# LECTURE 5
# SUBNETTING

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# Subnetting Basics

- You learned how to define and find the valid host ranges used in a Class A, Class B, and Class C network address by turning the host bits all off and then all on.
- This is very good, but here's the catch: **You were defining only one network**. What happens if you wanted to take **one network address and create six networks** from it? You would have to do something called **subnetting**, because that's what allows you to **take one larger network and break it into a bunch of smaller networks.**
- There are loads of reasons in favor of subnetting, including the following benefits:
  - Reduced network traffic
  - Optimized network performance
  - Simplified management
  - Facilitated spanning of large geographical distances

# Address Depletion

- Shortly after the IPv4 addressing scheme was implemented, it became apparent that there were not enough addresses to meet demand. More and more organizations were using computers and networking equipment, and then-current scheme was wasting thousands of addresses.
- Say, for example, that a company was given a Class A address. Remember that Class A addresses could only be allocated to 126 companies.
- If every combination of numbers on the remaining 24 digits (3 x 8) was used, that would equal over 16 million hosts (16,777,216, in fact) per network.

# Address Depletion

- They would need around **10,000 host addresses and waste the other 16 million plus**. Because they owned the network number, it could not be shared with other organizations, so the other addresses were wasted.

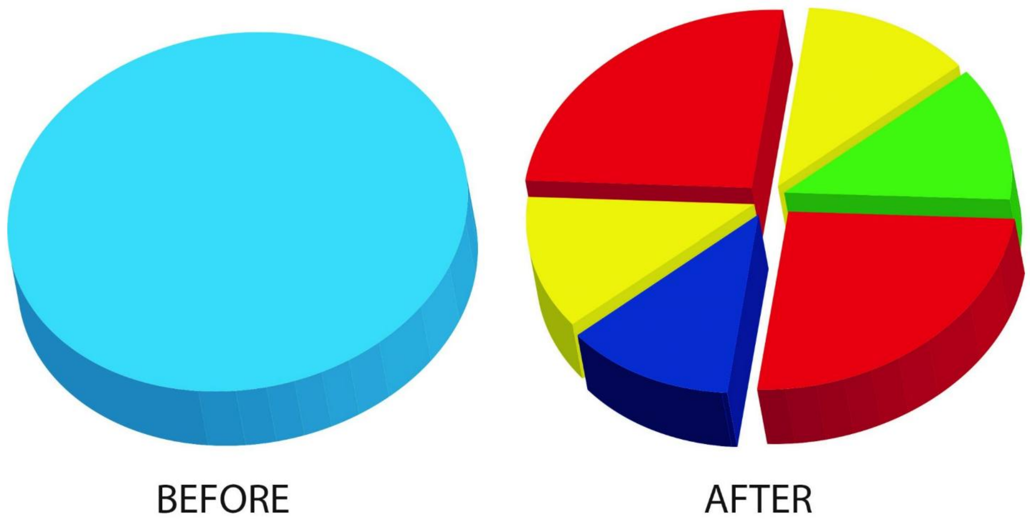
- Another issue was network **broadcasts**. You couldn’t split the network into smaller portions (at the time), so the entire network would have to be attached to one router interface, and all the hosts would be in the same broadcast domain.

# How to create Subnet

- To create subnetworks, you take bits from the host portion of the IP address and reserve them to define the subnet address.
- This means fewer bits for hosts, so the more subnets, the fewer bits available for defining hosts.

- **To create a subnet follow these steps:**

1. Determine the number of required network IDs
2. Determine the number of required host IDs per subnet
3. Based on the above requirements, create the following:
   - One subnet mask for your entire network
   - A unique subnet ID for each physical segment
   - A range of host IDs for each subnet



# Subnet Masks

- Default subnet masks are as follows:

Class A – 255.0.0.0, or in binary: **11111111.00000000.00000000.00000000**
Class B – 255.255.0.0, or in binary: **11111111.11111111.00000000.00000000**
Class C – 255.255.255.0, or in binary: **11111111.11111111.11111111.00000000**

- One rule for subnet masks is that the 1 and 0 network and host bits must be contiguous (i.e., connected), without a break from left to right. So, you can have:

**11111111.11111111.00000000.00000000**

but you cannot have:

**11111111.00011111.00000000.00000000.**

- When you start to add host addresses from 1, 2, 3, and upward, you will start from the far right:

**11111111.11111111.00000000.00000001.**

# Classless Inter-Domain Routing (CIDR)

- The method that ISPs (Internet service providers) use to allocate a number of addresses to a company, a home—a customer.

  **192.168.10.32/28**
- This is telling you what your subnet mask is.
- The slash notation (/) means how many bits are turned on (1s).
- Obviously, the maximum could only be /32 because a byte is 8 bits and there are 4 bytes in an IP address: ($4 \times 8 = 32$).
- But **keep in mind** that the largest subnet mask available (regardless of the class of address) can only be a **/30** because you've got to keep at least 2 bits for host bits.
- Take, for example, a Class A default subnet mask, which is 255.0.0.0. This means that the first byte of the subnet mask is all ones (1s), or 11111111. When referring to a slash notation, you need to count all the 1s bits to figure out your mask. The 255.0.0.0 is considered a /8 because it has 8 bits that are 1s—that is, 8 bits that are turned on.

# CIDR values

| Subnet Mask | CIDR Value |
|---|---|
| 255.0.0.0 | /8 |
| 255.128.0.0 | /9 |
| 255.192.0.0 | /10 |
| 255.224.0.0 | /11 |
| 255.240.0.0 | /12 |
| 255.248.0.0 | /13 |
| 255.252.0.0 | /14 |
| 255.254.0.0 | /15 |

- The /8 through /15 can only be used with Class A network addresses.

# CIDR values

| Subnet Mask | CIDR Value |
| --- | --- |
| 255.255.0.0 | /16 |
| 255.255.128.0 | /17 |
| 255.255.192.0 | /18 |
| 255.255.224.0 | /19 |
| 255.255.240.0 | /20 |
| 255.255.248.0 | /21 |
| 255.255.252.0 | /22 |
| 255.255.254.0 | /23 |

- /16 through /23 can be used by Class A and B network addresses.

# CIDR values

| Subnet Mask | CIDR Value |
|---|---|
| 255.255.255.0 | /24 |
| 255.255.255.128 | /25 |
| 255.255.255.192 | /26 |
| 255.255.255.224 | /27 |
| 255.255.255.240 | /28 |
| 255.255.255.248 | /29 |
| 255.255.255.252 | /30 |

- /24 through /30 can be used by Class A, B, and C network addresses.

