Understanding the TCP/IP Internet Layer

Building a Simple Network

Why IP Addresses?

- They uniquely identify each device on an IP network.
- Every host (computer, networking device, peripheral) must have a unique address.
- Host ID:
  - Identifies the individual host
  - Is assigned by organizations to individual devices

Network.Host

IP Address Format: Dotted Decimal Notation

	Example			
An IP address is a 32-bit binary number	10101100	00010000	10000000	00010001
For readability, the 32-bit binary number can be divided into four 8-bit octets	10101100	00010000	10000000	00010001
Each octet (or byte) can be converted to decimal	172	16	128	17
The address can be written in dotted decimal notation	172.	16.	128.	17

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The binary-to-decimal and decimal-to-binary conversion will be detailed later in this course.

IP Address Classes: The First Octet

A B C … Easy as 1 2 3

Class A … First 1 bit fixed	0 x x x x x x x	Host	Host	Host
Class B … First 2 bits fixed	1 0 x x x x x x	Network	Host	Host
Class C … First 3 bits fixed	1 1 0 x x x x x	Network	Network	Host

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IP Address Ranges

IP Address Class	First Octet Binary Value	First Octet Decimal Value	Possible Number of Hosts
Class A	1-126	00000001 to 01111110*	16,777,214
Class B	128-191	10000000 to 10111111	65,534
Class C	192-223	11000000 to 11011111	254

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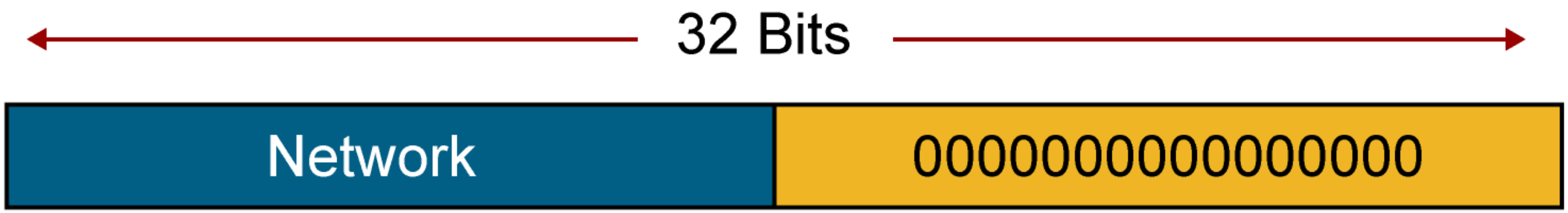
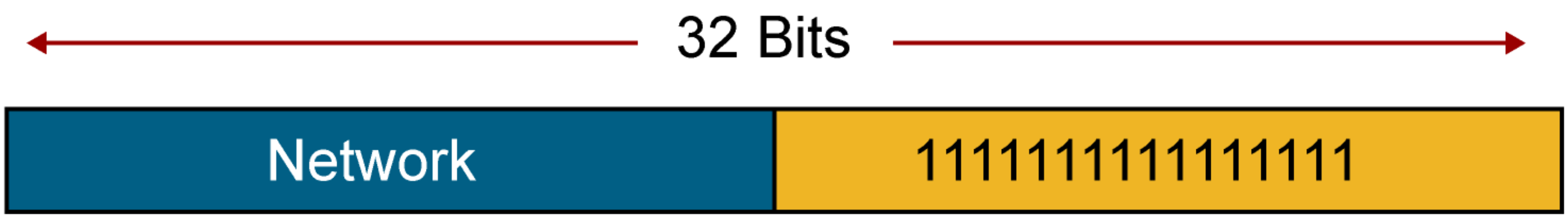
*127 (01111111) is a Class A address reserved for loopback testing and cannot be assigned to a network.

Reserved Address

- Network Addresses



- Broadcast Addresses



Public IP Addresses

Class	Public IP Ranges
A	1.0.0.0 to 9.255.255.255 11.0.0.0 to 126.255.255.255
B	128.0.0.0 to 172.15.255.255 172.32.0.0 to 191.255.255.255
C	192.0.0.0 to 192.167.255.255 192.169.0.0 to 223.255.255.255

