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.
- Examine the most common Network layer protocol, Internet Protocol (IP), and its features for providing connectionless and best-effort service.
- 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.

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6.1 Network Layer Protocols

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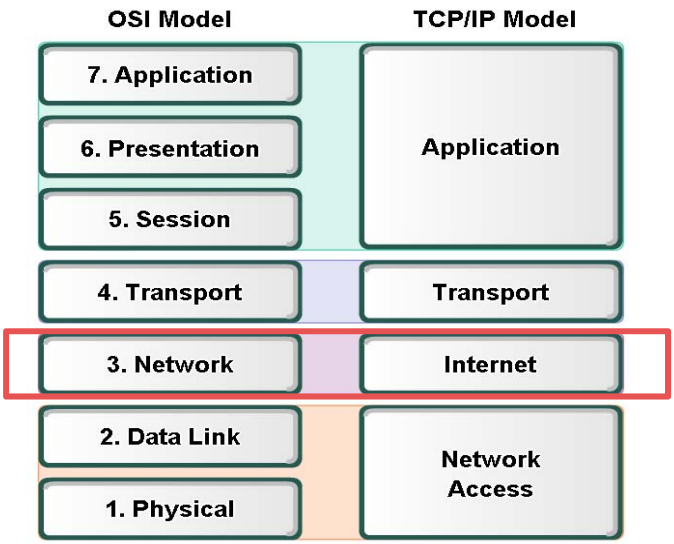
Network Layer



The key parallels are in the Transport and Network layers.

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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.

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Network Layer Protocols

Common network layer protocols include:

- Internet Protocol version 4 (IPv4)
- Internet Protocol version 6 (IPv6)

Legacy network layer protocols include:

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

The Internet Protocol (IPv4 and IPv6) are the most widely-used Layer 3 data carrying protocol and will be the focus of this module.

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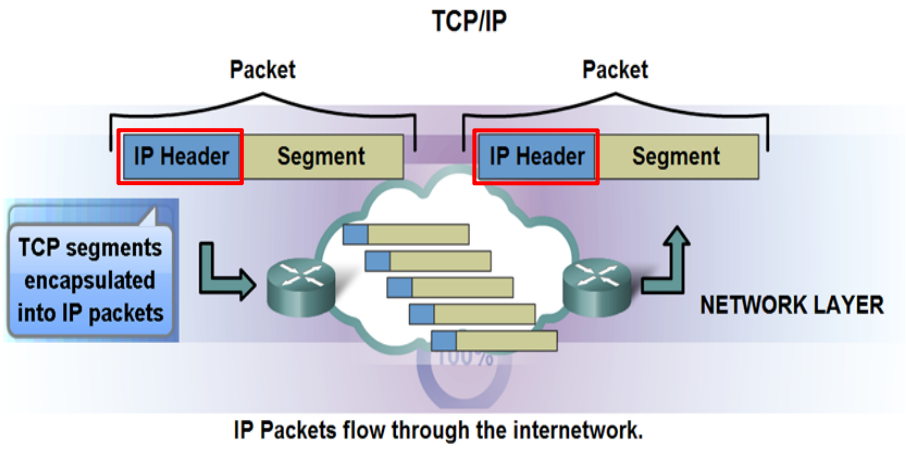
IPv4 Protocol



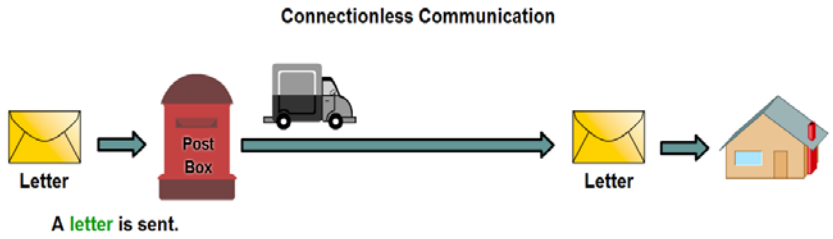
IP Packets flow through the internetwork.

IPv4 Protocol

- **IPv4 basic characteristics:**
  - **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.

IPv4 Protocol - Connectionless Service

- An example of connectionless communication is sending a letter to someone without notifying the recipient in advance.



The sender doesn't know:

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

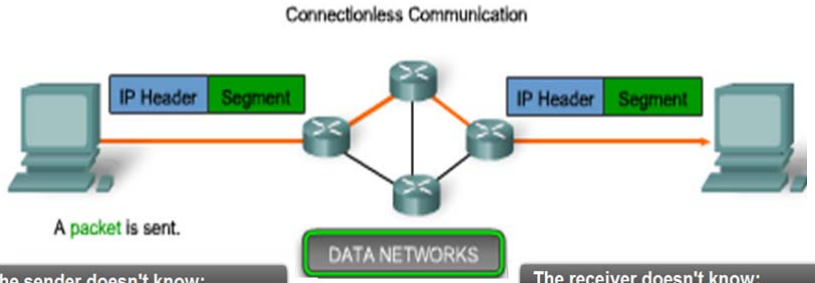
The receiver doesn't know:

- when it is coming

IPv4 Protocol - Connectionless Service

Connectionless data communications works on the same principle.