# Subnetting Class C Addresses

- ➢ In a Class C address, only 8 bits are available for defining the hosts. Remember that subnet bits start at the left and go to the right, without skipping bits.
- ➢ We can't use a /31 or /32 because we have to have at least 2 host bits for assigning IP addresses to hosts.

| Binary | | Decimal | CIDR |
|---|---|---|---|
| 00000000 | = | 0 | /24 |
| 10000000 | = | 128 | /25 |
| 11000000 | = | 192 | /26 |
| 11100000 | = | 224 | /27 |
| 11110000 | = | 240 | /28 |
| 11111000 | = | 248 | /29 |
| 11111100 | = | 252 | /30 |

- ✓ How many subnets does the chosen subnet mask produce?
- ✓ How many valid hosts per subnet are available?
- ✓ What are the valid subnets?
- ✓ What's the broadcast address of each subnet?
- ✓ What are the valid hosts in each subnet?

# Subnetting Class C Addresses

- **How many subnets?**
- $\mathbf{2^x}$ = number of subnets. **x is the number of masked bits, or the 1s.**
- For example, in 11000000, the number of 1s gives us $2^2$ subnets. In this example, there are 4 subnets.
- **How many hosts per subnet?**
- $\mathbf{2^y - 2}$ = number of hosts per subnet. **y is the number of unmasked bits, or the 0s**. For example, in 11000000, the number of 0s gives us $2^6 - 2$ hosts.
- In this example, there are 62 hosts per subnet. You need to subtract 2 for the subnet address and the broadcast address, which are not valid hosts.
- **What are the valid subnets?**
- 256 – subnet mask = block size, or increment number. An example would be 256 – 192 = 64. The block size of a 192 mask is always 64. Start counting at zero in blocks of 64 until you reach the subnet mask value and these are your subnets. 0, 64, 128, 192.

# Subnetting Class C Addresses

- **What's the broadcast address for each subnet?**
- Since we counted our subnets in the last section as 0, 64, 128, and 192, the broadcast address is always the number right before the next subnet.
- For example, **the 0 subnet has a broadcast address of 63** because the next subnet is 64. **The 64 subnet has a broadcast address of 127** because the next subnet is 128. And so on. And remember, **the broadcast address of the last subnet is always 255.**
- **What are the valid hosts?**

Valid hosts are the numbers between the subnets, omitting the all 0s and all 1s.

For example, if 64 is the subnet number and 127 is the broadcast address, then 65–126 is the valid host range—it's always the numbers between the subnet address and the broadcast address.

# IP subnet zero

- This command allows you to use the first and last subnet in your network design.
- For example, the Class C mask of 192 provides subnets 64 and 128 but with the `ip subnet-zero` command, you now get to use subnets 0, 64, 128, and 192.
- That is two more subnets for every subnet mask we use.

# Subnetting Practice Examples: Class C Addresses

Class C network address 192.168.10.0.

**Practice Example #1C: 255.255.255.128 (/25)**

192.168.10.0 = Network address

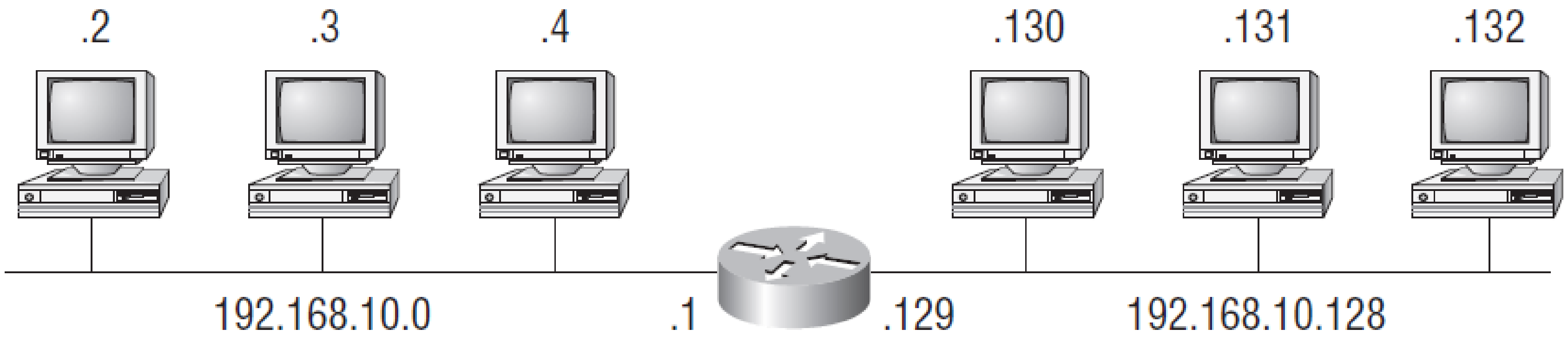
255.255.255.128 = Subnet mask

- *How many subnets?* Since 128 is 1 bit on(1000 0000), the answer is $2^1 = 2$
- *How many hosts per subnet?* We have 7 host bits off (1000 0000), so the answer is $2^7 - 2 = 126\ hosts$
- *What are the valid subnets?* 256-128=128, our subnets are 0,128
- *What's the broadcast address for each subnet?* The broadcast address of the 0 subnet is 127
  The broadcast address of the 128 subnet is 255
- *What are the valid hosts?*

| Subnet | 0 | 128 |
|---|---|---|
| First host | 1 | 129 |
| Last host | 126 | 254 |
| Broadcast | 127 | 255 |

# Implementing a class C/25 logical network

Implementing a Class C /25 logical network




```
Router#show ip route
[output cut]
C 192.168.10.0 is directly connected to Ethernet 0.
C 192.168.10.128 is directly connected to Ethernet 1.
```

# Subnetting Practice Examples: Class C Addresses

Class C network address 192.168.10.0.

**Practice Example #2C: 255.255.255.192 (/26)**

192.168.10.0 = Network address

255.255.255.192 = Subnet mask

- *How many subnets?* Since 192 is 2 bit on(1100 0000), the answer is $2^2 = 4$
- *How many hosts per subnet?* We have 6 host bits off (1100 0000), so the answer is $2^6 - 2 = 62$ *hosts*
- *What are the valid subnets?* 256-192=64, our subnets are 0 , 64 , 128 , 192
- *What's the broadcast address for each subnet?*

We have 6 host bits off (1100 0000), so the answer is $2^6 - 2 = 62$ *hosts*

| | | | | |
|---|---|---|---|---|
| The subnets (do this first) | 0 | 64 | 128 | 192 |
| Our first host (perform host addressing last) | 1 | 65 | 129 | 193 |
| Our last host | 62 | 126 | 190 | 254 |
| The broadcast address (do this second) | 63 | 127 | 191 | 255 |

# Subnetting Practice Examples: Class C Addresses

Class C network address 192.168.10.0.

