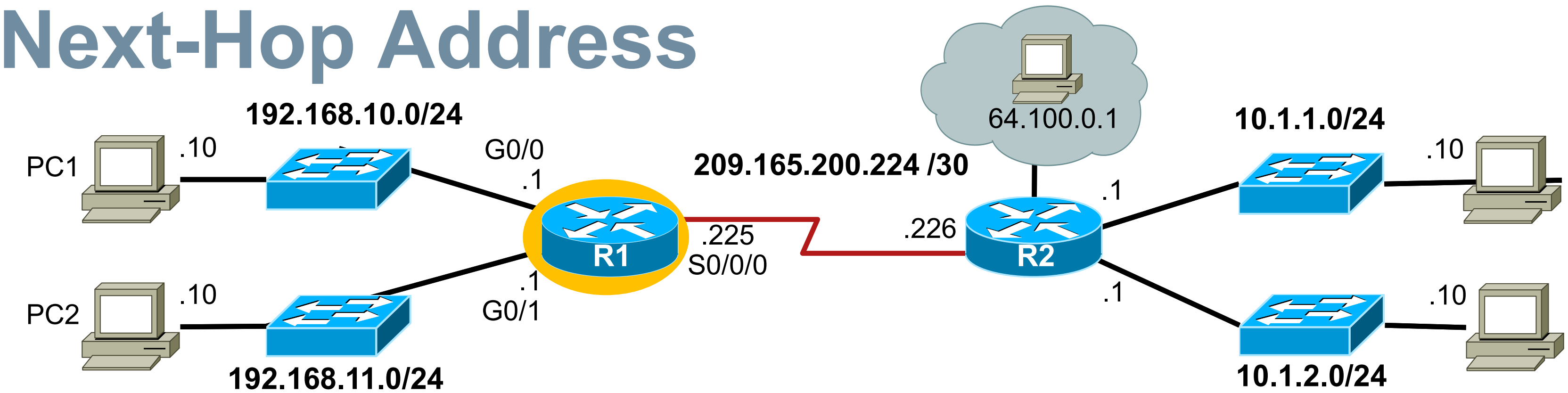
Remote Network Routing Table Entries




```
D        10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
```

A	Identifies how the network was learned by the router.
B	Identifies the destination network.
C	Identifies the administrative distance (trustworthiness) of the route source.
D	Identifies the metric to reach the remote network.
E	Identifies the next hop IP address to reach the remote network.
F	Identifies the amount of elapsed time since the network was discovered.
G	Identifies the outgoing interface on the router to reach the destination network.

Next-Hop Address




```
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       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, 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

Gateway of last resort is not set

     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
D       10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
D       10.1.2.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
     192.168.10.0/24 is variably subnetted, 2 subnets, 3 masks
C       192.168.10.0/24 is directly connected, GigabitEthernet0/0
L       192.168.10.1/32 is directly connected, GigabitEthernet0/0
     192.168.11.0/24 is variably subnetted, 2 subnets, 3 masks
C       192.168.11.0/24 is directly connected, GigabitEthernet0/1
L       192.168.11.1/32 is directly connected, GigabitEthernet0/1
     209.165.200.0/24 is variably subnetted, 2 subnets, 3 masks
C       209.165.200.224/30 is directly connected, Serial0/0/0
L       209.165.200.225/32 is directly connected, Serial0/0/0
R1#
```

6.3 Routers

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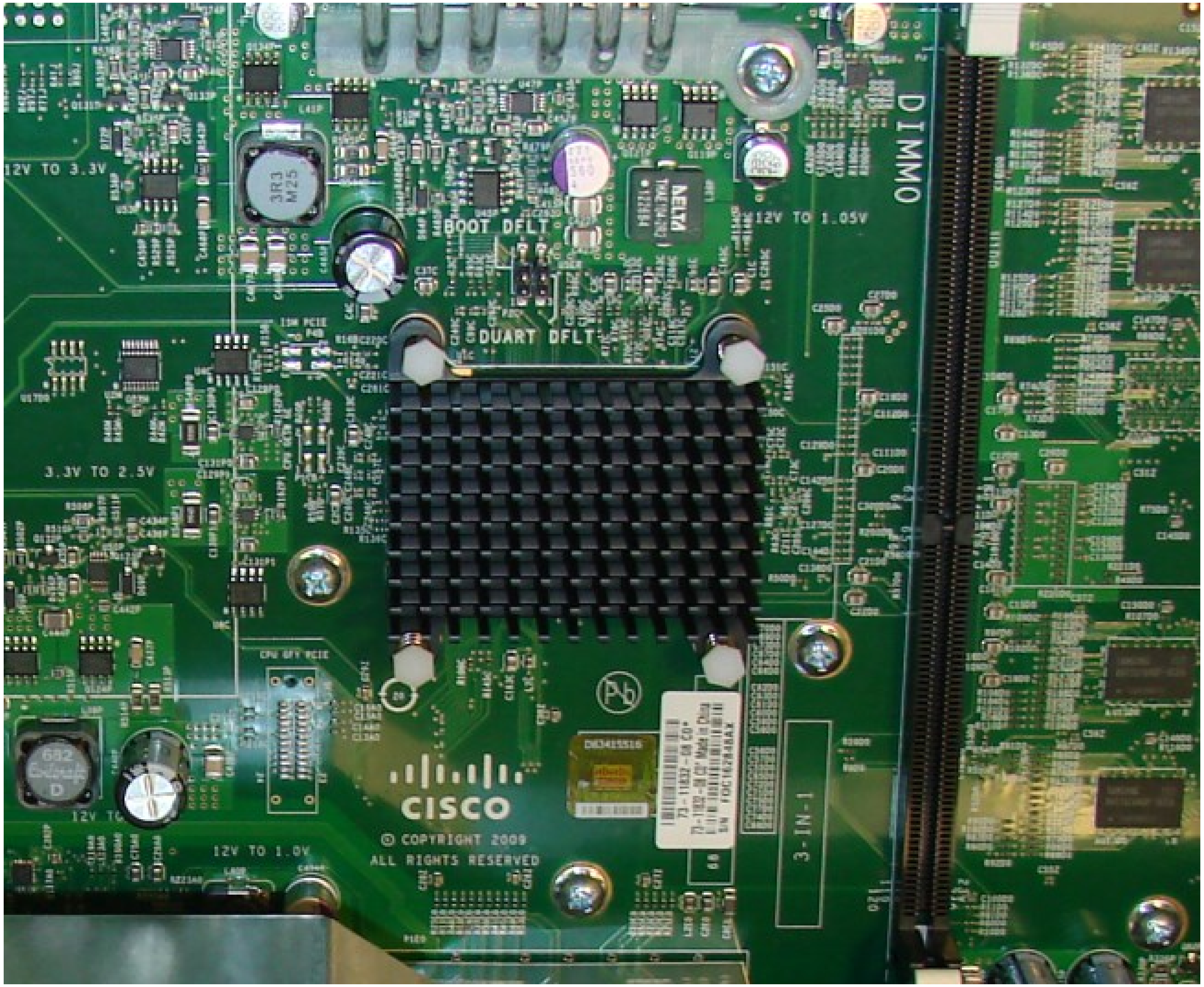
Anatomy of a Router