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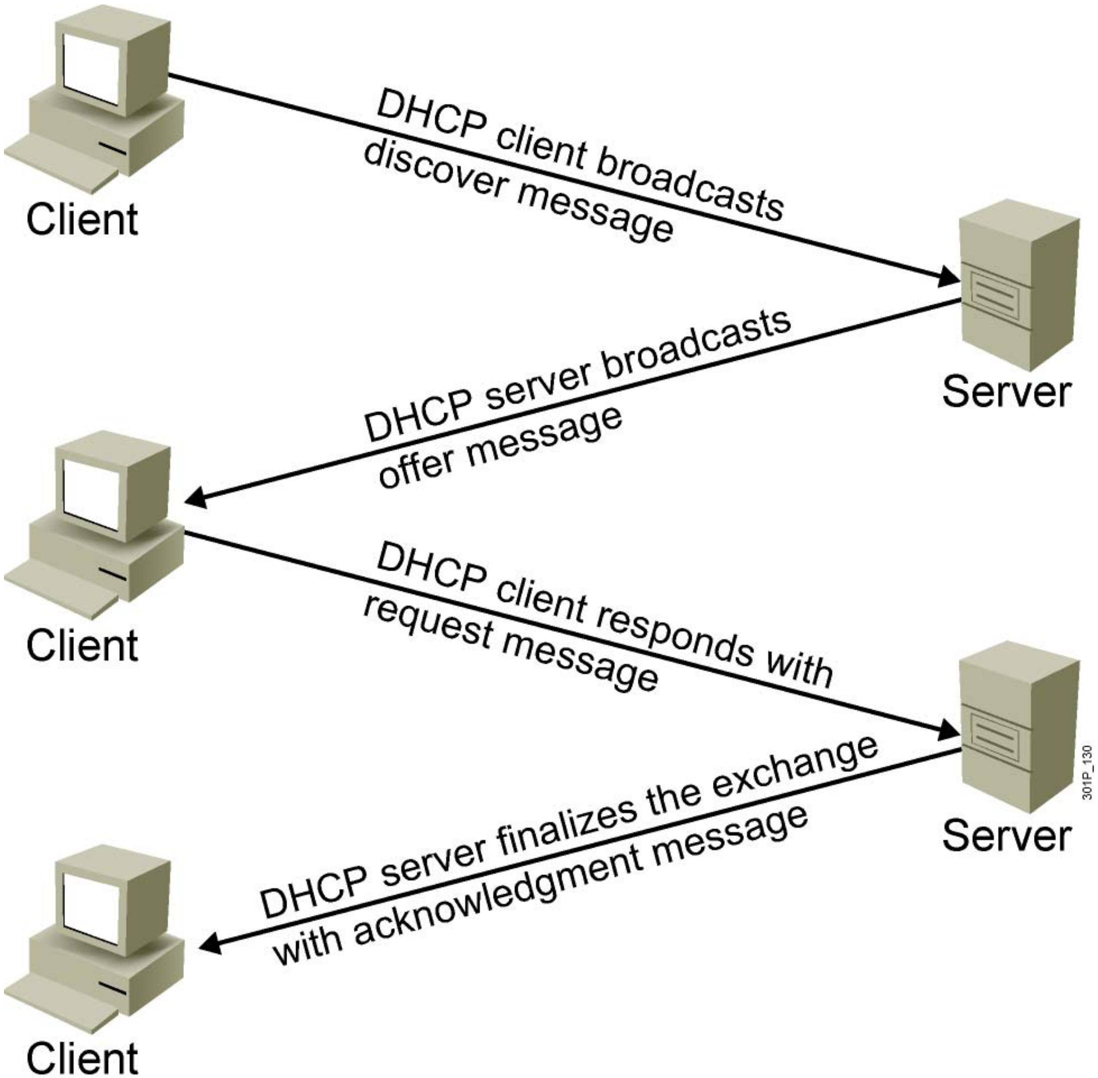
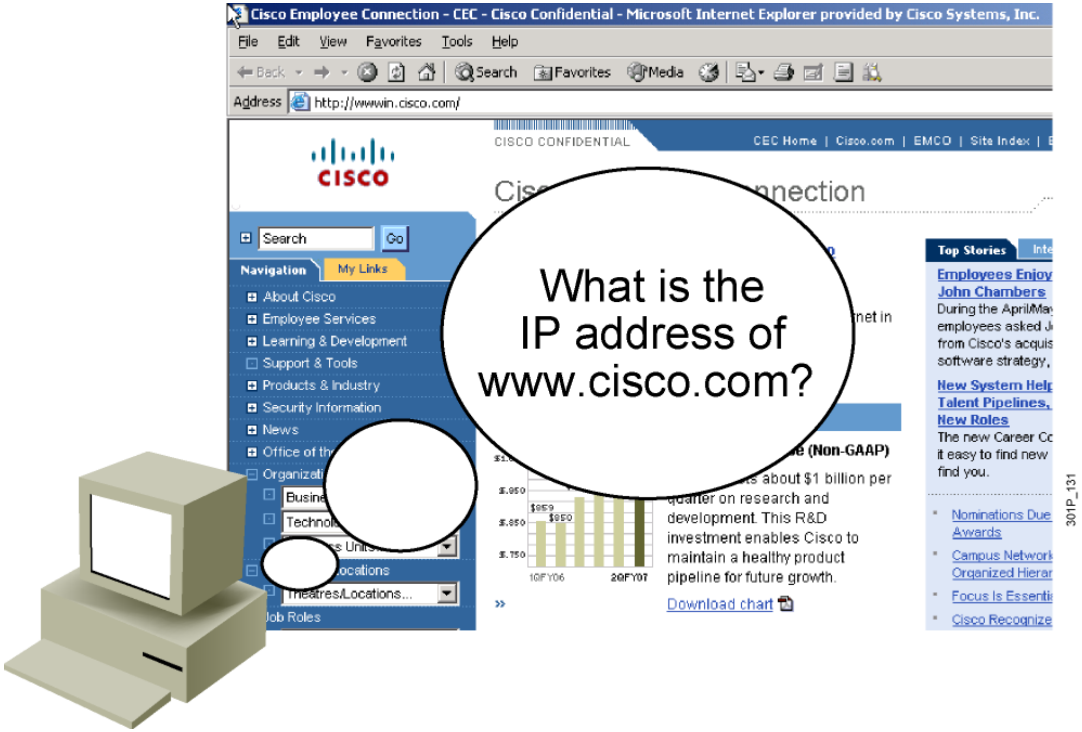
Private IP Addresses

Class	Private Address Range
A	10.0.0.0 to 10.255.255.255
B	172.16.0.0 to 172.31.255.255
C	192.168.0.0 to 192.168.255.255