- IP packets are sent without notifying the end host that they are coming.



The sender doesn't know:

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

The receiver doesn't know:

- when it is coming

IPv4 Protocol - Connectionless Service

- **Connection-oriented** protocols, such as TCP:
  - Requires that control data be exchanged to establish the connection as well as additional fields in the PDU header.
  - **IP is connectionless**, it requires no initial exchange of control information to establish an end-to-end connection.
- Connectionless packet delivery may result in packets arriving at the destination out of sequence.
  - Upper layer services (TCP) will help to resolve out-of-order or missing packets problems.

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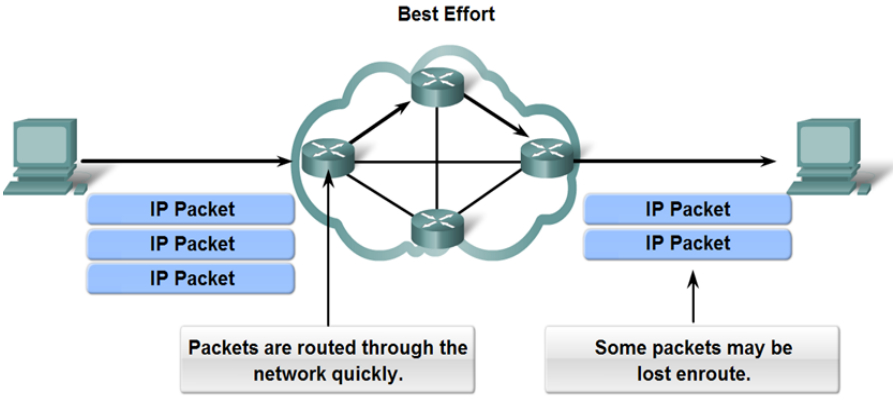
Best Effort Service (unreliable)



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.

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Best Effort Service (unreliable)

- IP is often referred to as an **unreliable protocol**.
  - The header of an IP packet does not include fields required for reliable data delivery.
    - There are no acknowledgments of packet delivery.
    - There is no error control for data.
    - Nor is there any form of packet tracking.
  - Unreliable in this context does NOT mean that IP don't function well.
  - Unreliable simply means that IP does not have the capability to manage and recover from undelivered or corrupt packets.

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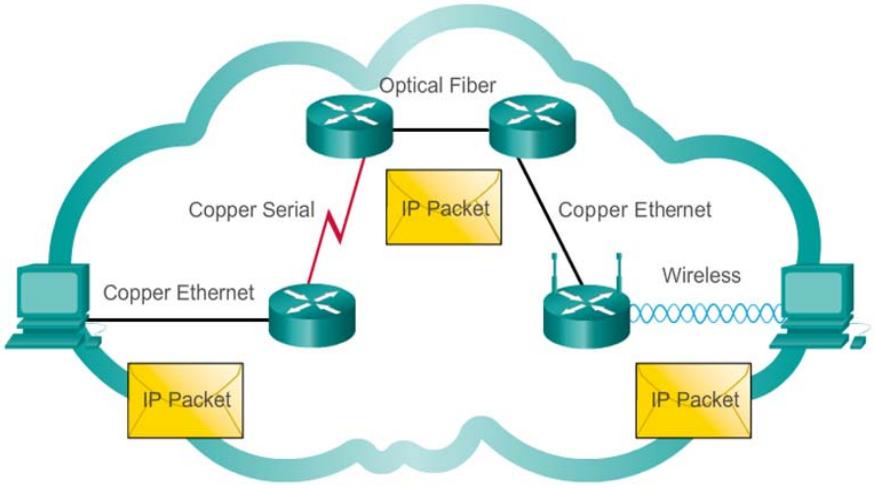
IP – Media Independent



IP packets can travel over different media.