**Practice Example #3C: 255.255.255.224 (/27)**

192.168.10.0 = Network address

255.255.255.224 = Subnet mask

- *How many subnets?* Since 224 is 3 bit on (1110 0000), the answer is $2^3 = 8$
- *How many hosts per subnet?* We have 5 host bits off (1110 0000), so the answer is $2^5 - 2 = 30\ hosts$
- *What are the valid subnets?* 256-224=32, our subnets are 0 , 32 , 64 , 96 , 128 , 160 , 192 , 224

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| The subnet address | 0 | 32 | 64 | 96 | 128 | 160 | 192 | 224 |
| The first valid host | 1 | 33 | 65 | 97 | 129 | 161 | 193 | 225 |
| The last valid host | 30 | 62 | 94 | 126 | 158 | 190 | 222 | 254 |
| The broadcast address | 31 | 63 | 95 | 127 | 159 | 191 | 223 | 255 |

# Subnetting Practice Examples: Class C Addresses

Class C network address 192.168.10.0.

**Practice Example #6C: 255.255.255.252 (/30)**

192.168.10.0 = Network address

255.255.255.252 = Subnet mask

- *How many subnets?* Since 252 is 6 bit on (1111 1100), the answer is $2^6 = 64$
- *How many hosts per subnet?* We have 2 host bits off (1111 1100), so the answer is $2^2 - 2 = 2\ hosts$
- *What are the valid subnets?* 256-252=4, our subnets are 0 , 4 , 8 , ……., 244 , 248 , 252

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subnet | 0 | 4 | 8 | 12 | ... | 240 | 244 | 248 | 252 |
| First host | 1 | 5 | 9 | 13 | ... | 241 | 245 | 249 | 253 |
| Last host | 2 | 6 | 10 | 14 | ... | 242 | 246 | 250 | 254 |
| Broadcast | 3 | 7 | 11 | 15 | ... | 243 | 247 | 251 | 255 |

# Example:

192.168.10.33 = Node address

255.255.255.224 = Subnet mask

Since 224 is 3 bit on (1110 0000), we have $2^3 = 8\ subnets$

- First determine the subnet address 256-224=32
  - The valid subnets 0 , 32, 64 , …..
- The address of 33 falls between the two subnets 32 and 64 and must be part of 192.168.10.32 subnet
- The broadcast address would be 192.168.10.63
- The valid host range would be 33 -- 62

# Example:

192.168.10.33 = Node address

255.255.255.240 = Subnet mask

Since 240 is 4 bit on (1111 0000), we have $2^4 = 16\ subnets$

- First determine the subnet address 256 - 240 = 16
  - The valid subnets 0 , 16 , 32, 48 , …..
- The address of 33 falls between the two subnets 32 and 48 and must be part of 192.168.10.32 subnet
- The broadcast address would be 192.168.10.47
- The valid host range would be 33 -- 46

# Example:

You have a node address of 192.168.10.174 with a mask of 255.255.255.240. What is the valid host range?

Since 240 is 4 bit on (1111 0000), we have $2^4 = 16\ subnets$

- First determine the subnet address 256 - 240 = 16 (Block Size)
  - The valid subnets 0 , 16 , 32, 48 , 64 , 80 , 96 , 112 , 128 , 144 , 160 , 176 , 192 , ….
- The address of 174 falls between the two subnets 160 and 176 and must be part of 192.168.10.160 subnet
- The broadcast address would be 192.168.10.175
- The valid host range would be 161 – 174

# What do we know?

When you see a subnet mask or slash notation (CIDR), you should know the following:

/25 What do we know about a /25?

- 128 mask
- 1 bits on and 7 bits off (10000000)
- Block size of 128
- 2 subnets, each with 126 hosts

/26 What do we know about a /26?

- 192 mask
- 2 bits on and 6 bits off (11000000)
- Block size of 64
- 4 subnets, each with 62 hosts

# What do we know?

When you see a subnet mask or slash notation (CIDR), you should know the following:

/27 What do we know about a /27?

- 224 mask
- 3 bits on and 5 bits off (11100000)
- Block size of 32
- 8 subnets, each with 30 hosts

/28 What do we know about a /28?

- 240 mask
- 4 bits on and 4 bits off
- Block size of 16
- 16 subnets, each with 14 hosts

/29 What do we know about a /29?

- 248 mask
- 5 bits on and 3 bits off
- Block size of 8
- 32 subnets, each with 6 hosts

/30 What do we know about a /30?

- 252 mask
- 6 bits on and 2 bits off
- Block size of 4
- 64 subnets, each with 2 hosts

# Subnetting Class B Addresses

- let’s look at all the possible Class B subnet masks first.

```
255.255.0.0     (/16)    255.255.255.0     (/24)
255.255.128.0   (/17)    255.255.255.128   (/25)
255.255.192.0   (/18)    255.255.255.192   (/26)
255.255.224.0   (/19)    255.255.255.224   (/27)
255.255.240.0   (/20)    255.255.255.240   (/28)
255.255.248.0   (/21)    255.255.255.248   (/29)
255.255.252.0   (/22)    255.255.255.252   (/30)
255.255.254.0   (/23)
```

# Variable Length Subnet Mask (VLSM)

- **classful and classless networking**

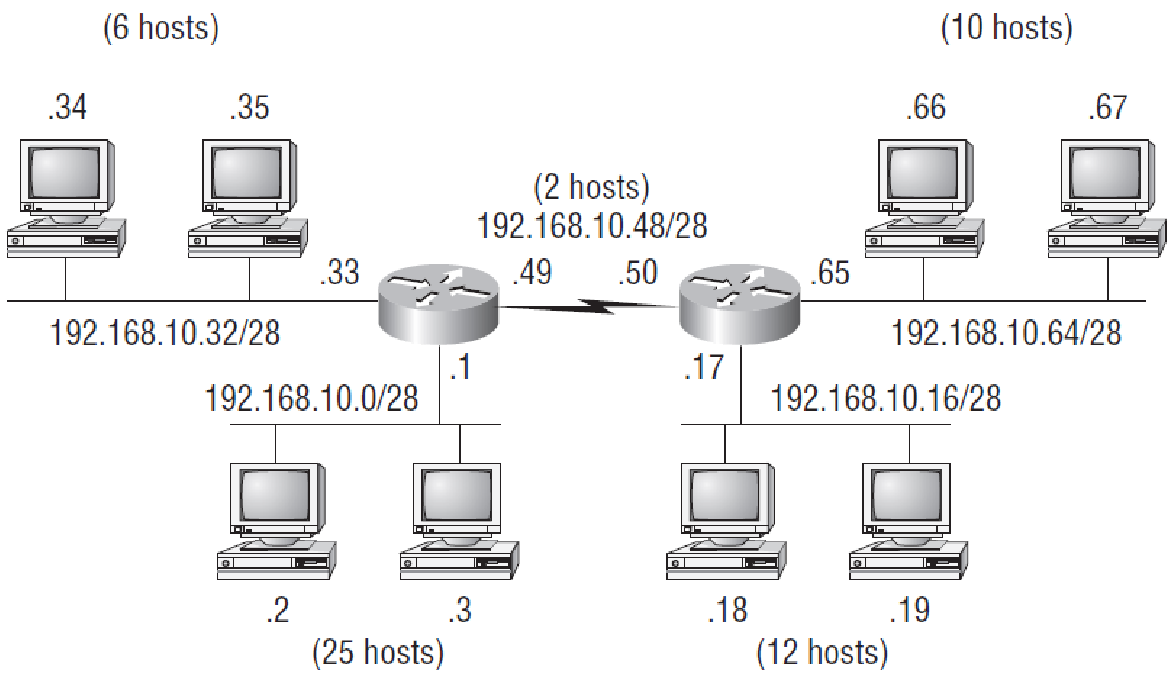
- **In classful networking**: all interfaces within the classful address space have the same subnet mask.
- **In classless networking**: we can have different subnet masks for different router interfaces.
  The benefit of this type of network is that you save a bunch of IP address space with it.