DHCP

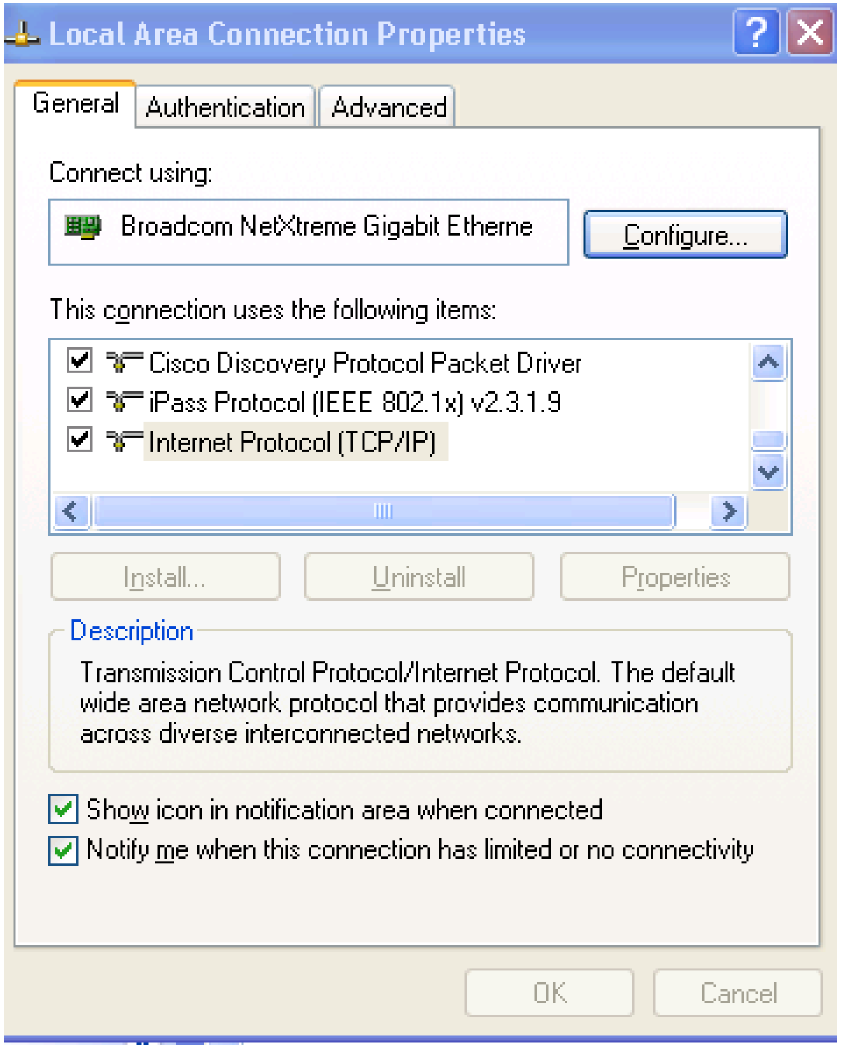

Client
DHCP client broadcasts discover message
Server
DHCP server broadcasts offer message
Client
DHCP client responds with request message
Server
301P_130
DHCP server finalizes the exchange with acknowledgment message
Client

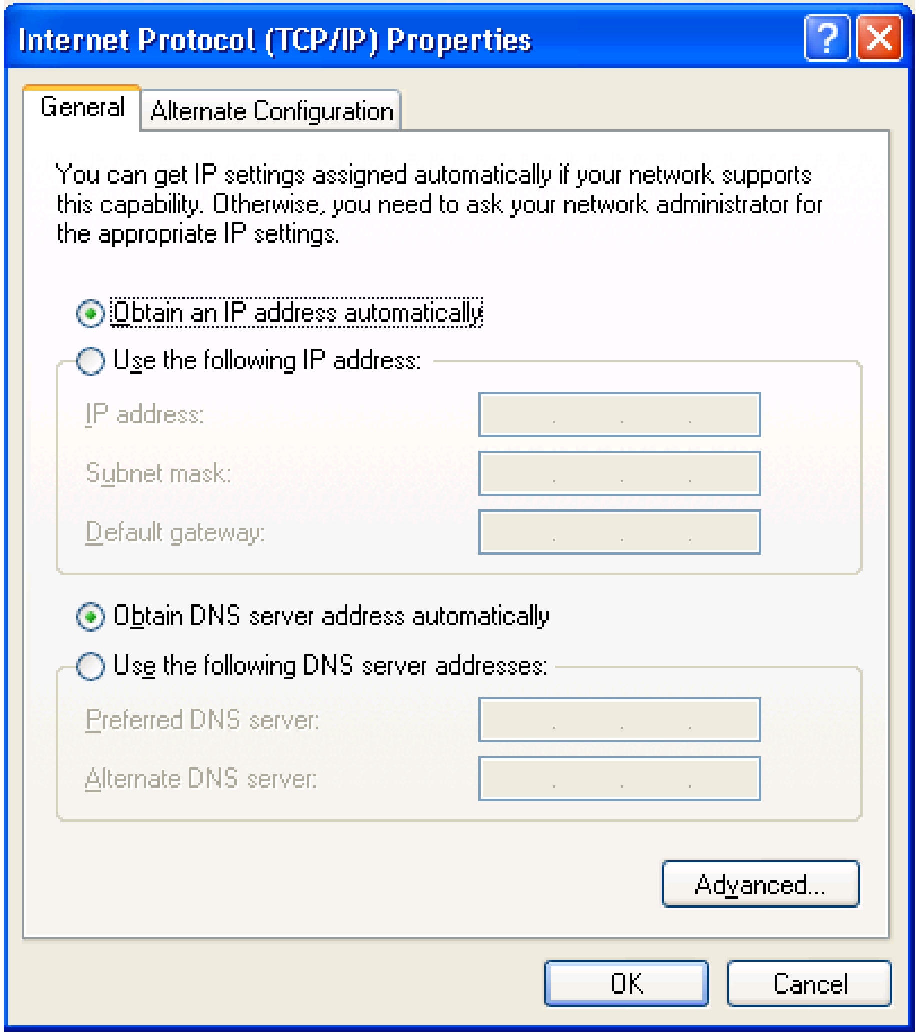
DNS



- Application specified in the TCP/IP suite
- A way to translate human-readable names into IP addresses

Network Connection





ipconfig

C:\WINDOWS\system32\cmd.exe

```
C:\Documents and Settings>ipconfig /all

Windows IP Configuration

        Host Name . . . . . . . . . . . . : PCUSER
        Primary Dns Suffix  . . . . . . . :
        Node Type . . . . . . . . . . . . : Hybrid
        IP Routing Enabled. . . . . . . . : No
        WINS Proxy Enabled. . . . . . . . : No
        DNS Suffix Search List. . . . . . :

Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        Description . . . . . . . . . . . : Intel(R) PRO/1000 PL Network Connection
        Physical Address. . . . . . . . . : 00-15-58-2F-21-E6
        Dhcp Enabled. . . . . . . . . . . : Yes
        Autoconfiguration Enabled . . . . : Yes
        IP Address. . . . . . . . . . . . : 192.168.1.102
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.1.1
        DHCP Server . . . . . . . . . . . : 192.168.1.1
        DNS Servers . . . . . . . . . . . : 127.107.241.185
                                            127.135.250.69
        Lease Obtained. . . . . . . . . . : Wednesday, April 25, 2007 12:27:51 AM
        Lease Expires . . . . . . . . . . : Thursday, April 26, 2007 12:27:51 AM
```

Summary

- IP network addresses consist of two parts: the network ID and the host ID.
- IPv4 addresses have 32 bits that are divided into octets and are generally shown in dotted decimal form (for example, 192.168.54.18).
- When written in a binary format, the first bit of a Class A address is always 0, the first 2 bits of a Class B address are always 10, and the first 3 bits of a Class C address are always 110.

