Chapter 4

IP Addresses: Classful Addressing

Outlines

- Introduction
- Classful addressing
- Other issues
- Subnetting and supernetting

4.1

INTRODUCTION

Introduction

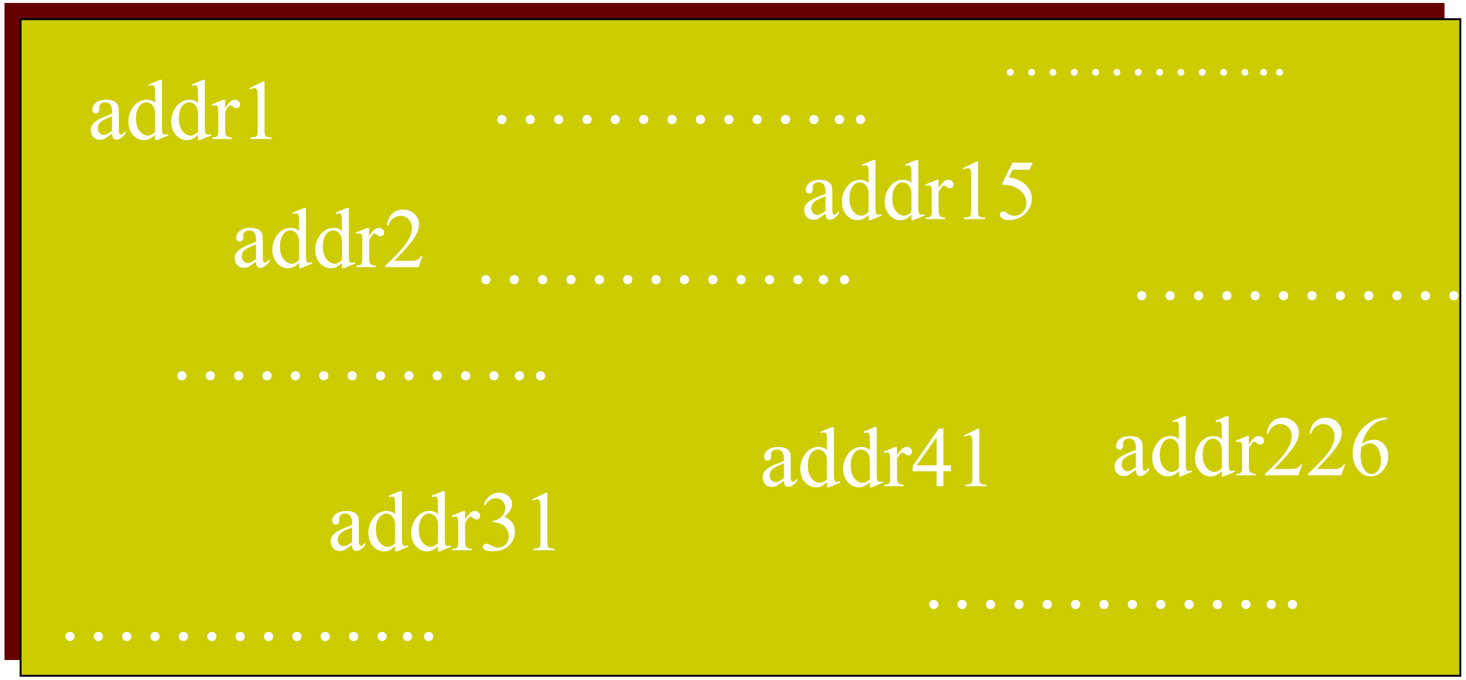
- IP address, or Internet Address
  - 32-bit binary address
  - Uniquely and universally defines the connection of a host or a router to the Internet
- Address Space
  - Total number of addresses used by the protocol
  - IPv4 uses 32-bit address and the address space is 2^32

Note

An IP address is a 32-bit address.

The IP addresses are unique.

Address Space



RULE:

If a protocol uses *N* bits to define an address, the address space is 2^N because each bit can have two different values (0 and 1) and *N* bits can have 2^N values.

Note

The address space of IPv4 is

2^{32}

or

4,294,967,296.