# Variable Length Subnet Mask (VLSM)

## ❑ Example of why classful network designs are inefficient.

- Our subnets would be (you know this part, right?) 0, 16, 32, 48, 64, 80, etc.
- This allows us to assign 16 subnets to our internetwork.
- Each subnet provides only 14 hosts. This means that each LAN has 14 valid hosts available—one LAN doesn't even have enough addresses needed for all the hosts!
- But the point-to-point WAN link also has 14 valid hosts, and we will never use more than two valid hosts! This wastes valuable IP address space

**FIGURE 3.3** Typical classful network

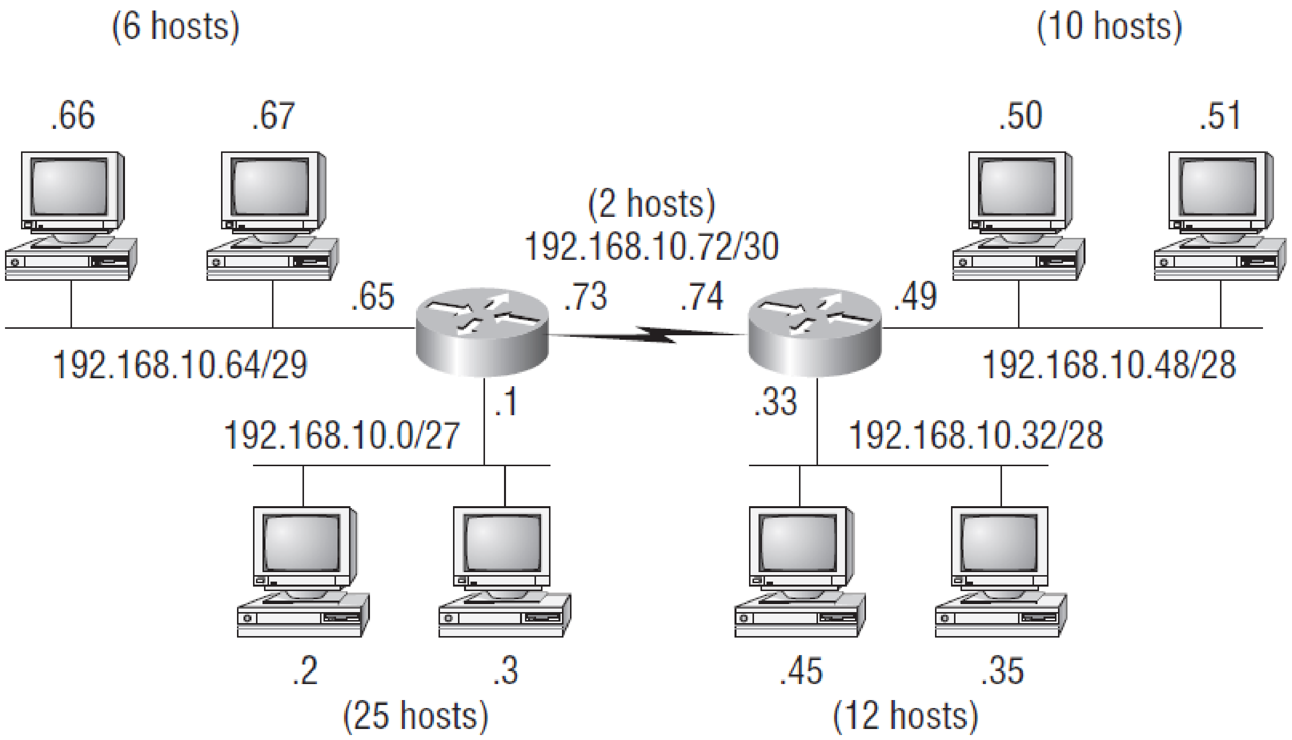


# VLSM Design

**TABLE 3.3** Block Sizes

| Prefix | Mask | Hosts | Block Size |
|---|---|---|---|
| /25 | 128 | 126 | 128 |
| /26 | 192 | 62 | 64 |
| /27 | 224 | 30 | 32 |
| /28 | 240 | 14 | 16 |
| /29 | 248 | 6 | 8 |
| /30 | 252 | 2 | 4 |