Summary (Cont.)

- Certain IP addresses (network and broadcast) are reserved and cannot be assigned to individual network devices.
- Internet hosts require a unique, public IP address, but private hosts can have any valid private address that is unique within the private network.
- DHCP is used to assign IP addresses automatically, and also to set TCP/IP stack configuration parameters such as the subnet mask, default router, and DNS servers.
- DNS is an application that is specified in the TCP/IP suite, providing a means to translate human-readable names into IP addresses.

Summary (Cont.)

- Host provides tools that can be used to verify the IP address of the host:
  - Network connections
  - IPCONFIG

Understanding Binary Basics

LAN Connections

Decimal vs. Binary Numbers

- Decimal numbers are represented by the numbers 0 through 9.
- Binary numbers are represented by a series of 1s and 0s.

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001

Decimal	Binary
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001
18	10010
19	10011

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Powers of 2

Power of 2	Calculation	Value
2^0		1
2^1	2	2
2^2	2 * 2	4
2^3	2 * 2 * 2	8
2^4	2 * 2 * 2 * 2	16
2^5	2 * 2 * 2 * 2 * 2	32
2^6	2 * 2 * 2 * 2 * 2 *2	64
2^7	2 * 2 * 2 * 2 * 2 *2 * 2	128

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Decimal-to-Binary Conversion

$Base^{Exponent}$	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	128	64	32	16	8	4	2	1
Example: Convert decimal 35 to binary	0	0	1	0	0	0	1	1

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$$35 = 2^5 + 2^1 + 2^0$$
$$35 = (32 * 1) + (2 * 1) + (1 * 1)$$
$$35 = 0 + 0 + 1 + 0 + 0 + 0 + 1 + 1$$
$$35 = \underline{00100011}$$

Binary-to-Decimal Conversion

$Base^{Exponent}$	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	128	64	32	16	8	4	2	1
Example: Binary Number	1	0	1	1	1	0	0	1
Decimal Number Total: 185	128	0	32	16	8	0	0	1

301P_142

1 0 1 1 1 0 0 1 = (128 * 1) + (64 * 0) + (32 * 1) + (16 * 1) + (8 * 1) + (4 * 0) + (2 * 0) + (1 * 1)
1 0 1 1 1 0 0 1 = 128 + 0 + 32 + 16 + 8 + 0 + 0 + 1
1 0 1 1 1 0 0 1 = 185

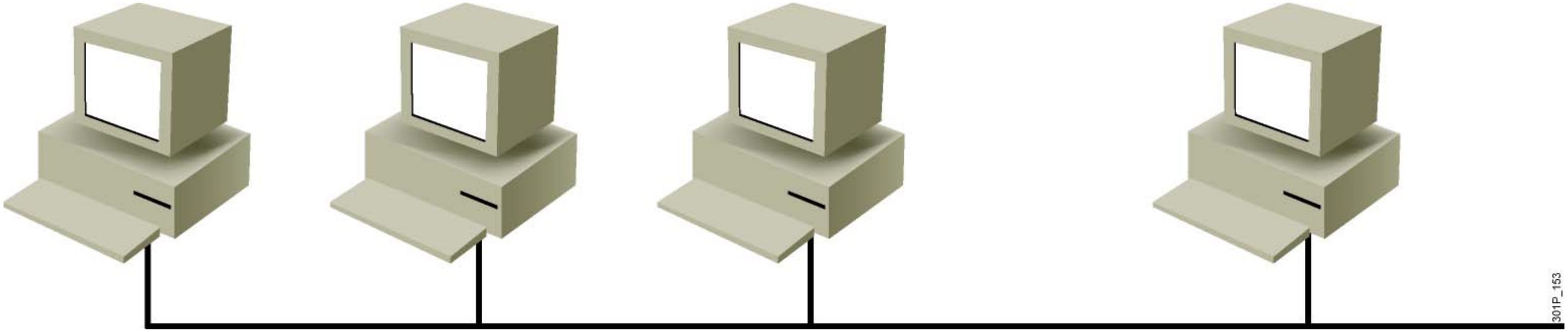
Summary

- All computers operate using a binary system.
- Binary systems (base 2) use only the numerals 0 and 1.
- Decimal systems (base 10) use the numerals 0 through 9.
- Using the powers of 2, a binary number can be converted into a decimal number.
- Using the powers of 2, a decimal number can be converted into a binary number.