Notation

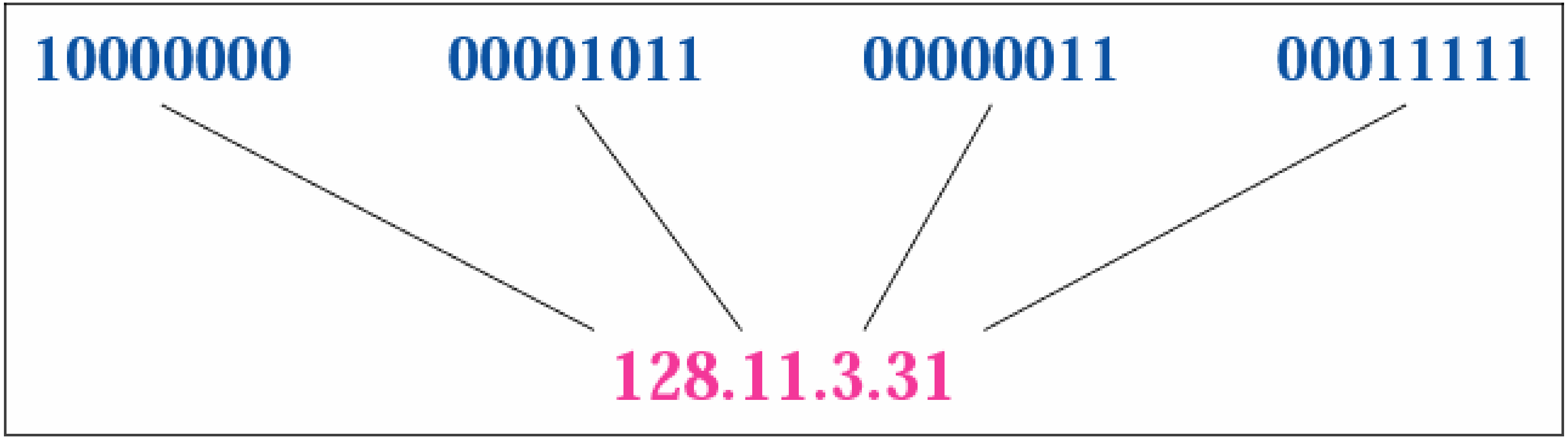
- Binary notation
- Dotted-decimal notation
- Hexadecimal notation

Binary Notation

01110101 10010101 00011101 11101010

Figure 4-1

Dotted-Decimal Notation



Hexadecimal Notation

0111 0101   1001 0101   0001 1101   1110 1010

75	**95**	**1D**	**EA**

0x75951DEA

Example 1

Change the following IP address from binary notation to dotted-decimal notation.

10000001 00001011 00001011 11101111

Solution

129.11.11.239

Example 2

Change the following IP address from dotted-decimal notation to binary notation.

111.56.45.78

Solution

01101111 00111000 00101101 01001110

Example 3

Find the error, if any, in the following IP address:

111.56.045.78

Solution

There are no leading zeroes in dotted-decimal notation (045).

Example 3 (continued)

Find the error, if any, in the following IP address:

221.34.7.8.20

Solution

We may not have more than four numbers in an IP address

Example 3 (continued)

Find the error, if any, in the following IP address:

75.45.301.14

Solution

In dotted-decimal notation, each number is less than or equal to 255; 301 is outside this range.

Example 3 (continued)

Find the error, if any, in the following IP address:

11100010.23.14.67

Solution

A mixture of binary notation and dotted-decimal notation is not allowed.

Example 4

Change the following IP addresses from binary notation to hexadecimal notation.