**FIGURE 3.4** Classless network design



# Implementing VLSM networks

**TABLE 3.3** Block Sizes

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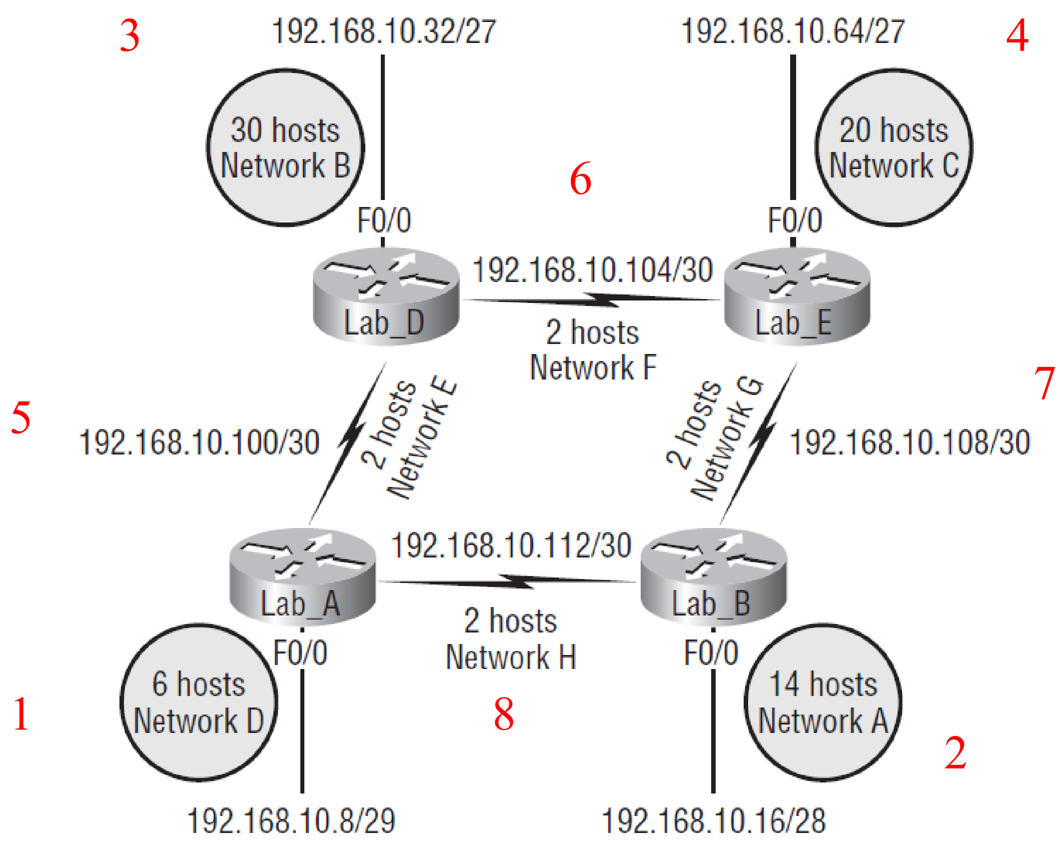
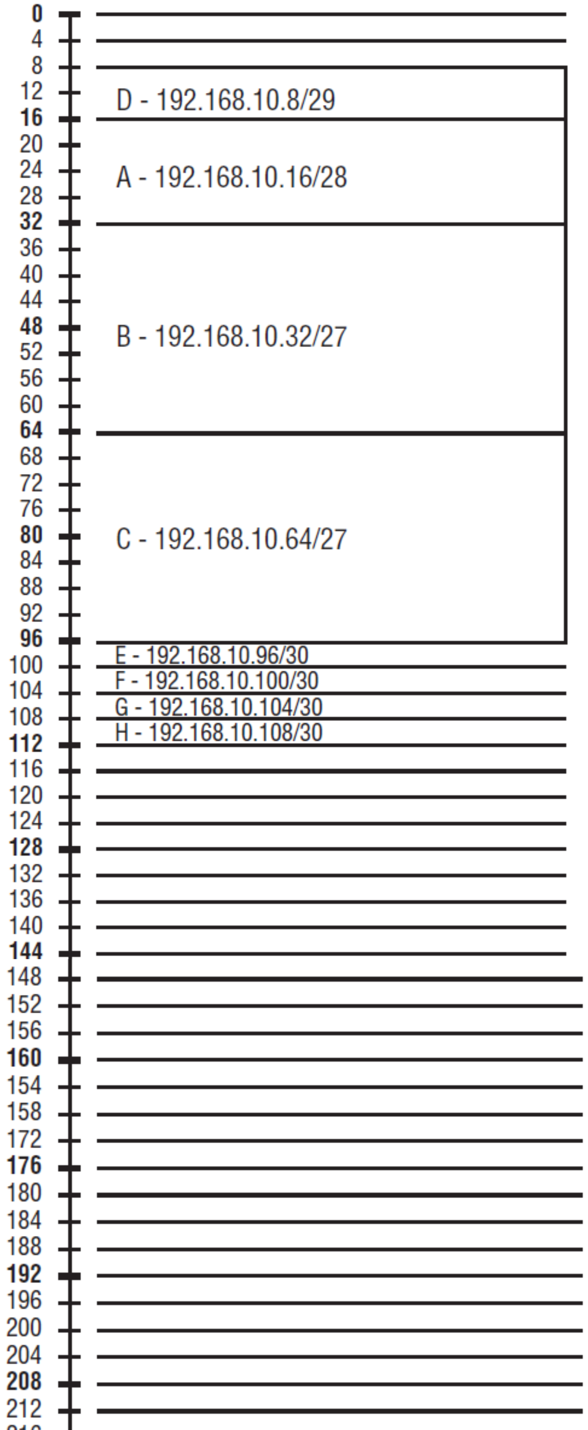
| /25 | 128 | 126 | 128 |
| /26 | 192 | 62 | 64 |
| /27 | 224 | 30 | 32 |
| /28 | 240 | 14 | 16 |
| /29 | 248 | 6 | 8 |
| /30 | 252 | 2 | 4 |

**Class C Network** 192.168.10.0

| Network | Hosts | Block | Subnet | Mask |
|---|---|---|---|---|
| A | 14 | 16 | /28 | 240 |
| B | 30 | 32 | /27 | 224 |
| C | 20 | 32 | /27 | 224 |
| D | 6 | 8 | /29 | 248 |
| E | 2 | 4 | /30 | 252 |
| F | 2 | 4 | /30 | 252 |
| G | 2 | 4 | /30 | 252 |
| H | 2 | 4 | /30 | 252 |