Constructing a Network Addressing Scheme

LAN Connections

Flat Topology

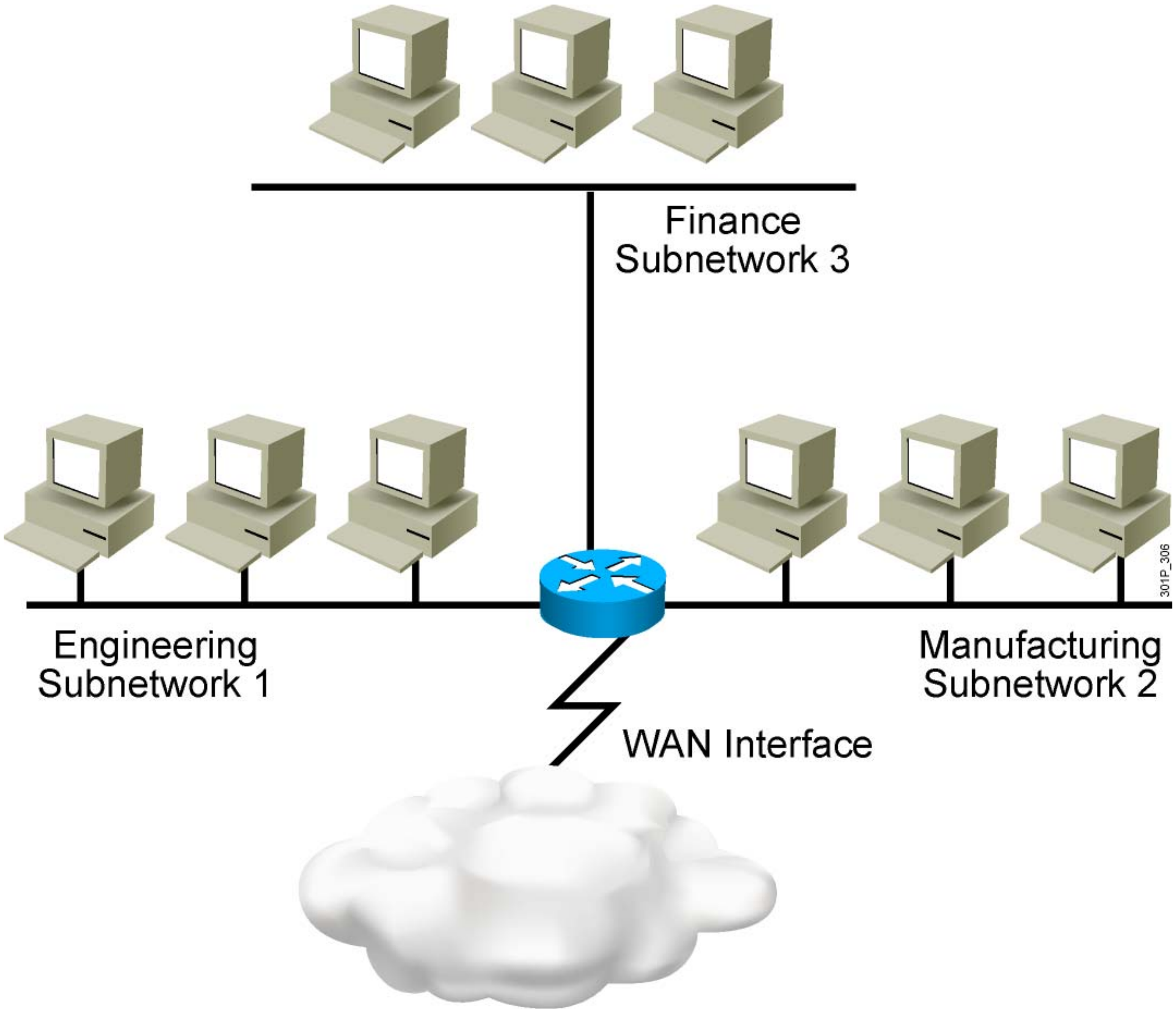


Problems

- All devices share the same bandwidth.
- All devices share the same broadcast domain.
- It is difficult to apply a security policy.

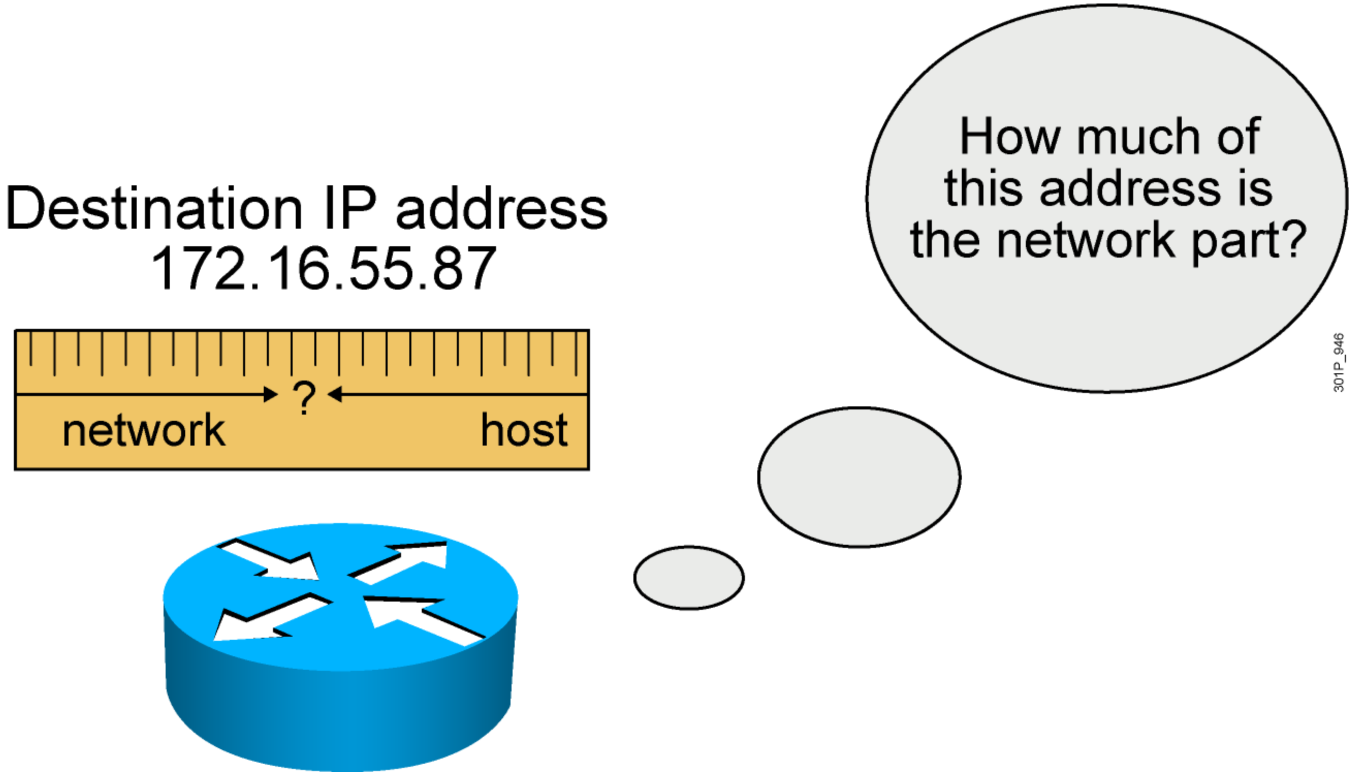
Subnetworks

- Smaller networks are easier to manage.
- Overall traffic is reduced.
- You can more easily apply network security policies.