10000001 00001011 00001011 11101111

Solution

0X810B0BEF or $810B0BEF_{16}$

4.2

CLASSFUL ADDRESSING

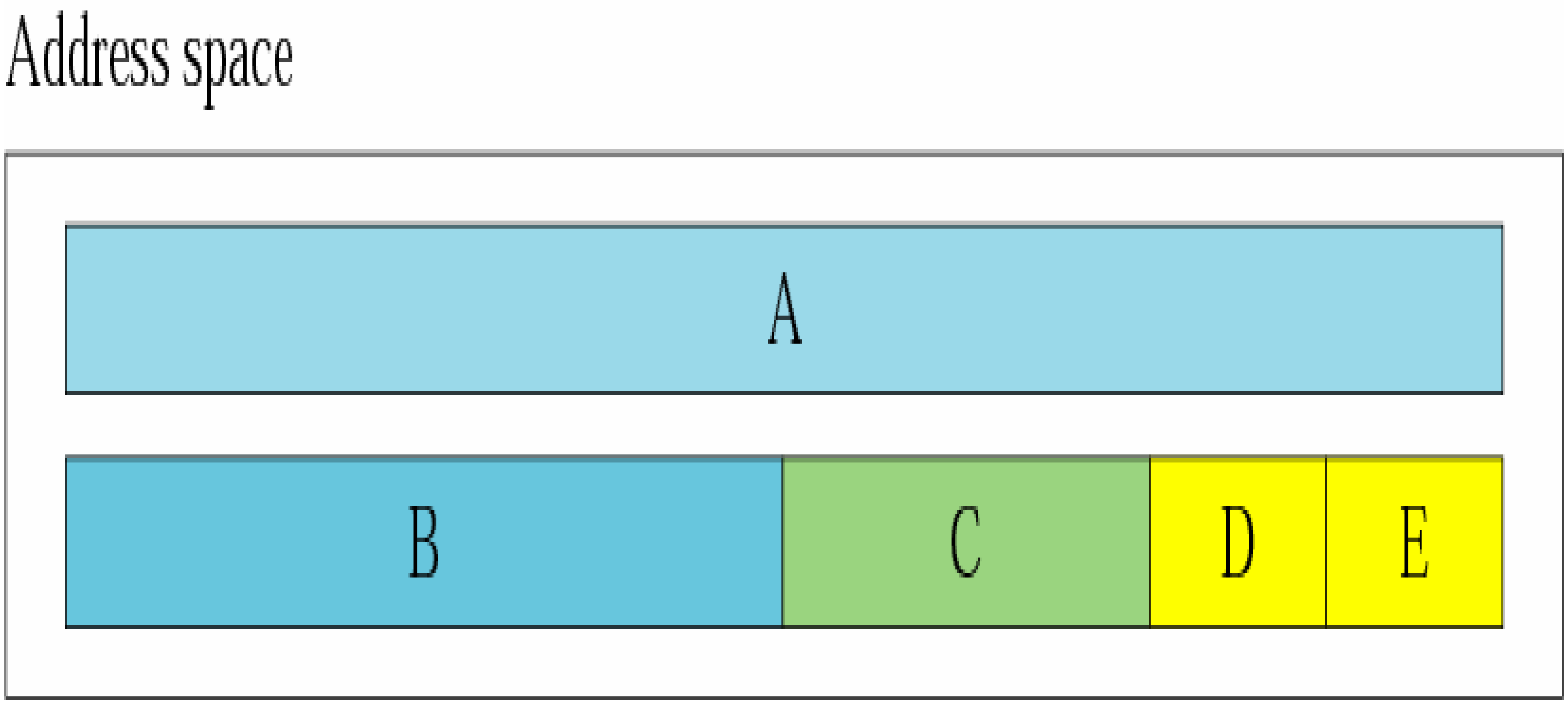
Classful Addressing

- IP address space is divided into five classes: A, B, C, D, E
  - A: 1/2
  - B: 1/4
  - C: 1/8
  - D: 1/16
  - E: 1/16

Occupation of the Address Space

Class	Addresses	Percentage
A	2^{31}	50%
B	2^{30}	25%
C	2^{29}	12.5%
D	2^{28}	6.25%
E	2^{28}	6.25%