A Router is a Computer

Router CPU and OS



Anatomy of a Router

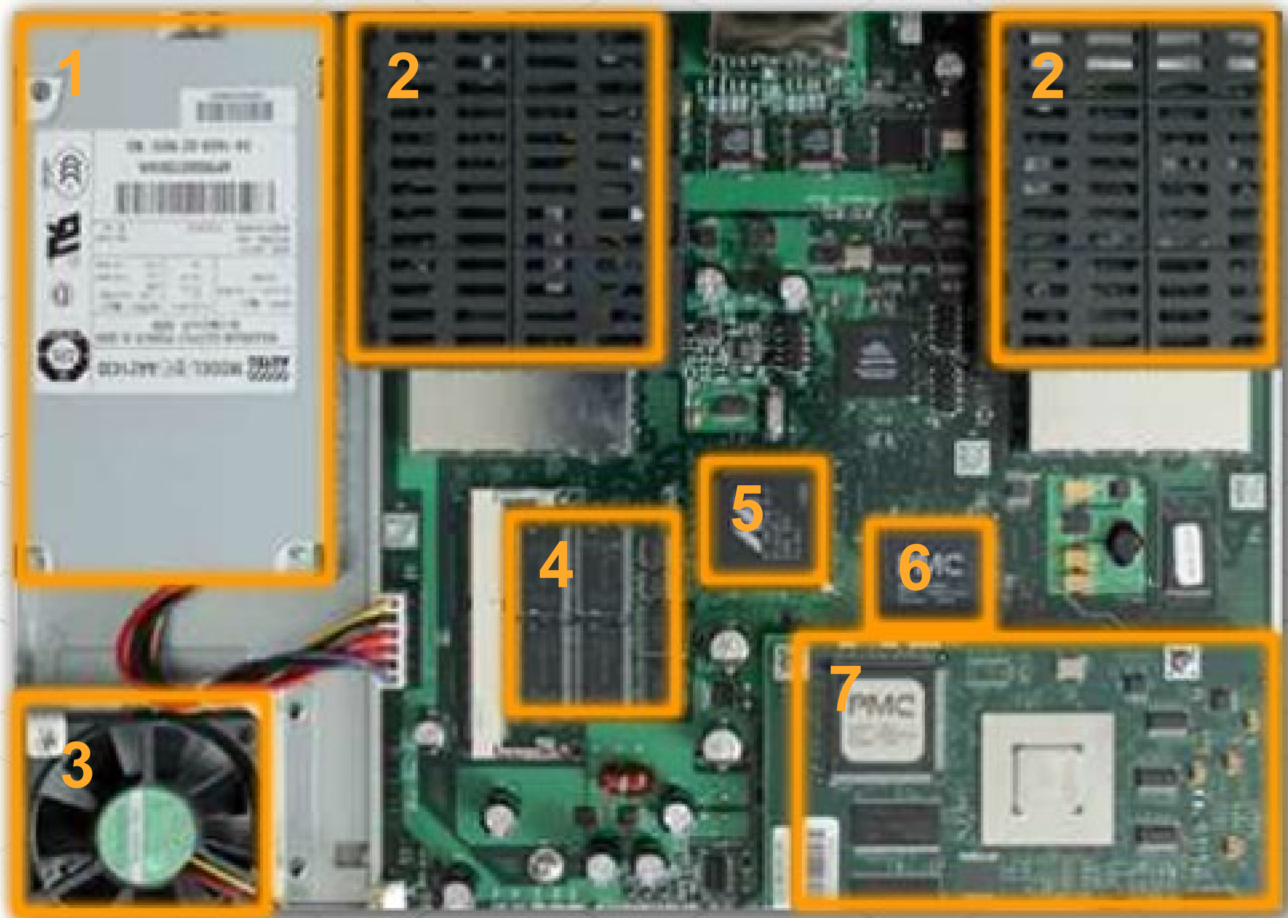
Router Memory

Memory	Volatile / Non-Volatile	Stores
RAM	Volatile	• Running IOS • Running configuration file • IP routing and ARP tables • Packet buffer
ROM	Non-Volatile	• Bootup instructions • Basic diagnostic software • Limited IOS
NVRAM	Non-Volatile	• Startup configuration file
Flash	Non-Volatile	• IOS • Other system files