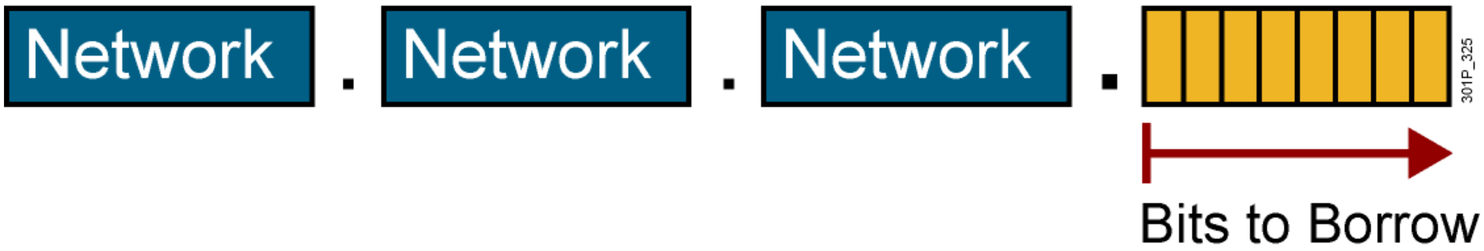


What a Subnet Mask Does

- Tells the router the number of bits to look at when routing
- Defines the Network ID of each Network or Subnetwork
- Used to know the Size of each Network or Subnetwork

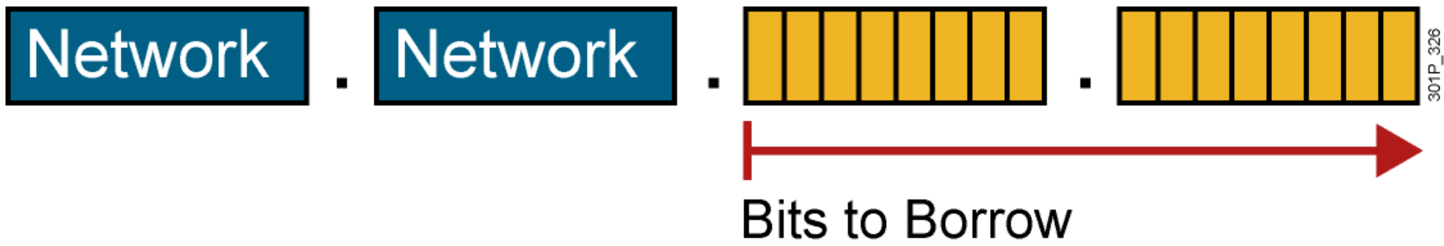


Possible Subnets and Hosts for a Class C Network



Number of Bits Borrowed (s)	Number of Subnets Possible (2^s)	Number of Bits Remaining in Host ID (8 - s = h)	Number of Hosts Possible Per Subnet (2^h - 2)
1	2	7	126
2	4	6	62
3	8	5	30
4	16	4	14
5	32	3	6
6	64	2	2
7	128	1	2

Possible Subnets and Hosts for a Class B Network



Number of Bits Borrowed (s)	Number of Subnets Possible (2^s)	Number of Bits Remaining in Host ID ($16 - s = h$)	Number of Hosts Possible Per Subnet ($2^h - 2$)
1	2	15	32,766
2	4	14	16,382
3	8	13	8,190
4	16	12	4,094
5	32	11	2,046
6	64	10	1,022
7	128	9	510
...	...	...	...

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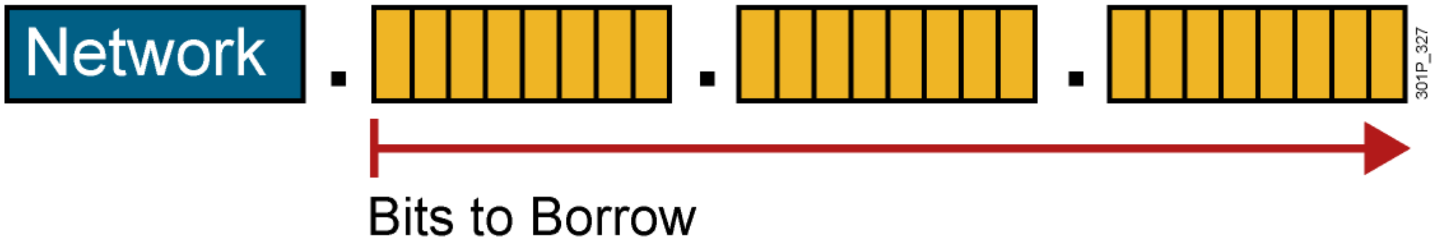
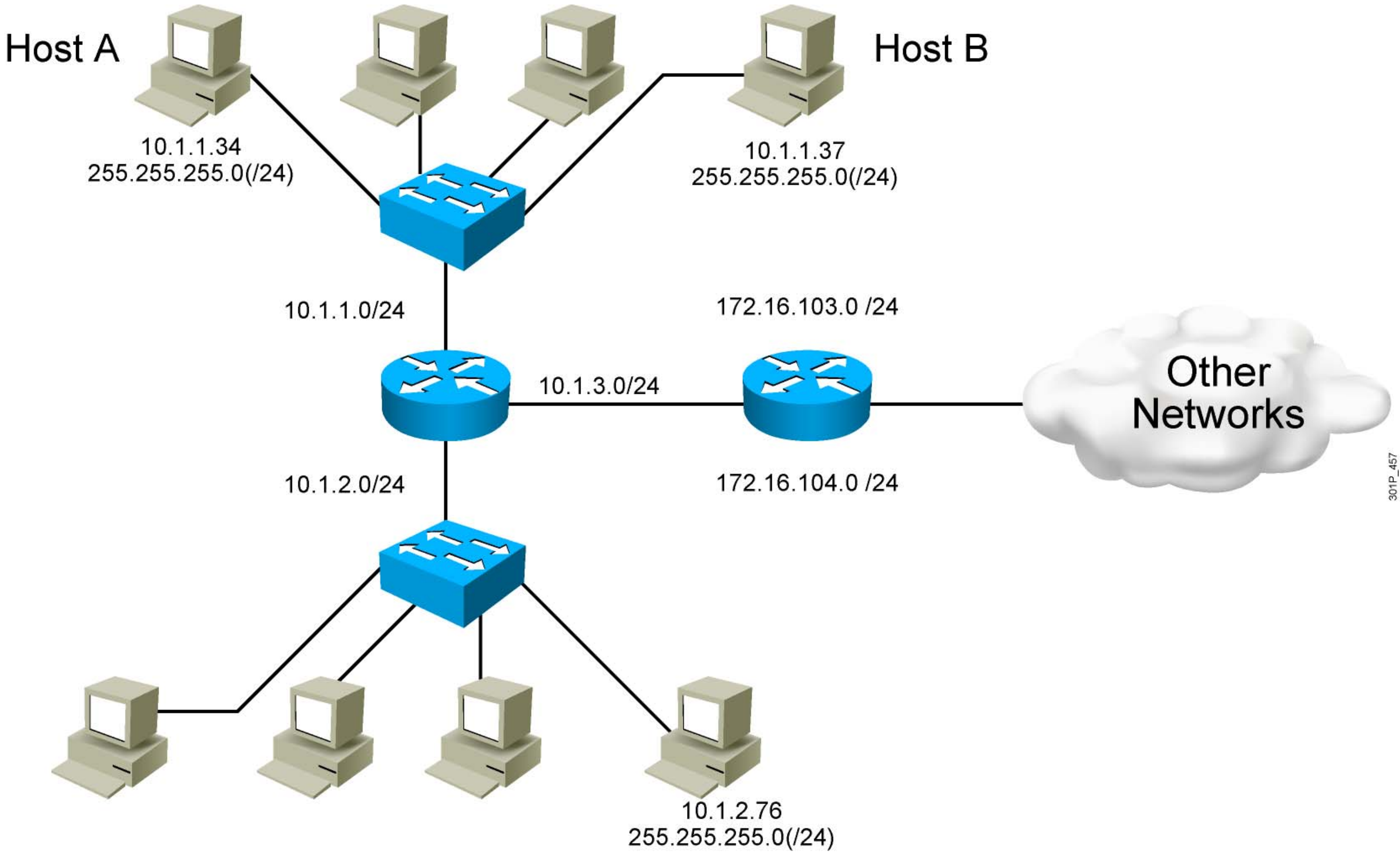
Possible Subnets and Hosts for a Class A Network