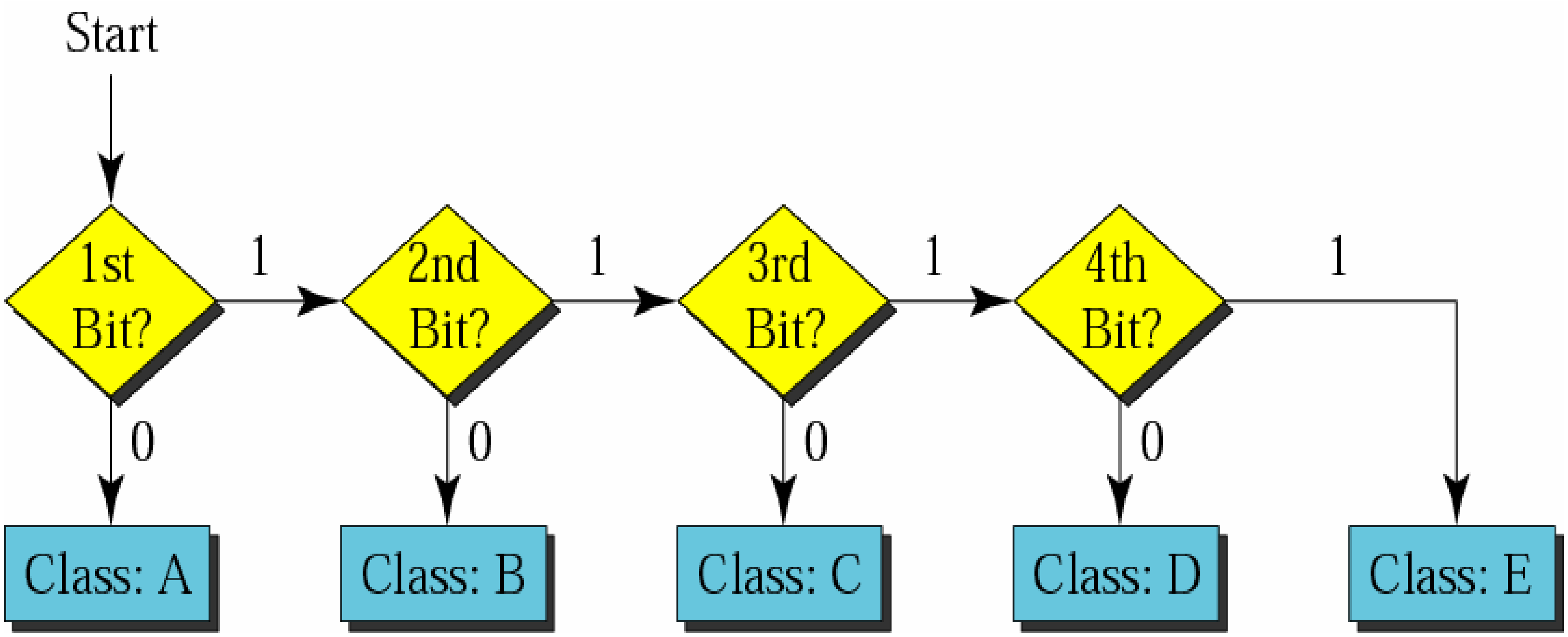
Occupation of the Address Space



Finding the Class in Binary Notation

	First byte	Second byte	Third byte	Fourth byte
Class A	0			
Class B	10			
Class C	110			
Class D	1110			
Class E	1111			

Finding the Address Class



Example 5

How can we prove that we have 2,147,483,648 addresses in class A?

Solution

In class A, only 1 bit defines the class. The remaining 31 bits are available for the address. With 31 bits, we can have 2^{31} or 2,147,483,648 addresses.

Example 6

Find the class of the address:

00000001 00001011 00001011 11101111

Solution

The first bit is 0. This is a class A address.

Example 6 (Continued)

Find the class of the address:

11000001 10000011 00011011 11111111

Solution

The first 2 bits are 1; the third bit is 0.
This is a class C address.

Finding the Class in Decimal Notation

	First byte	Second byte	Third byte	Fourth byte
Class A	**0 to 127**			
Class B	**128 to 191**			
Class C	**192 to 223**			
Class D	**224 to 239**			
Class E	**240 to 255**			

Example 7

Find the class of the address:

227.12.14.87

Solution

The first byte is 227 (between 224 and 239); the class is D.

Example 7 (Continued)

Find the class of the address:

193.14.56.22

Solution

The first byte is 193 (between 192 and 223); the class is C.

Example 8

In Example 4 we showed that class A has 2^{31} 2,147,483,648) addresses. How can we prove this same fact using dotted-decimal notation?

Solution

The addresses in class A range from 0.0.0.0 to 127.255.255.255. We notice that we are dealing with base 256 numbers here.

Solution (Continued)

Each byte in the notation has a weight. The weights are as follows: 256^3 , 256^2, 256^1, 256^0

Last address: $127 \times 256^3 + 255 \times 256^2 + 255 \times 256^1 + 255 \times 256^0 = 2{,}147{,}483{,}647$