Anatomy of a Router

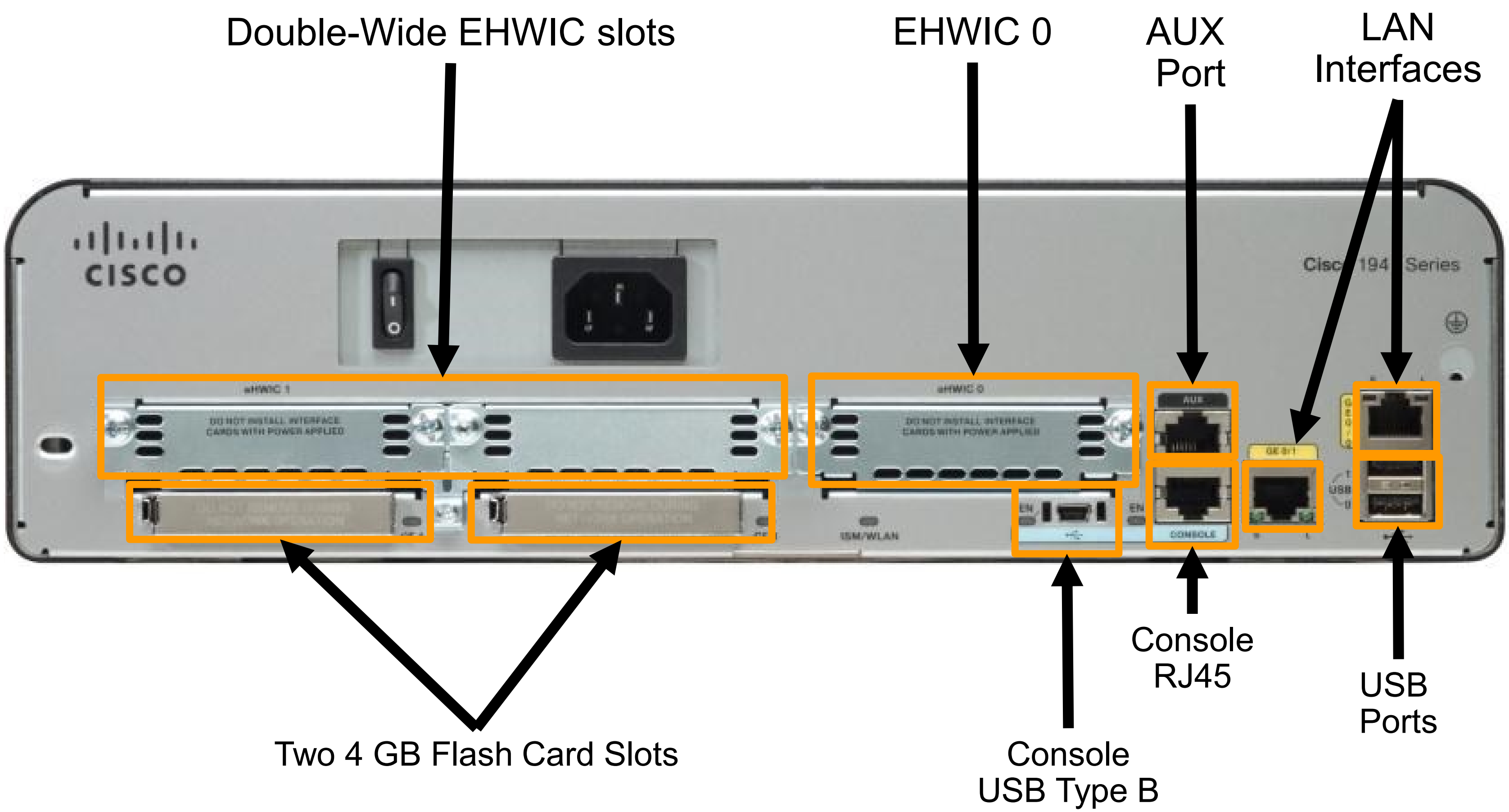
Inside a Router

1. Power Supply
2. Shield for WIC
3. Fan
4. SDRAM
5. NVRAM
6. CPU
7. Advanced Integration Module (AIM)

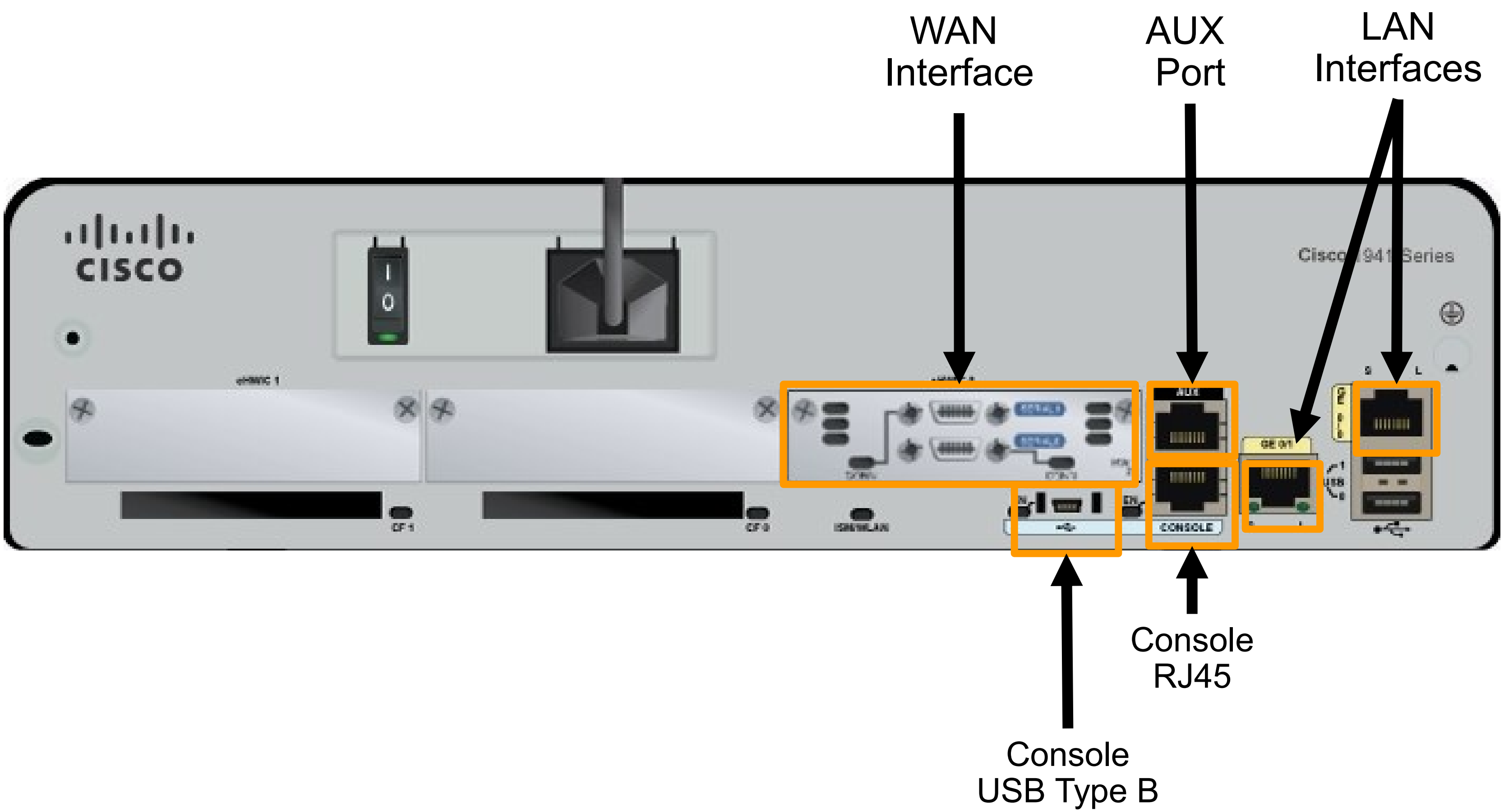


Anatomy of a Router

Router Backplane

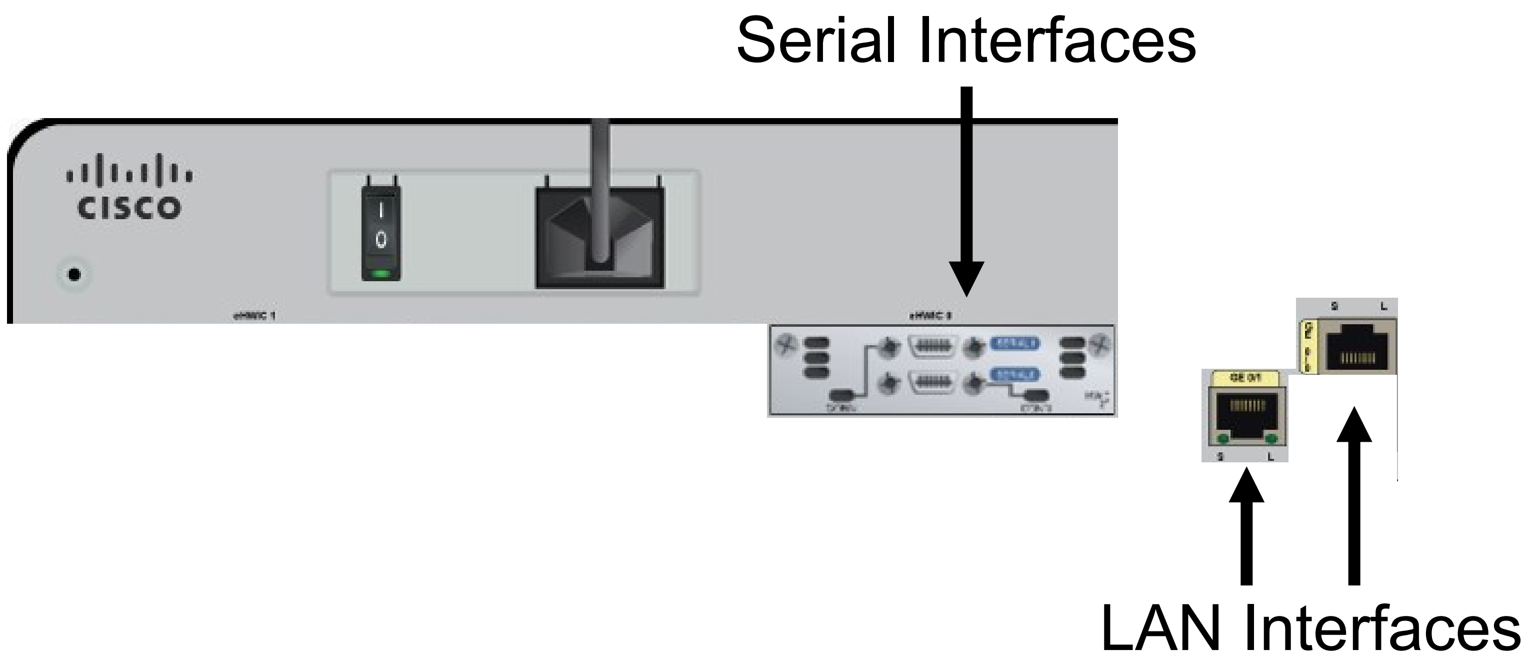