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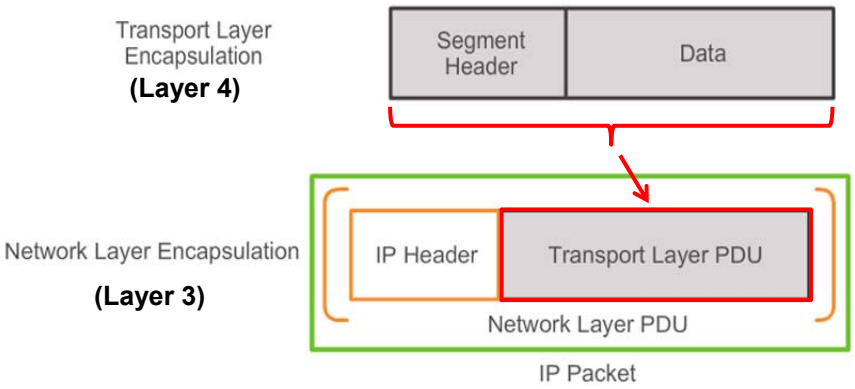
Encapsulating IP



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.

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IPv4 Packet

- IPv4 encapsulates the Transport layer segment (or Transport layer PDU) so that the network can deliver it to the destination host.
  - The process of encapsulating data by layer enables the services at the different layers to develop and scale without affecting other layers.
  - In all cases, the data portion of the packet - that is, the encapsulated Transport layer PDU (segment) - remains unchanged during the Network layer processes.

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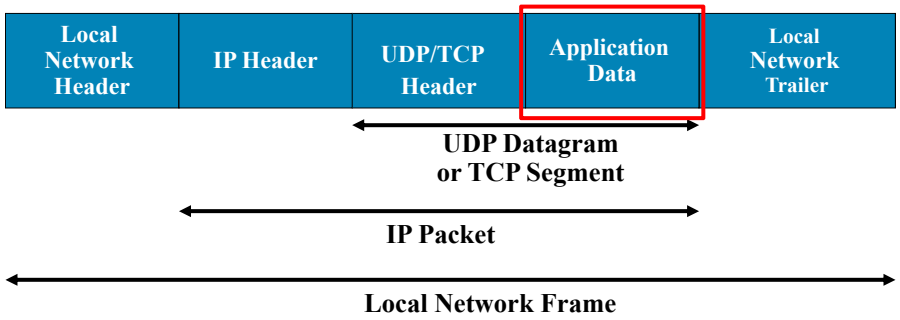
IPv4 Packet



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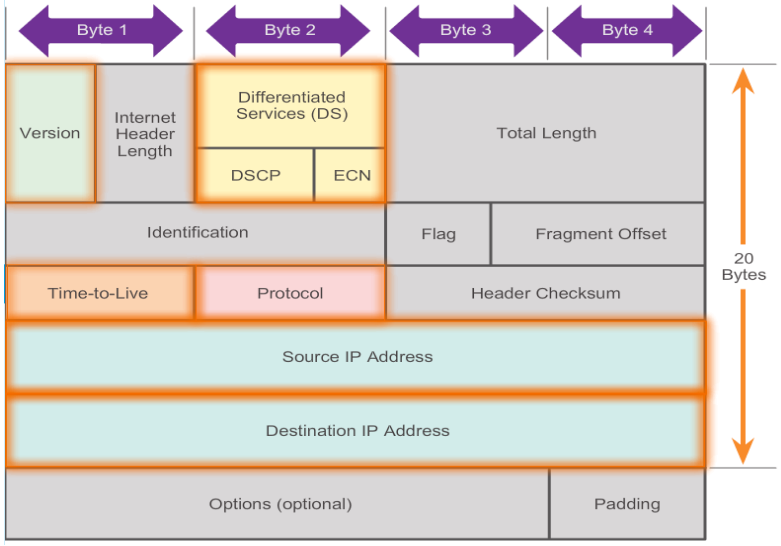
IPv4 Packet Header

Contents of the IPv4 packet header



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IPv4 Packet Header

- IP Source Address (32 bits)
  - represents the source Network layer host address.
- IP Destination Address (32 bits)
  - represents the destination Network layer host address.
- Time-to-Live (8 bits)
  - The Time-to-Live (TTL) indicates the remaining "life" of the packet.
  - The TTL value is decreased by one each time the packet is processed by a router (that is, each hop).
  - When the value becomes zero, the router discards or drops the packet and it is removed from the network.
  - This mechanism prevents packets that cannot reach their destination from being forwarded indefinitely between routers in a routing loop.

IPv4 Packet Header (contd)

- Protocol (8 bits)
  - The Protocol field enables the Network layer to pass the data to the appropriate upper-layer protocol.
  - Example values are: 01 ICMP; 06 TCP; 17 UDP
- Header Checksum (16 bits)
  - The checksum field is used for error checking the packet header.
- Identification (16 bits)
  - This field is primarily used for uniquely identifying fragments of an original IP packet.
- Fragment Offset (13 bits)
  - The fragment offset field identifies the order in which to place the packet fragment in the reconstruction.