First address: $= 0$

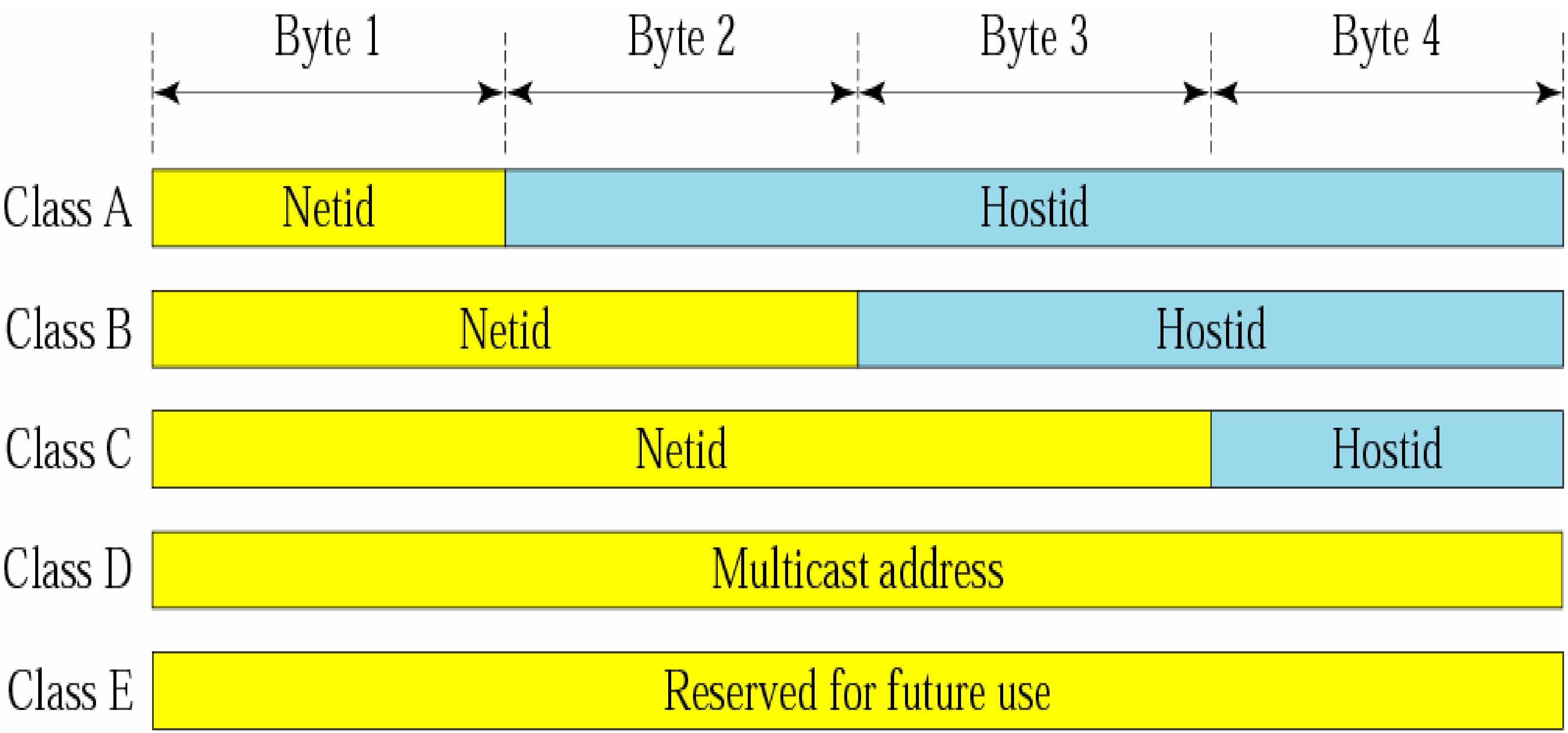
If we subtract the first from the last and add 1, we get 2,147,483,648.

Netid and Hostid

- An IP address in classes A, B, C is divided into
  - ***Netid***
  - ***Hostid***