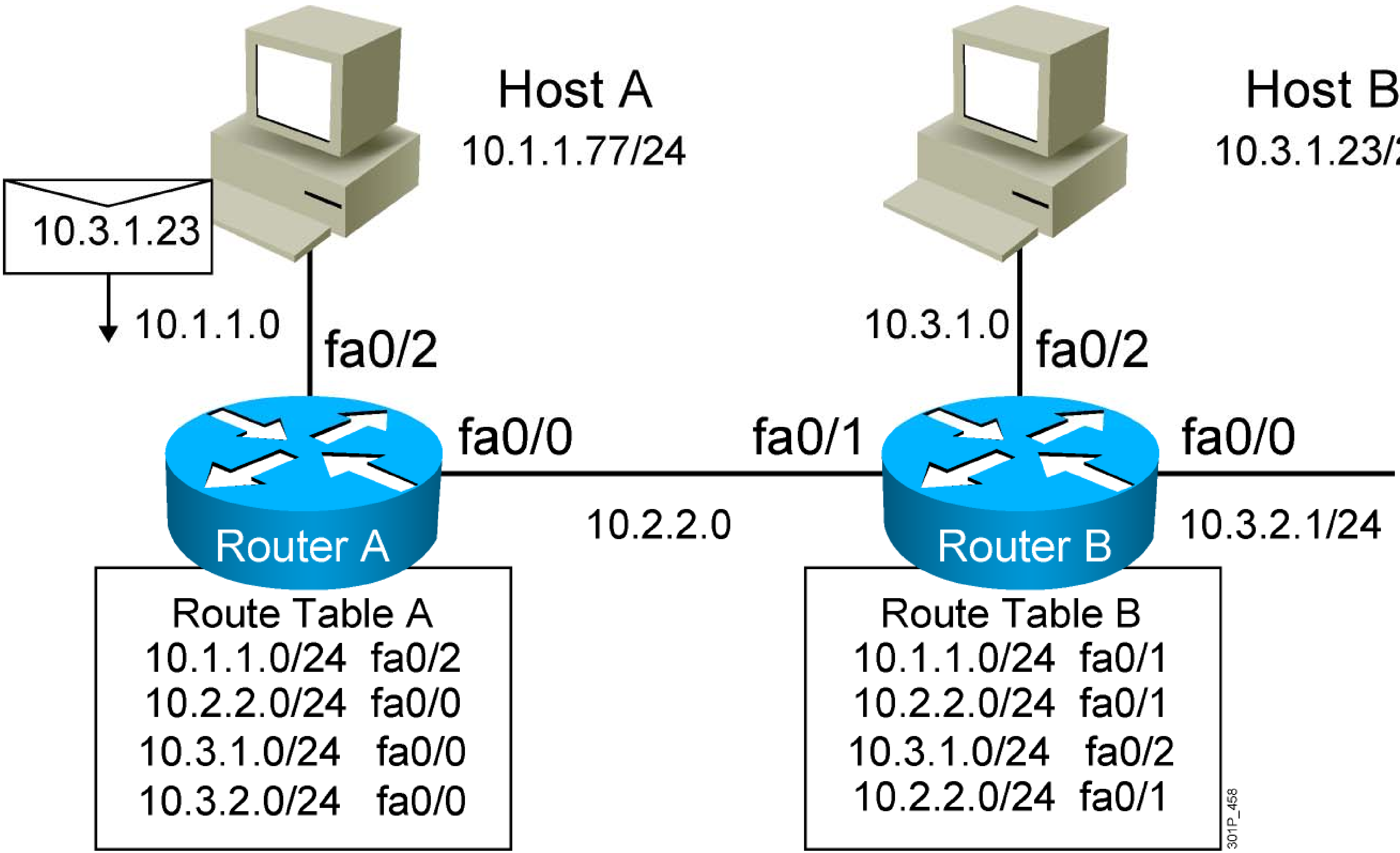


Number of Bits Borrowed (s)	Number of Subnets Possible (2^s)	Number of Bits Remaining in Host ID ($24 - s = h$)	Number of Hosts Possible Per Subnet ($2^h - 2$)
1	2	23	8,388,606
2	4	22	4,194,302
3	8	21	2,097,150
4	16	20	1,048,574
5	32	19	524,286
6	64	18	262,142
7	128	17	131,070
...	...	...	...