IPv4 Packet Header (contd)

- Type-of-Service (8 bits)
  - The field is used to determine the priority of each packet.
  - This value enables a Quality-of-Service (QoS) mechanism to be applied to high priority packets, such as those carrying telephony voice data.
- Version (4 bits)
  - Contains the IP version number (4).
- Header Length (IHL) (4 bits)
  - Specifies the size of the packet header.
- Packet Length (16 bits)
  - This field gives the entire packet size, including header and data, in bytes.
- Options (variable length)
  - There is provision for additional fields in the IPv4 header to provide other services but these are rarely used.

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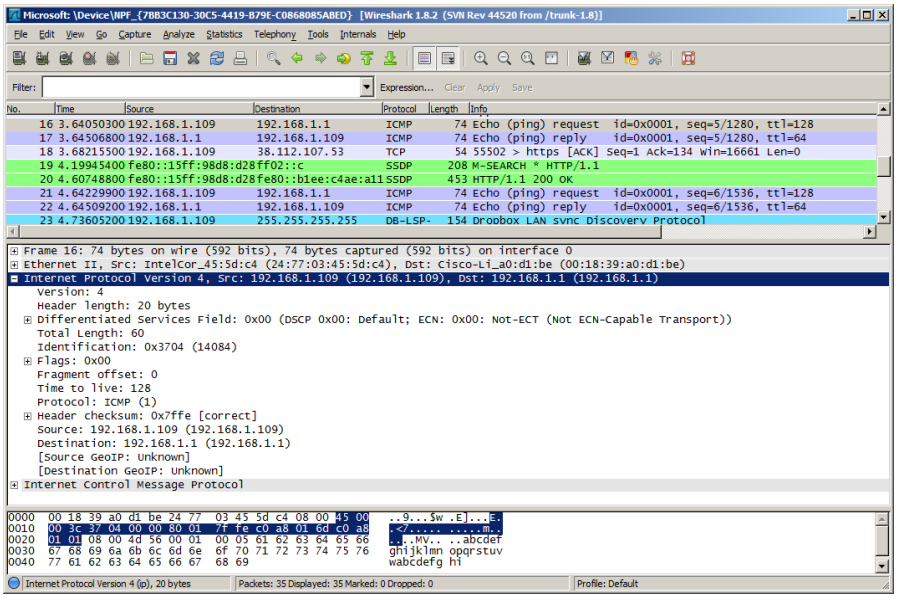
Sample IPv4 Headers



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Limitations of IPv4

- IPv4 address has 32 bits.

  (**4 billion** IPv4 addresses).
- IP Address depletion.
- Internet routing table expansion
- Lack of end-to-end connectivity

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Introducing IPv6

- IPv6 Address has 128 bits.
- Increased address space - IPv6 addresses are 128-bit as opposed to IPv4 with 32 bits.
- Improved packet handling.
- Eliminates the need for NAT.
- Integrated security.
- **4 billion** IPv4 addresses (**4,000,000,000)**
- **340 undecillion** IPv6 addresses (3.4 x 10^{38} addresses). 340,000,000,000,000,000,000,000,000,000,000,000,000 or 340,000,000,000,000,000,000,000,000,000 Billion

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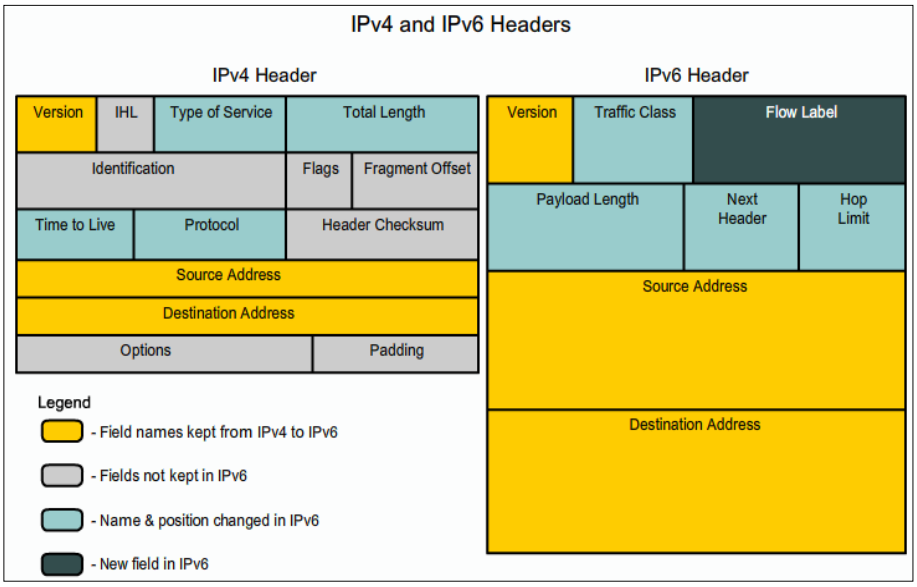
Encapsulating IPv6