- Notably, classes D and E are not divided into netid and hostid

Netid and Hostid



Classes and Blocks

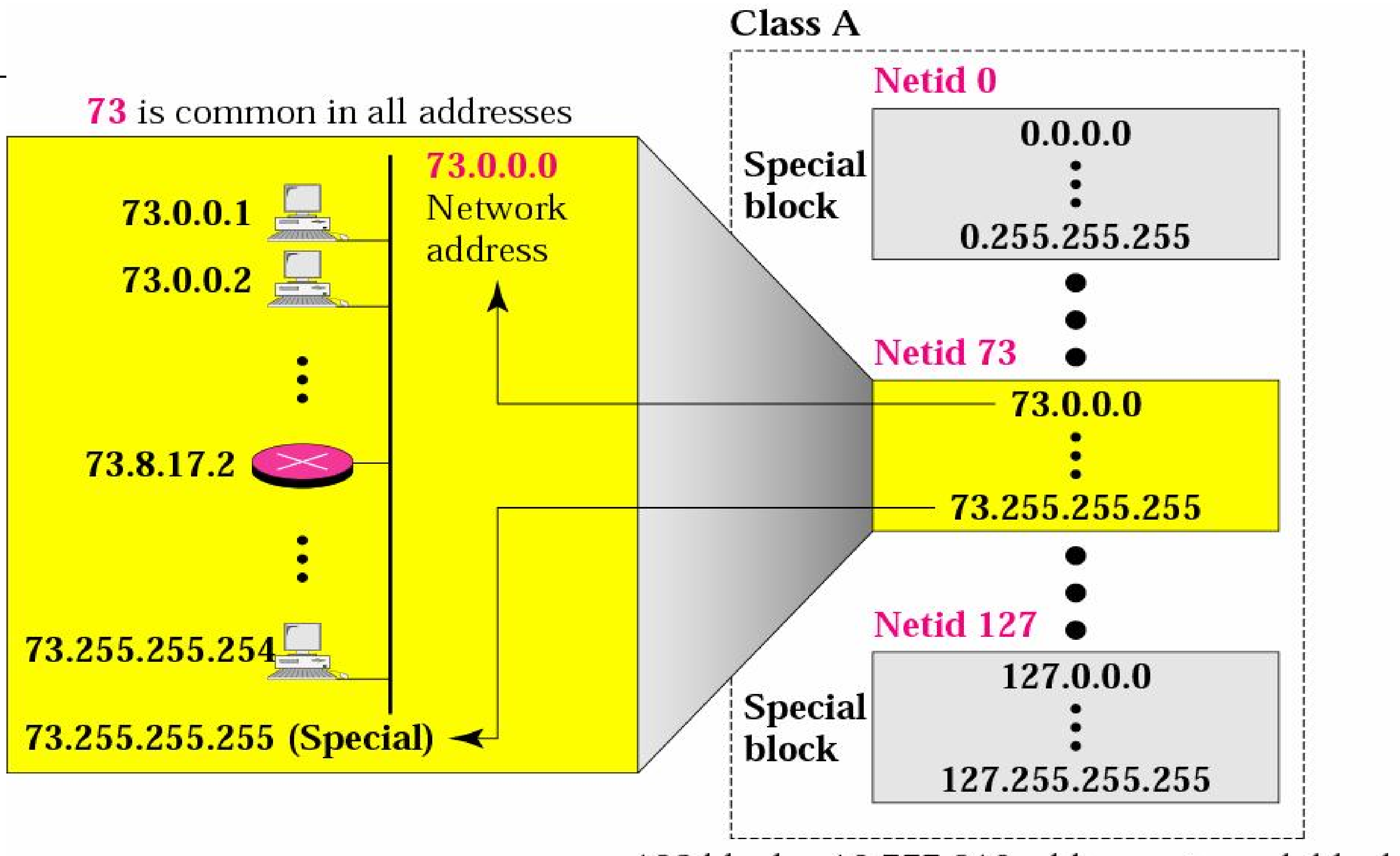
- Each class is divided into a fixed number of blocks with each block having a fixed size
- The number of blocks is based on the ***netid***
- Each block's size is depends on the ***hostid***

Class A

- Class A: divided into 128 blocks
  - First block: **0**.0.0.0 ~ **0**.255.255.255
  - ….
  - Last block: **127**.0.0.0 ~ **127**.255.255.255
- Each block contains 16777216 addresses
  - Too large than the needs of almost all organizations
- In each block, the first address, e.g., 73.0.0.0, is called the network address
  - Identify the network of the organization, not individual hosts