Connecting to a Router



Anatomy of a Router

LAN and WAN Interfaces



Router Boot-up

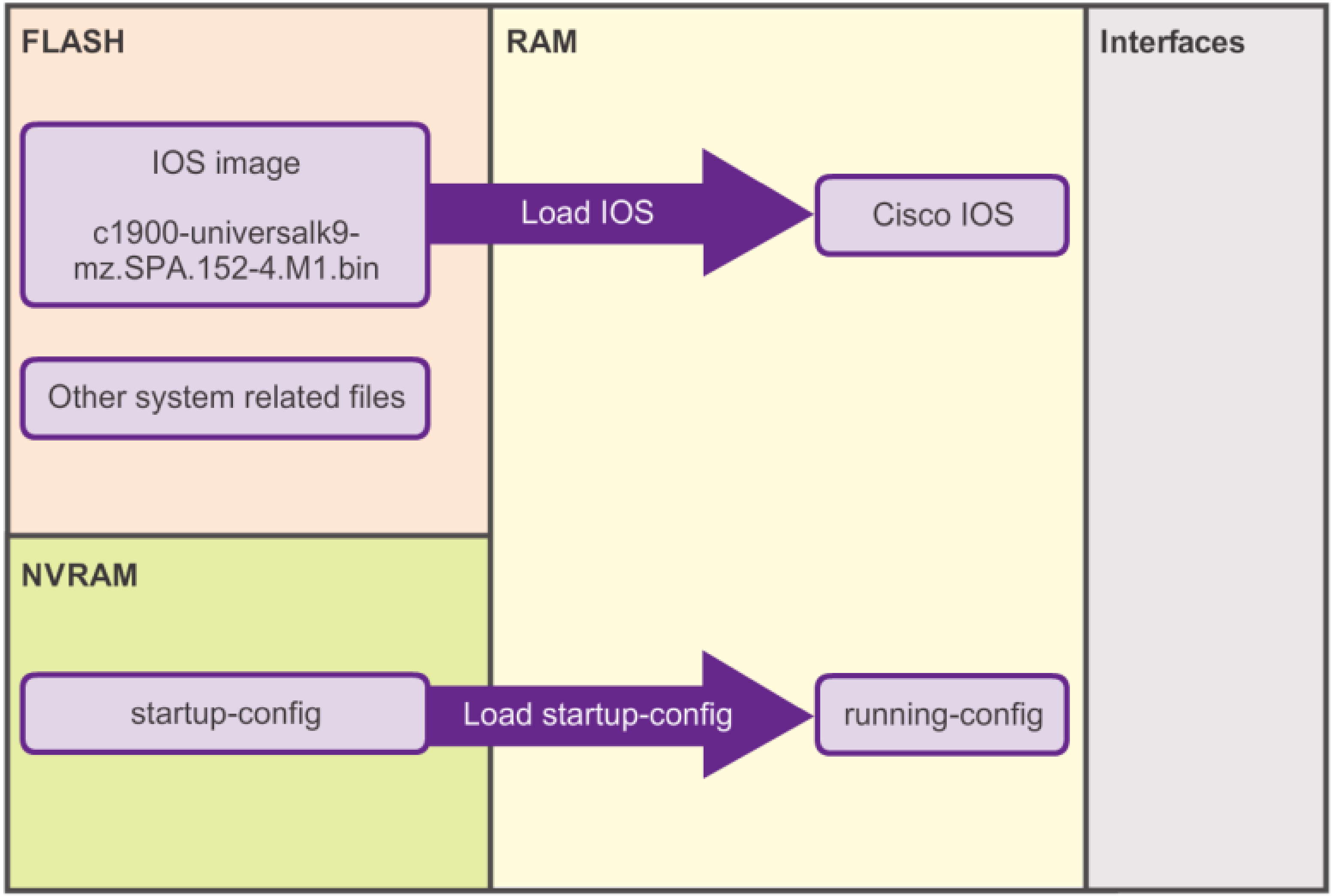
Cisco IOS

The Cisco IOS operational details vary on different internetworking devices, depending on the device's purpose and feature set. However, Cisco IOS for routers provides the following:

- Addressing
- Interfaces
- Routing
- Security
- QoS
- Resources Management

Router Boot-up

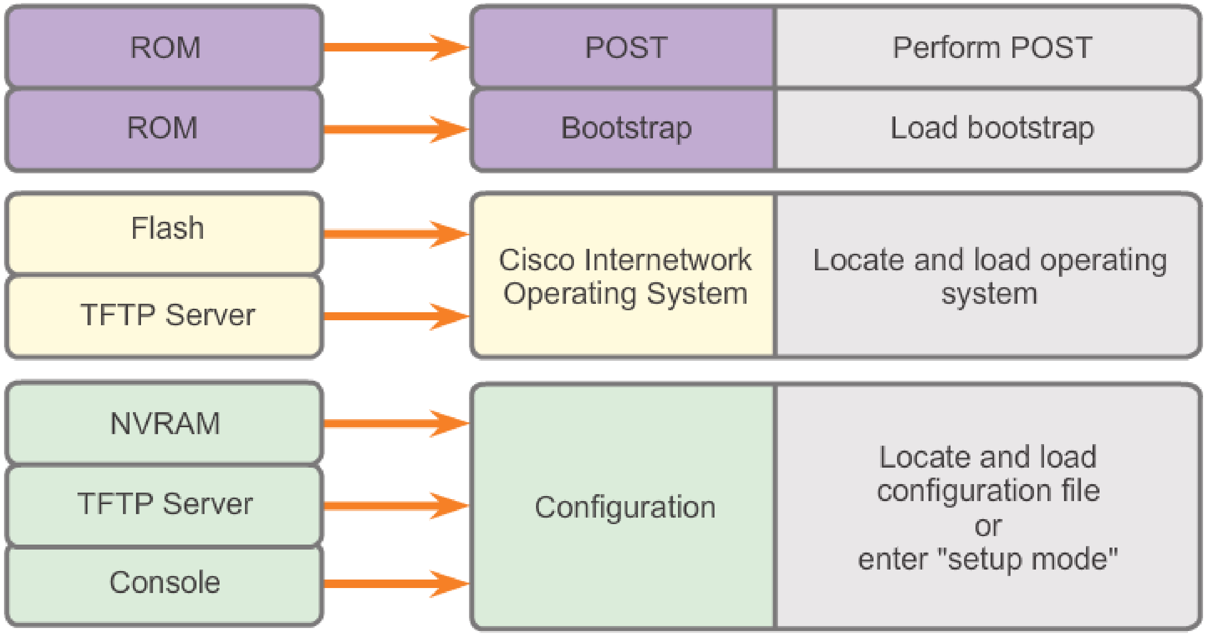
Bootset Files



Router Boot-up

Router Bootup Process

How a Router Boots Up




```
System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport


<output omitted>
```