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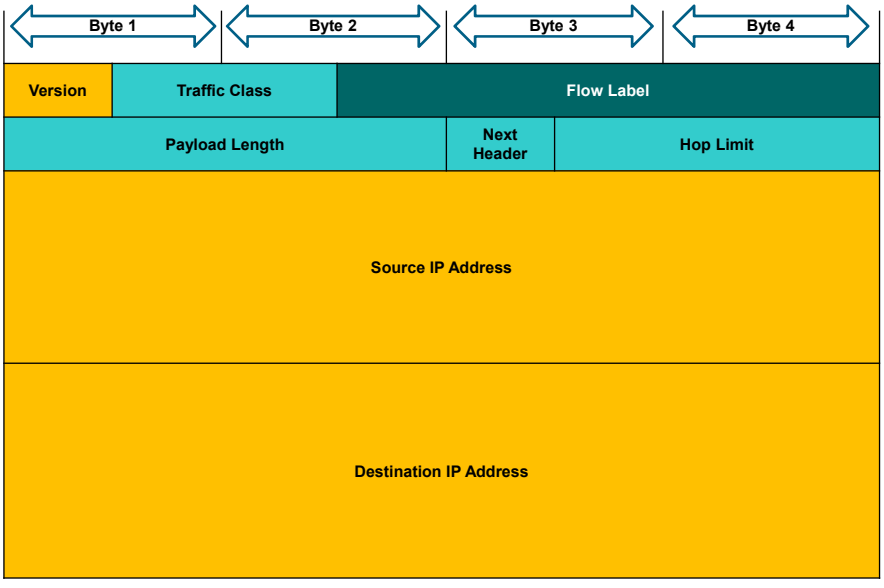
IPv6 Packet Header



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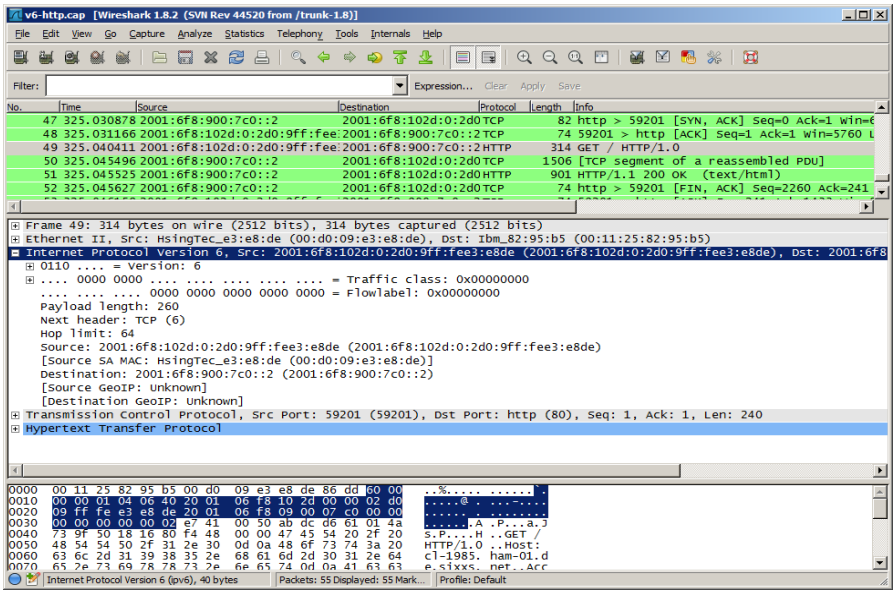
Sample IPv6 Header



6.2 Routing

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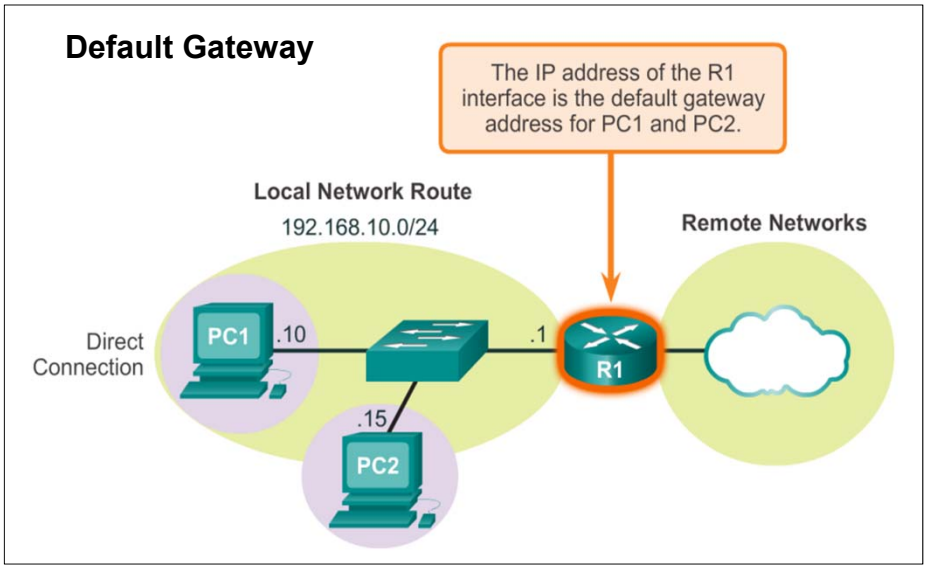
Host Packet Forwarding Decision