Figure 4.7

Blocks in Class A



128 blocks: 16,777,216 addresses in each block

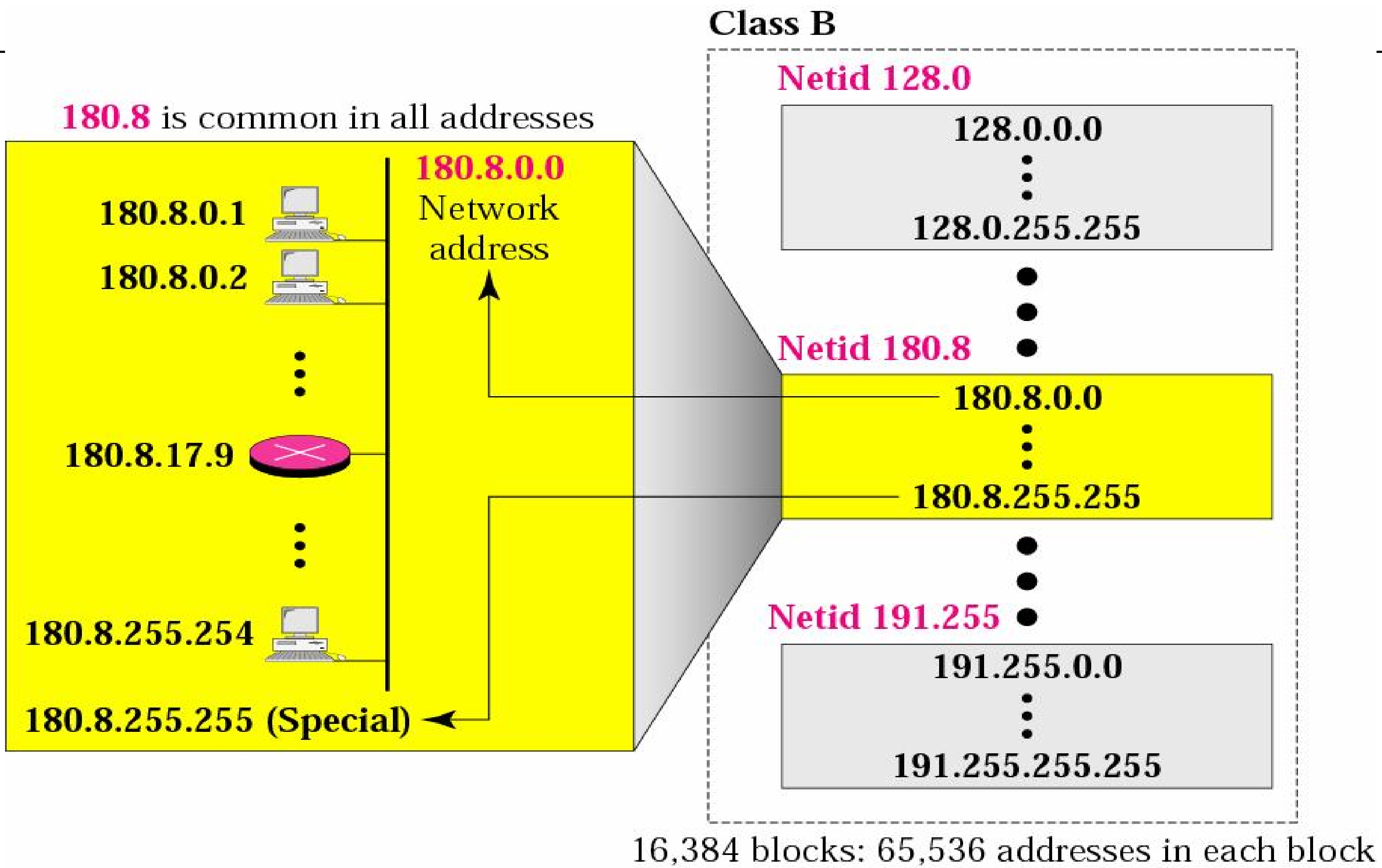
Note

Millions of class A addresses are wasted.

Class B

- Class B: divided into 16,384 blocks
  - First block: **128.0**.0.0 ~ **128.0**.255.255
  - ….
  - Last block: **191.255**.0.0 ~ **191.255**.255.255
- Each block contains 65,535 addresses
  - larger than the needs of most mid-size organizations
- In each block, the first address, e.g., 180.8.0.0, is called the network address
  - Identify the network of the organization, not individual hosts