End System Subnet Mask Operation



How Routers Use Subnet Masks



Octet Values of a Subnet Mask

128	64	32	16	8	4	2	1		
1	0	0	0	0	0	0	0	=	128
1	1	0	0	0	0	0	0	=	192
1	1	1	0	0	0	0	0	=	224
1	1	1	1	0	0	0	0	=	240
1	1	1	1	1	0	0	0	=	248
1	1	1	1	1	1	0	0	=	252
1	1	1	1	1	1	1	0	=	254
1	1	1	1	1	1	1	1	=	255

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Subnet masks, like IP addresses, are represented in the dotted decimal format like 255.255.255.0

Default Subnet Masks

Example Class A address (decimal):	10.0.0.0
Example Class A address (binary):	00001010.00000000.00000000.00000000
Default Class A mask (binary):	11111111.00000000.00000000.00000000
Default Class A mask (decimal):	255.0.0.0
Default classful prefix length:	/8

Example Class B address (decimal):	172.16.0.0
Example Class B address (binary):	10010001.10101000.00000000.00000000
Default Class B mask (binary):	11111111.11111111.00000000.00000000
Default Class B mask (decimal):	255.255.0.0
Default classful prefix length:	/16

Example Class C address (decimal):	192.168.42.0
Example Class C address (binary):	11000000.10101000.00101010.00000000
Default Class C mask (binary):	11111111.11111111.11111111.00000000
Default Class C mask (decimal):	255.255.255.0
Default classful prefix length:	/24

Procedure for Implementing Subnets

1. Based on the organizational and administrative structure, determine the number of subnets required.
2. Based on the address class and required number of subnets, determine the number of bits you need to borrow from the host ID.
3. Determine the binary and decimal value of the subnet mask.
4. Apply the subnet mask to the network IP address to determine the subnet and host addresses.
5. Assign subnet addresses to specific interfaces.

Eight Easy Steps for Determining Subnet Addresses

IP Address: 192.168.221.37   Subnet Mask /29

Step	Description	Example
1.	Write the octet that is being split in binary.	Fourth octet: 00100101
2.	Write the mask or classful prefix length in binary.	Assigned mask: 255.255.255.248 (/29) Fourth octet: 11111000
3.	Draw a line to delineate the significant bits in the assigned IP address. Cross out the mask so you can view the significant bits in the IP address.	Split octet (binary): 00100|101 Split mask (binary): 11111|000

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Eight Easy Steps for Determining Subnet Addresses (Cont.)

Step	Description	Example
4.	Copy the significant bits four times.	00100 000 (network address) 00100 001 (first address in subnet) 00100 110 (last address in subnet) 00100 111 (broadcast address)?
5.	In the first line, define the network address by placing all zeros in the significant bits.	
6.	In the last line, define the broadcast address by placing all ones in the significant bits.	
7.	In the middle lines, define the first and last host number.	
8.	Increment the subnet bits by one.	00101 000 (next subnet)

Completed Subnet Addresses

Network address: 192.168.221.32
Subnet mask: 255.255.255.248
First subnet: 192.168.221.32
First host address: 192.168.221.33
Last host address: 192.168.221.38
Broadcast address: 192.168.221.39
Next subnet: 192.168.221.40

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Example: Applying a Subnet Mask for a Class C Address

IP Address 192.168.5.139 Subnet Mask 255.255.255.224

IP Address	192	168	5	139	
IP Address	11000000	10101000	00000101	10001011	
Subnet Mask	11111111	11111111	11111111	11100000	/27
Subnetwork	11000000	10101000	00000101	10000000	
Subnetwork	192	168	5	128	
First Host	192	168	5	10000001=129	
Last Host	192	168	5	10011110=158	
Directed Broadcast	192	168	5	10011111=159	
Next Subnet	192	168	5	10100000=160	

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Example: Applying a Subnet Mask for a Class B Address

IP Address 172.16.139.46 Subnet Mask /20

IP Address	172	16	139	46	
IP Address	10101100	00010000	10001011	00101110	
Subnet Mask	11111111	11111111	11110000	00000000	/20
Subnetwork	10101100	00010000	10000000	00000000	
Subnetwork	172	16	128	0	
First Host	172	16	10000000	00000001=128.1	
Last Host	172	16	10001111	11111110=143.254	
Directed Broadcast	172	16	10001111	11111111=143.255	
Next Subnet	172	16	10010000	00000000=144.0	

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Example: Applying a Subnet Mask for a Class A Address

IP Address 10.172.16.211 Subnet Mask /18

IP Address	10	172	16	211	
IP Address	00001010	10101100	00010000	11010011	
Subnet Mask	11111111	11111111	11000000	00000000	/18
Subnetwork	00001010	10101100	00000000	00000000	
Subnetwork	10	172	0	0	
First Host	10	172	00000000	00000001=0.1	
Last Host	10	172	00111111	11111110=63.254	
Directed Broadcast	10	172	00111111	11111111=63.255	
Next Subnet	10	172	01000000	00000000=64.0	

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Summary

- Networks, particularly large networks, are often divided into smaller subnetworks, or subnets. Subnets can improve network performance and control.
- A subnet address extends the network portion, and is created by borrowing bits from the original host portion and designating them as the subnet field.
- Determining the optimal number of subnets and hosts depends on the type of network and the number of host addresses required.
- The algorithm for computing a number of subnets is 2^s, where *s* is the number of subnet bits.

Summary (Cont.)

- The subnet mask is the tool that the router uses to determine which bits are routing (network and subnet) bits and which bits are host bits.
- End systems use subnet masks to compare the network portion of the local network addresses with the destination addresses of the packets to be sent.
- Routers use subnet masks to determine if the network portion of an IP address is on the corresponding routing table or if the packet needs to be sent to the next router.

Summary (Cont.)

Follow these steps to determine the subnetwork and host addresses using a subnet mask:

1. Write the octet being split in binary.
2. Write the mask in binary and draw a line to delineate the significant bits.
3. Cross out the mask so you can view the significant bits.
4. Copy the subnet bits four times.
5. Define the network address by placing all zeroes in the host bits.
6. Define the broadcast address by placing all ones in the host bits.
7. Define the first and last host numbers.
8. Increment the subnet bits by one.