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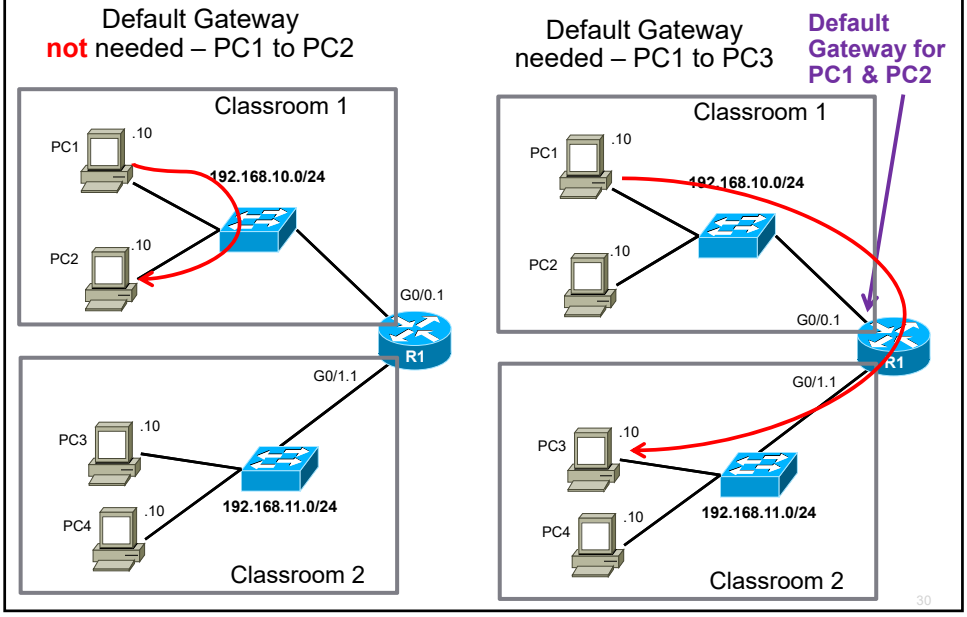
Default Gateway on a Host



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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

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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>
```

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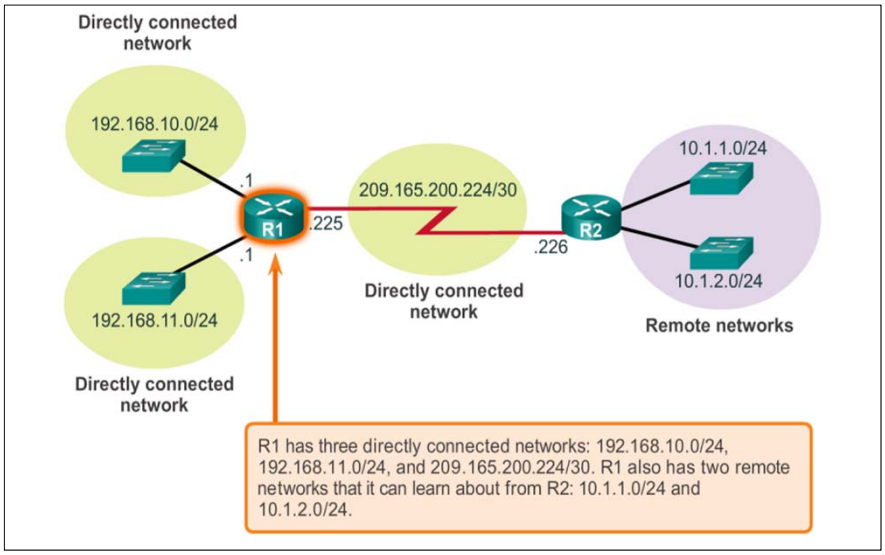
Router uses routing table for Packet Forwarding Decision



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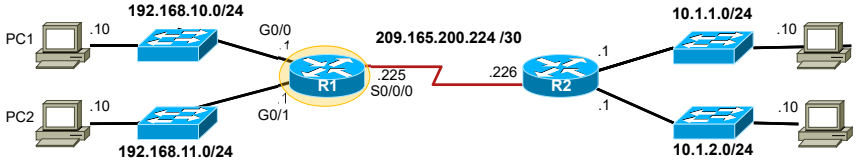
IPv4 Router Routing Table