**FIGURE 3.6** VLSM network example 1






# Implementing VLSM networks

# Implementing VLSM networks

VLSM design example 1

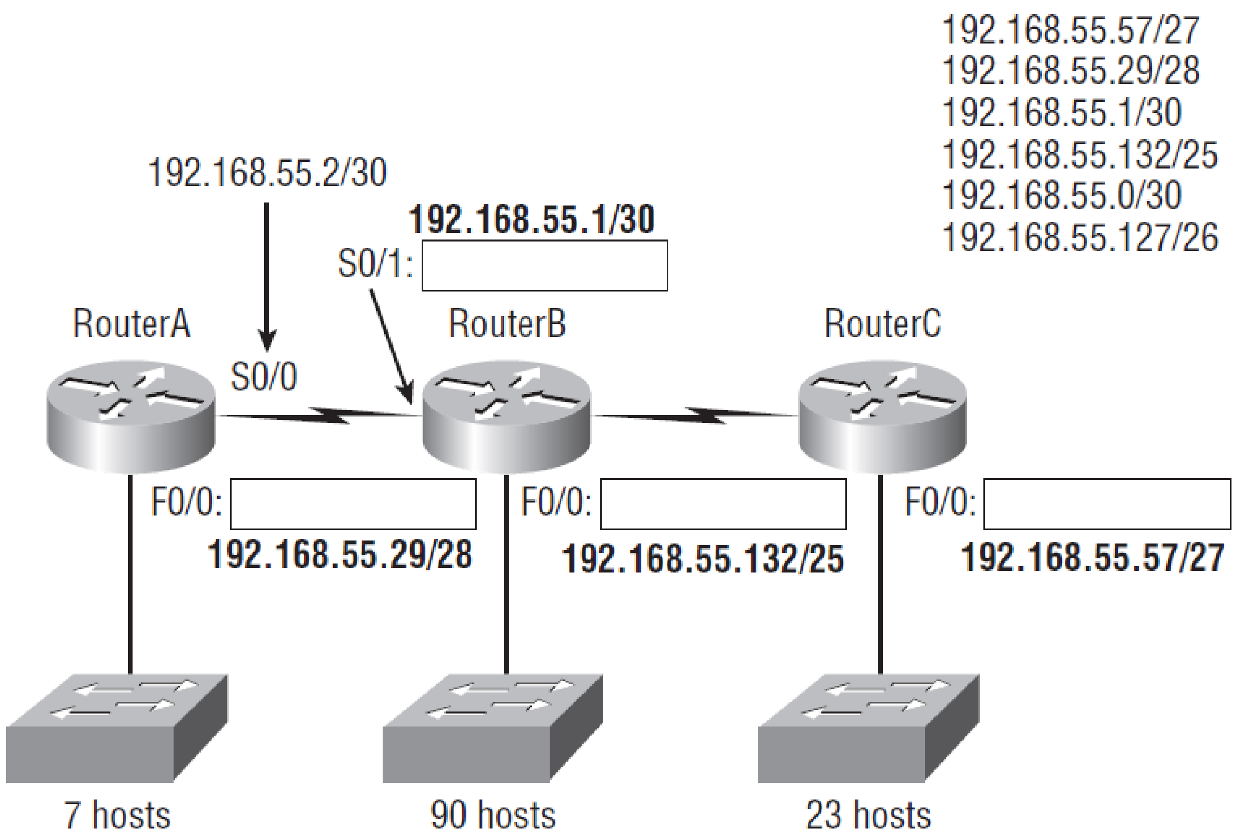



**TABLE 3.3** Block Sizes

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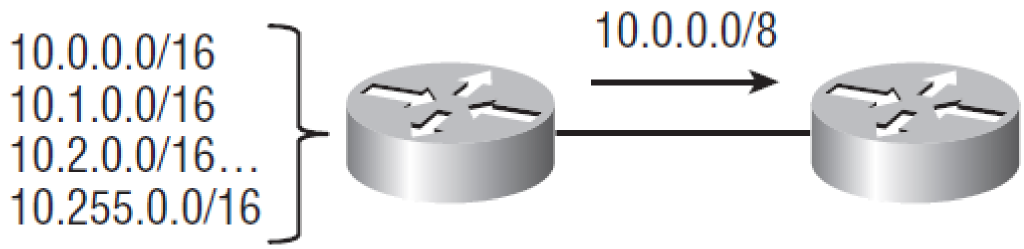
| /25 | 128 | 126 | 128 |
| /26 | 192 | 62 | 64 |
| /27 | 224 | 30 | 32 |
| /28 | 240 | 14 | 16 |
| /29 | 248 | 6 | 8 |
| /30 | 252 | 2 | 4 |

# Summarization

- Summarization, also called route aggregation, allows routing protocols to advertise many networks as one address.

- The purpose of this is to reduce the size of routing tables on routers to save memory, which also shortens the amount of time for IP to parse the routing table and find the path to a remote network.

**FIGURE 3.14** Summary address used in an internetwork



# Summarization

- For example, if you wanted to summarize the following networks into one network advertisement, you just have to find the block size first; then you can easily find your answer:

**192.168.16.0 through network 192.168.31.0**

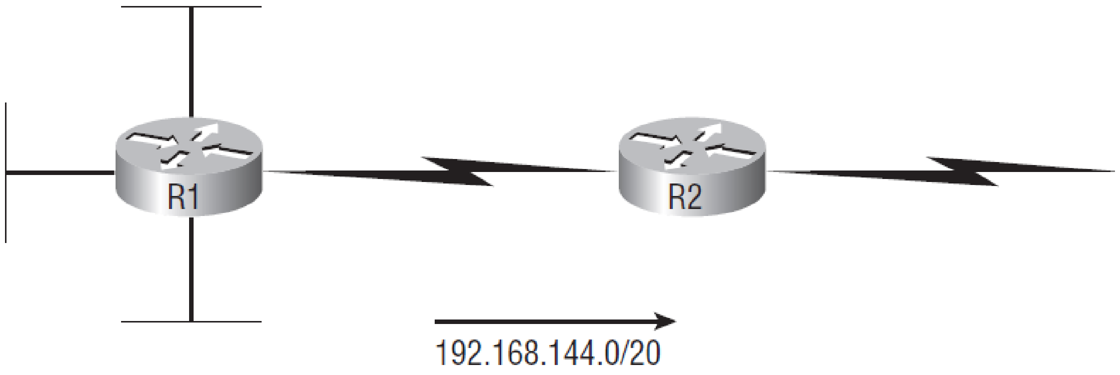
- What's the block size? There are exactly 16 Class C networks, so this neatly fits into a block size of 16.

- The network address used to advertise the summary address is always the first network address in the block—in this example, 192.168.16.0.

- what mask is used to get a block size of 16? Yes, 240 So, the mask would be 255.255.240.0.