Router Boot-up

Show Versions Output

```
Router# show version
Cisco IOS Software, C1900 Software (C1900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 19:34 by prod_rel_team

ROM: System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)

Router uptime is 10 hours, 9 minutes
System returned to ROM by power-on
System image file is "flash0:c1900-universalk9-mz.SPA.152-4.M1.bin"
Last reload type: Normal Reload
Last reload reason: power-on

<Output omitted>

Cisco CISCO1941/K9 (revision 1.0) with 446464K/77824K bytes of memory.
Processor board ID FTX1636848Z
2 Gigabit Ethernet interfaces
2 Serial(sync/async) interfaces
1 terminal line
DRAM configuration is 64 bits wide with parity disabled.
255K bytes of non-volatile configuration memory.
250880K bytes of ATA System CompactFlash 0 (Read/Write)

<Output omitted>

Technology Package License Information for Module:'c1900'

-----------------------------------------------------------------
Technology    Technology-package           Technology-package
              Current       Type           Next reboot
------------------------------------------------------------------
ipbase        ipbasek9      Permanent      ipbasek9
security      None          None           None
data          None          None           None

Configuration register is 0x2142 (will be 0x2102 at next reload)

Router#
```

6.4 Configuring a Cisco Router

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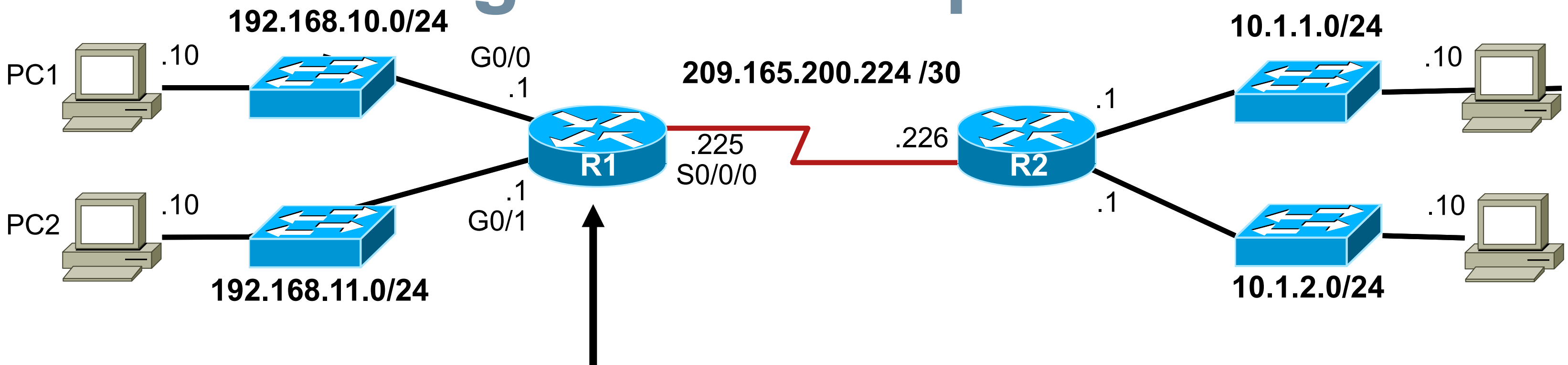
Configure Initial Settings

Router Configuration Steps




```
Router> enable
Router# configure terminal
Enter configuration commands, one per line.
End with CNTL/Z.
Router(config)# hostname R1
R1(config)#
```

OR

```
Router> en
Router# conf t
Enter configuration commands, one per line.
End with CNTL/Z.
Router(config)# ho R1
R2(config)#
```

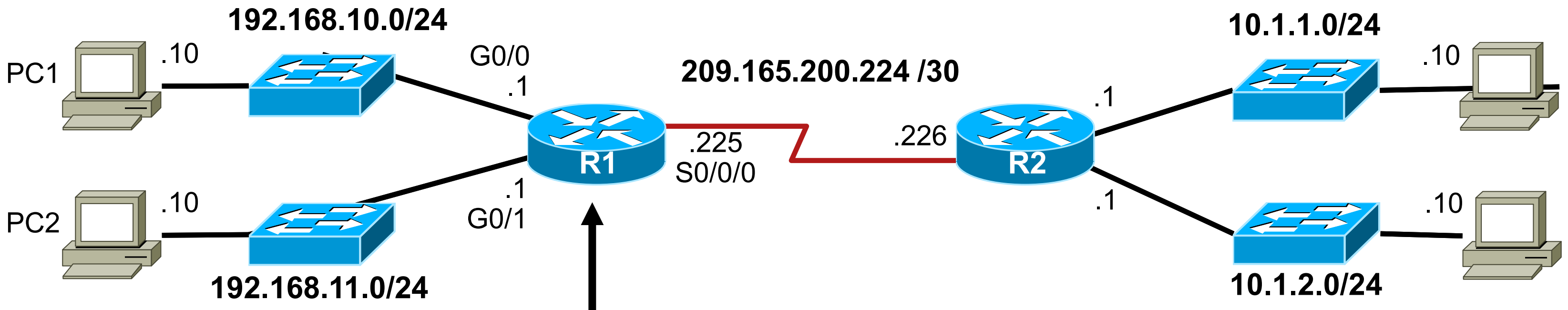
```
R1(config)# enable secret class
R1(config)#
R1(config)# line console 0
R1(config-line)# password cisco
R1(config-line)# login
R1(config-line)# exit
R1(config)#
R1(config)# line vty 0 4
R1(config-line)# password cisco
R1(config-line)# login
R1(config-line)# exit
R1(config)#
R1(config)# service password-encryption
R1(config)#
```

```
R1(config)# banner motd #
Enter TEXT message.  End with the character '#'.
    **********************************************
      WARNING: Unauthorized access is prohibited!
    **********************************************
#

R1(config)#
```

```
R1# copy running-config startup-config
Destination filename [startup-config]?
Building configuration...
[OK]
R1#
```