```
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#
```

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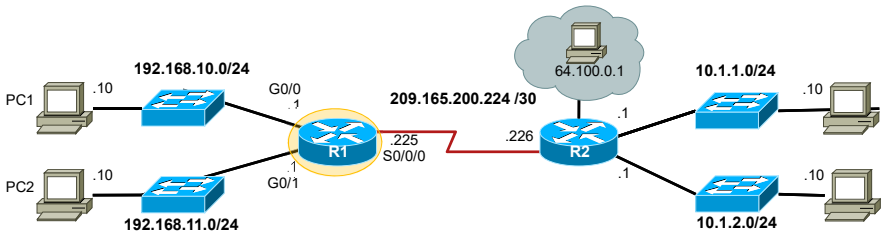
Directly Connected Routing Table Entries



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.

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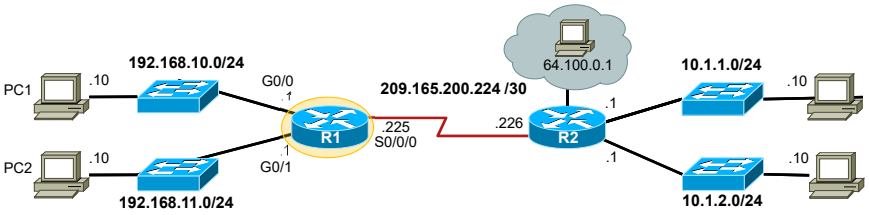
Remote Network Routing Table Entries



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.

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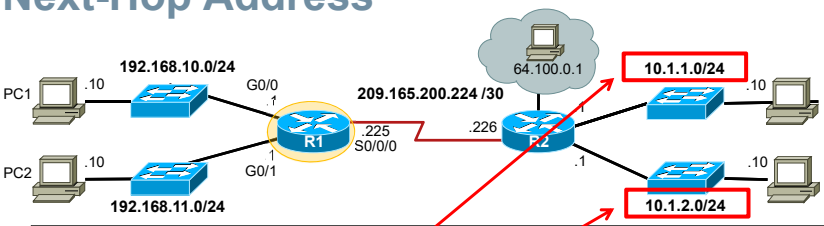
Next-Hop Address