# Summarization Example:

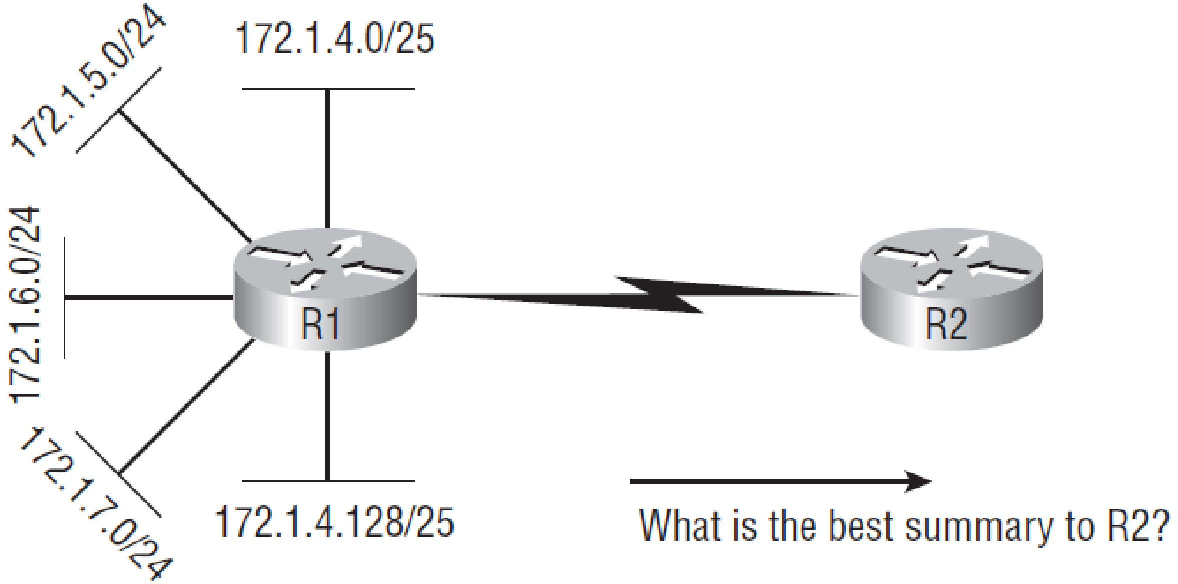
- Your summary address is **192.168.144.0/20**—what's the range of host addresses that would be forwarded according to this summary?
- The /20 provides a summary address of 192.168.144.0 and mask of 255.255.240.0.
- The third octet has a block size of 16, and starting at summary address 144, the next block of 16 is 160, so our network summary range is 144 to 159 in the third octet
- A router that has this summary address in the routing table will forward any packet with destination IP addresses of 192.168.144.1 through 192.168.159.254.



# Summarization Example:

- The first thing to do with this is to write down all the networks and see if you can find anything in common with all six:

  - 172.1.4.128/25
  - 172.1.7.0/24
  - 172.1.6.0/24
  - 172.1.5.0/24
  - 172.1.4.0/25




- It's the third octet. 4, 5, 6, 7, and yes, it's a block size of 4. So you can summarize 172.1.4.0 using a mask of 255.255.252.0, which means you will use a block size of 4 in the third octet.
- The IP addresses forwarded with this summary are 172.1.4.1 through 172.1.7.255.

# Basic DOS Commands

- **`traceroute`** Displays the list of routers on a path to a network destination by using TTL time-outs and ICMP error messages. This command will not work from a DOS prompt.
- **`tracert`** Same command as `traceroute`, but it's a Microsoft Windows command and will not work on a Cisco router.
- **`arp -a`** Displays IP-to-MAC-address mappings on a Windows PC.
- **`show ip arp`** Same command as `arp -a`, but displays the ARP table on a Cisco router. Like the commands `traceroute` and `tracert`, they are not interchangeable through DOS and Cisco.
- **`ipconfig /all`** Used only from a DOS prompt, shows you the PC network configuration.

# Troubleshooting IP Addressing

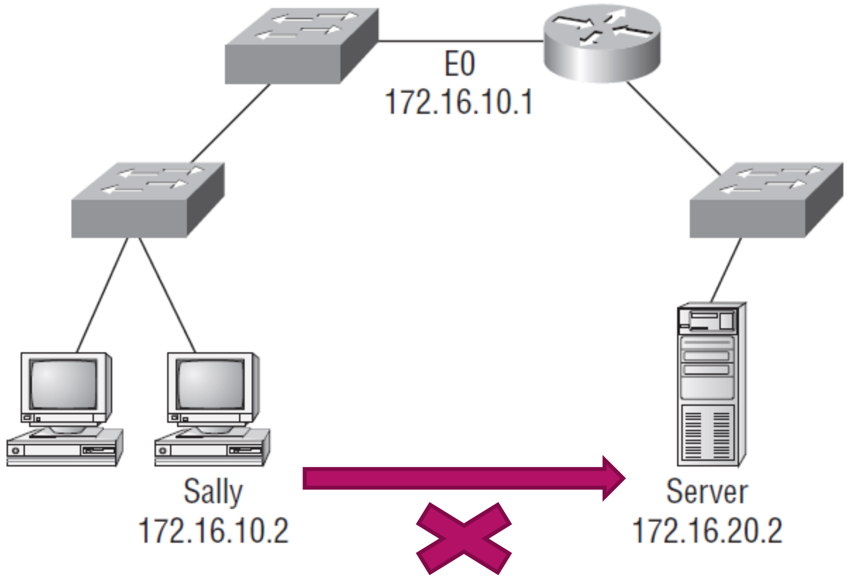
Here are the four troubleshooting steps Cisco recommends:

1. Open a DOS window and ping 127.0.0.1.

   If it fails, then you have an IP stack failure

```
C:\>ping 127.0.0.1
Pinging 127.0.0.1 with 32 bytes of data:
Reply from 127.0.0.1: bytes=32 time<1ms TTL=128
Reply from 127.0.0.1: bytes=32 time<1ms TTL=128
Reply from 127.0.0.1: bytes=32 time<1ms TTL=128
Reply from 127.0.0.1: bytes=32 time<1ms TTL=128
Ping statistics for 127.0.0.1:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 0ms, Average = 0ms
```

**FIGURE 3.17** Basic IP troubleshooting




2. From the DOS window, ping the IP address of the local host.

If that's successful, your network interface card (NIC) is functioning.

# Troubleshooting IP Addressing

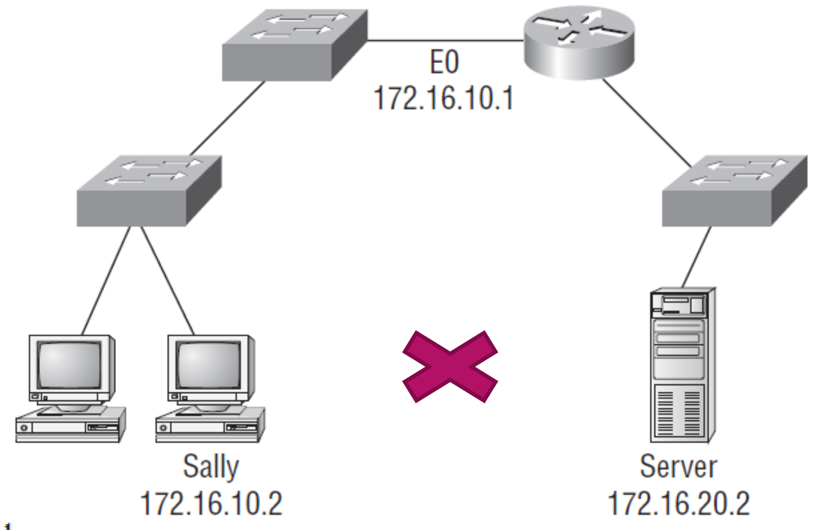
3. From the DOS window, ping the default gateway (router).