Configure Interfaces

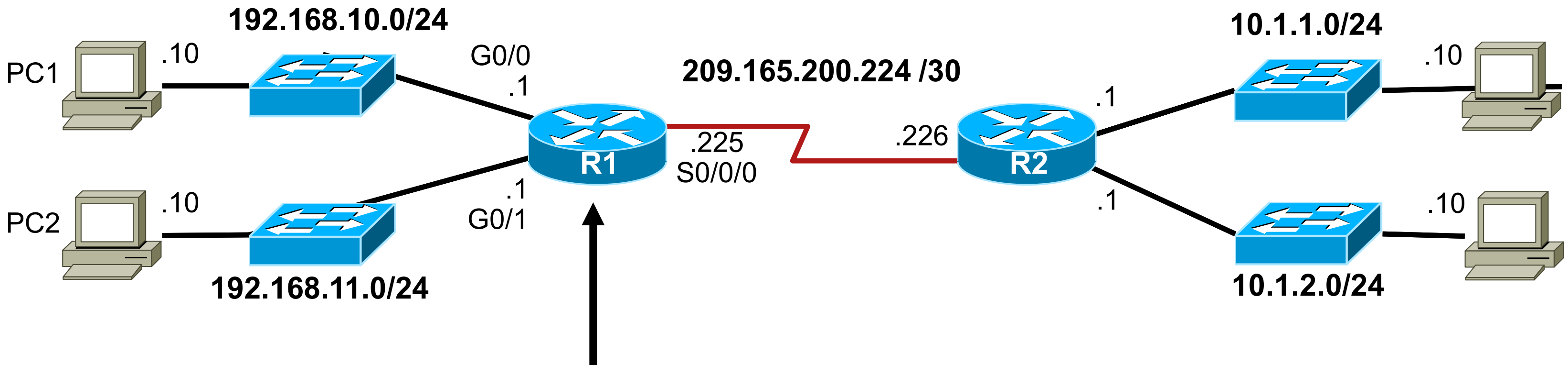
Configure LAN Interfaces




```
R1# conf t
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)#
R1(config)# interface gigabitethernet 0/0
R1(config-if)# ip address 192.168.10.1 255.255.255.0
R1(config-if)# description Link to LAN-10
R1(config-if)# no shutdown
%LINK-5-CHANGED: Interface GigabitEthernet0/0, changed state to up
%LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/0,
changed state to up
R1(config-if)# exit
R1(config)#
R1(config)# int g0/1
R1(config-if)# ip add 192.168.11.1 255.255.255.0
R1(config-if)# des Link to LAN-11
R1(config-if)# no shut
%LINK-5-CHANGED: Interface GigabitEthernet0/1, changed state to up
%LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/1,
changed state to up
R1(config-if)# exit
R1(config)#
```