```
R1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
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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
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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#
```

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6.3 Routers

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A Router is a Computer

- Routers, like all computers require a CPU (Central Processing Unit) to execute OS (Operating Systems) instructions for their routing and switching functions.
- Cisco routers uses The Cisco Internetwork Operating System (IOS).
- Routers is a **OSI Layer 3 device** (**Network Layer device**) as it uses Network Layer information found in **IP headers** to **route** packets.

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Inside the Router

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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

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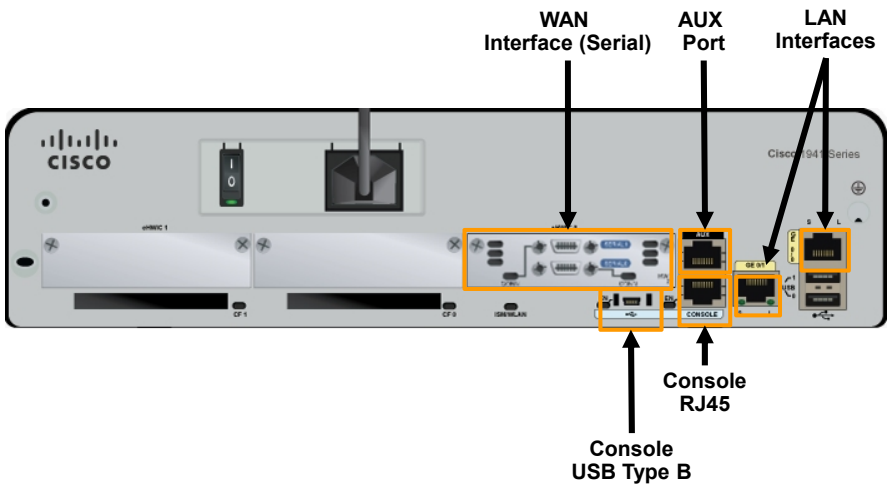
Connecting to a Router



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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

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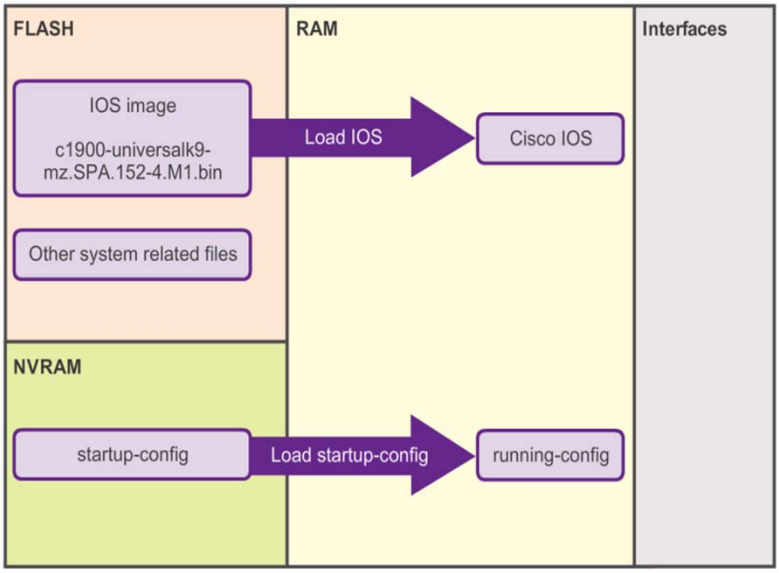
Router Boot-up Files



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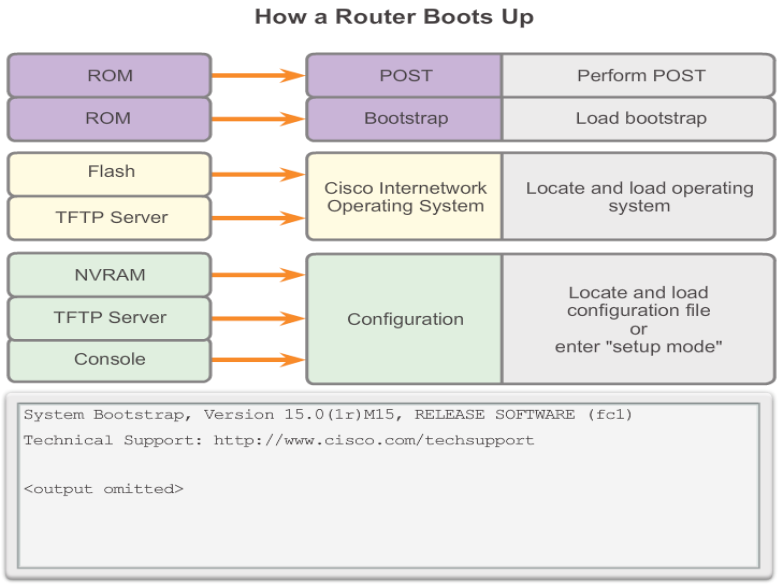
Router Bootup Process



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 FTX16368482
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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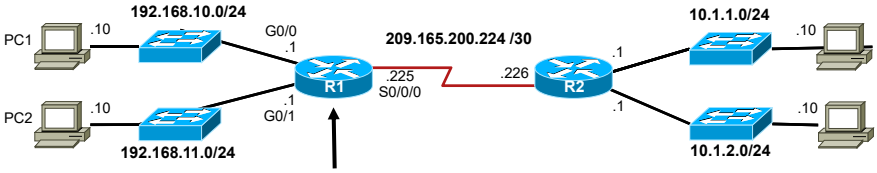
Router Configuration Steps




```
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 ter
Enter configuration commands, one per line.  End with CNTL/Z.
Router(config)# host R1
R2(config)#
```

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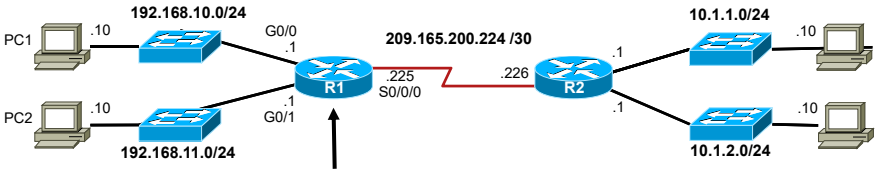
Router Configuration Steps




```
R1(config)# enable secret class
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# copy running-config startup-config  OR  copy run start
Destination filename [startup-config]?
Building configuration...
[OK]
R1#
```

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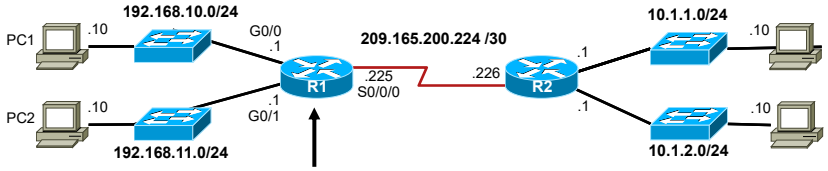
Configure LAN Interfaces




```
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

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

R1(config-if)# exit
R1(config)#
```

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Default Gateway on a Host