   If the ping works, it means that the NIC is plugged into the network and can communicate on the local network.

   If it fails, you have a local physical network problem that could be anywhere from the NIC to the router.

4. If steps 1 through 3 were successful, try to ping the remote server.

**FIGURE 3.17** Basic IP troubleshooting

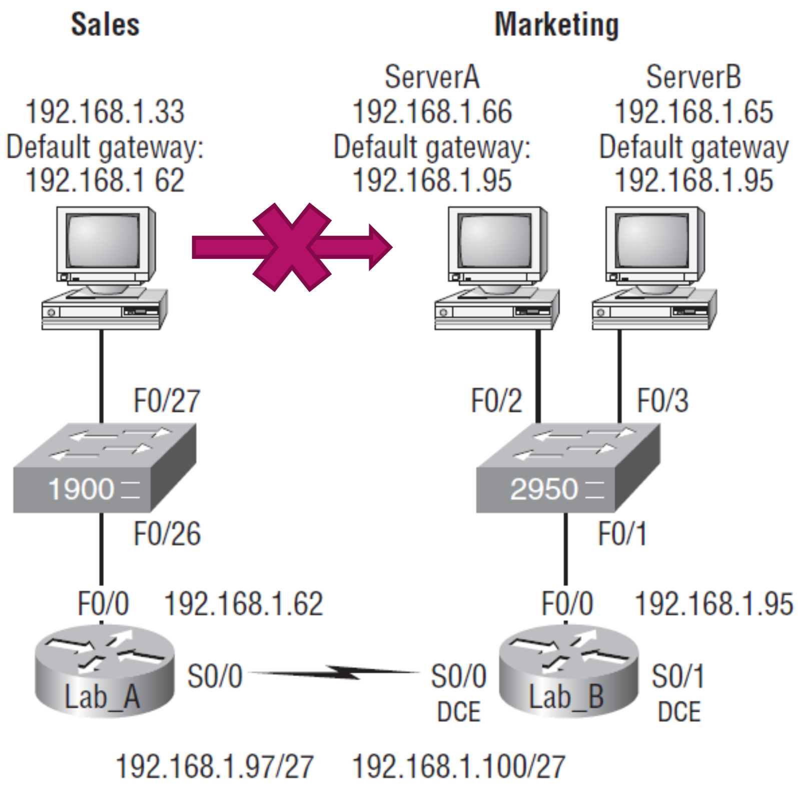



- If the user still can't communicate with the server after steps 1 through 4 are successful, you probably have some type of name resolution problem and need to check your Domain Name System (DNS) settings.
- But if the ping to the remote server fails, then you know you have some type of remote physical network problem and need to go to the server and work through steps 1 through 3 until you find the snag.

# Determining IP Address Problems

- It's common for a host, router, or other network device to be configured with the wrong IP address, subnet mask, or default gateway.
- Steps 1 through 3 work, but step 4 fails.

FIGURE 3.18 IP address problem 1




First, the WAN link between the Lab_A router and the Lab_B router shows the mask as a /27.

mask is 255.255.255.224

What are our valid subnets and hosts? 256 – 224 = 32, so this makes our subnets 32, 64, 96, 128, etc.

subnet 32 is being used by the sales department → valid hosts 33 through 62

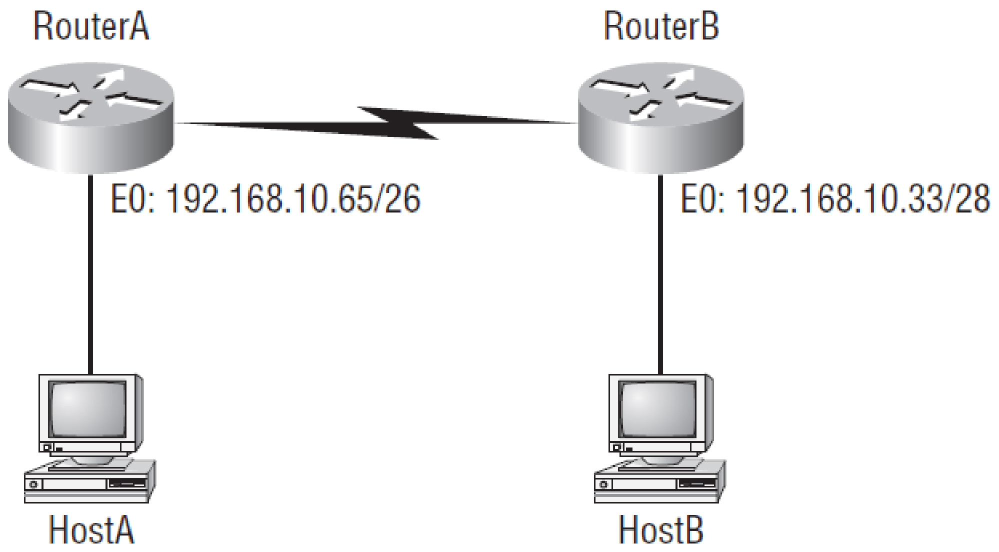
marketing department is using subnet 64 → valid hosts 65 through 94 (broadcast 95)

WAN link is using subnet 96 → valid hosts 97 through 126

- By looking at the figure, you can determine that the default gateway on the Lab_B router router is incorrect. That address is the broadcast address of the 64 subnet

# Determining IP Address Problems

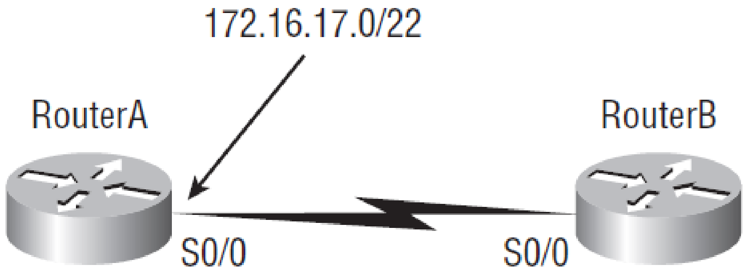
**FIGURE 3.21** Find the valid host #2




192.168.10.66
through
192.168.10.126

192.168.10.34
through
192.168.10.46

**FIGURE 3.22** Find the valid host address #3




172.16.16.1
through
172.16.19.254

# Determining IP Address Problems

5 subnets needed and the Wyoming office needs 16 users

What block size is needed for the Wyoming office? 32.

What mask provides you with a block size of 32? 224.

This provides 8 subnets, each with 30 hosts.

**FIGURE 3.23** Find the valid subnet mask.