Configure Interfaces

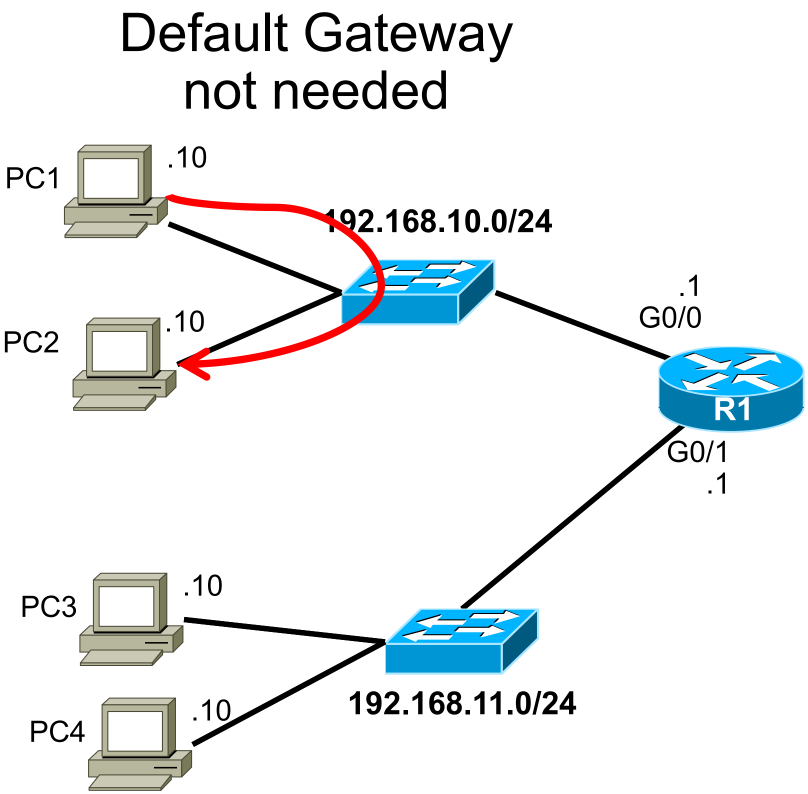
Verify Interface Configuration

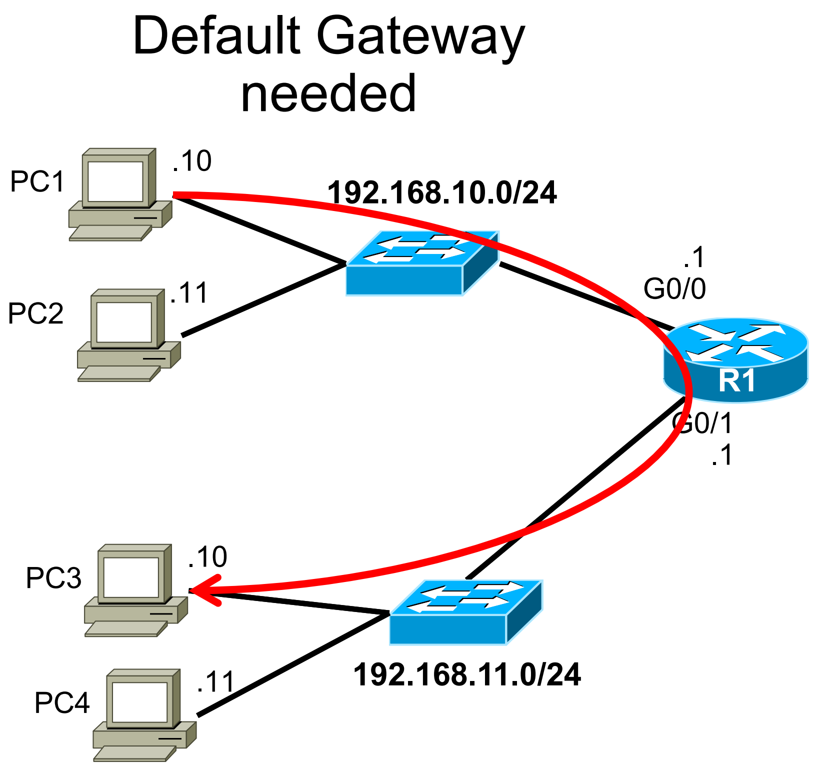



```
R1# show ip interface brief
Interface              IP-Address      OK? Method Status                Protocol

GigabitEthernet0/0     192.168.10.1    YES manual up                    up
GigabitEthernet0/1     192.168.11.1    YES manual up                    up
Serial0/0/0            209.165.200.225 YES manual up                    up
Serial0/0/1            unassigned      YES NVRAM  administratively down down
Vlan1                  unassigned      YES NVRAM  administratively down down
R1#
R1# ping 209.165.200.226

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 209.165.200.226, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/9 ms

R1#
```

Configuring the Default Gateway

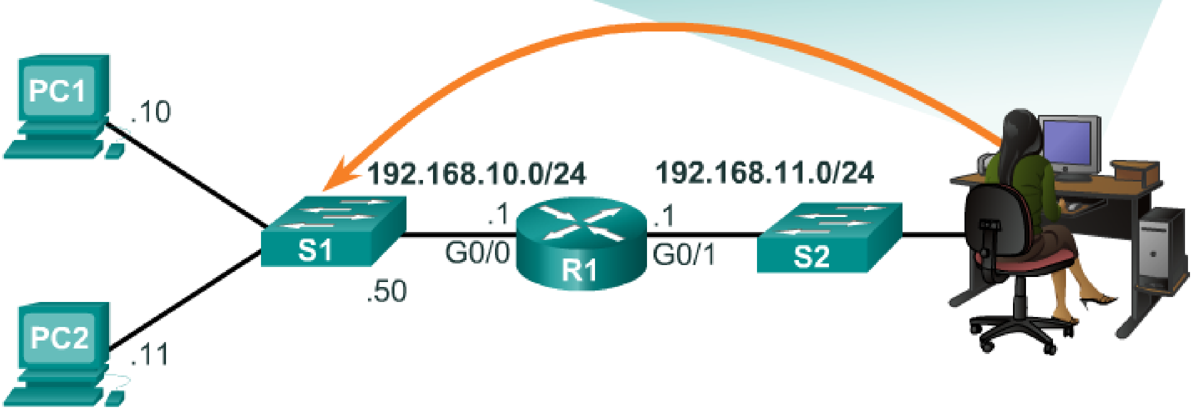
Default Gateway on a Host





Default Gateway on a Switch

```
S1# show running-config
Building configuration...
!
<output omitted>
service password-encryption
!
hostname S1
!
Interface Vlan1
ip address 192.168.10.50
!
ip default-gateway 192.168.10.1
<output omitted>
```



If the default gateway was not configured on S1, response packets from S1 would not be able to reach the administrator at 192.168.11.10. The administrator would not be able to manage the device remotely.

Network Layer

Summary

In this chapter, you learned:

- The network layer, or OSI Layer 3, provides services to allow end devices to exchange data across the network.
- The network layer uses four basic processes: IP addressing for end devices, encapsulation, routing, and de-encapsulation.
- The Internet is largely based on IPv4, which is still the most widely-used network layer protocol.
- An IPv4 packet contains the IP header and the payload.
- The IPv6 simplified header offers several advantages over IPv4, including better routing efficiency, simplified extension headers, and capability for per-flow processing.

Summary (cont.)

- In addition to hierarchical addressing, the network layer is also responsible for routing.
- Hosts require a local routing table to ensure that packets are directed to the correct destination network.
- The local default route is the route to the default gateway.
- The default gateway is the IP address of a router interface connected to the local network.
- When a router, such as the default gateway, receives a packet, it examines the destination IP address to determine the destination network.

Summary (cont.)

- The routing table of a router stores information about directly-connected routes and remote routes to IP networks. If the router has an entry in its routing table for the destination network, the router forwards the packet. If no routing entry exists, the router may forward the packet to its own default route, if one is configured or it will drop the packet.
- Routing table entries can be configured manually on each router to provide static routing or the routers may communicate route information dynamically between each other using a routing protocol.
- For routers to be reachable, the router interface must be configured.

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