Blocks in Class B



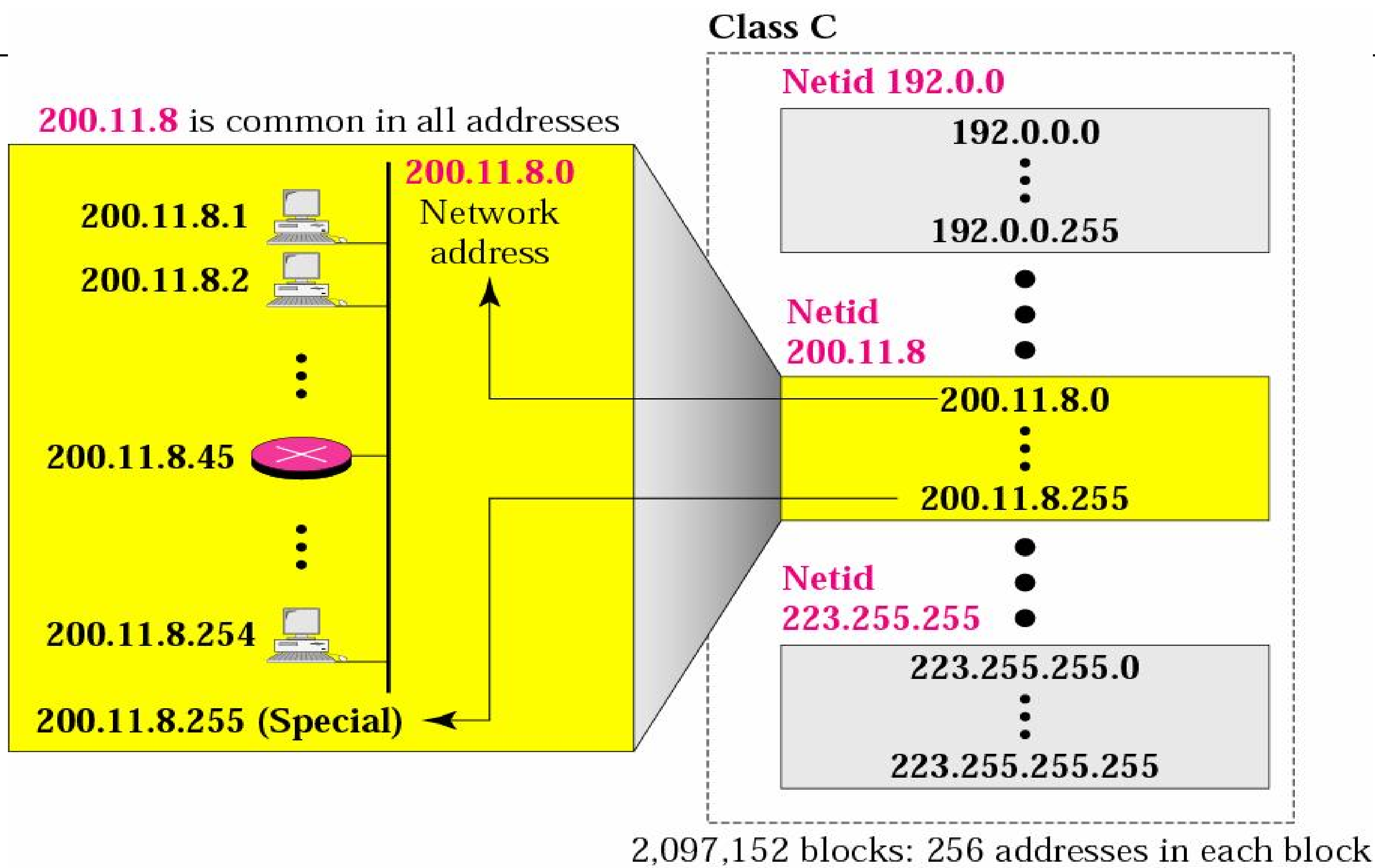
Note

Many class B addresses are wasted.

Class C

- Class C: divided into 2.097,152 blocks
  - First block: **192.0.0**.0 ~ **192.0.0**.255
  - ….
  - Last block: **223.255.255**.0 ~ **223.255.255**.255
- Each block contains 256 addresses
  - Most organizations do not want such a block
- In each block, the first address, e.g., 200.11.8.0, is called the network address
  - Identify the network of the organization, not individual hosts

Blocks in Class C



Note

The number of addresses in a class C block is smaller than the needs of most organizations.

Class D and Class E

- Class D
  - Just one block
  - Designed for multicasting and each address is used to identify one multicasting group
- Class E
  - Just one block
  - Designed for use as reserved addresses

Note

Class D addresses are used for multicasting; there is only one block in this class.

Note

Class E addresses are reserved for special purposes; most of the block is wasted.

Network Addresses

The network address is the first address.

The network address defines the network to the rest of the Internet. Routers route a packet based on the network address.

Given the network address, we can find the class of the address, the block, and the range of the addresses in the block

Note

In classful addressing,
the network address
(the first address in the block)
is the one that is assigned
to the organization.

Example 9

Given the network address 17.0.0.0, find the class, the block, and the range of the addresses.

Solution

The class is A because the first byte is between 0 and 127. The block has a netid of 17. The addresses range from 17.0.0.0 to 17.255.255.255.

Example 10

Given the network address 132.21.0.0, find the class, the block, and the range of the addresses.

Solution

The class is B because the first byte is between 128 and 191. The block has a netid of 132.21. The addresses range from 132.21.0.0 to 132.21.255.255.

Example 11

Given the network address 220.34.76.0, find the class, the block, and the range of the addresses.

Solution

The class is C because the first byte is between 192 and 223. The block has a netid of 220.34.76. The addresses range from 220.34.76.0 to 220.34.76.255.

Mask

- If the network address is given
  - We can obtain the block and block size
- However, if an address is given, how to find out the ***network address***?
  - First, find the *class* of the address
  - Second, derive the *netid* and *hostid*
  - Finally, network address is obtained *by setting the hostid to zero.*

Mask

A mask is a 32-bit binary number that gives the first address in the block (the network address) when bitwise ANDed with an address in the block.

Figure 4-10

Masking concept

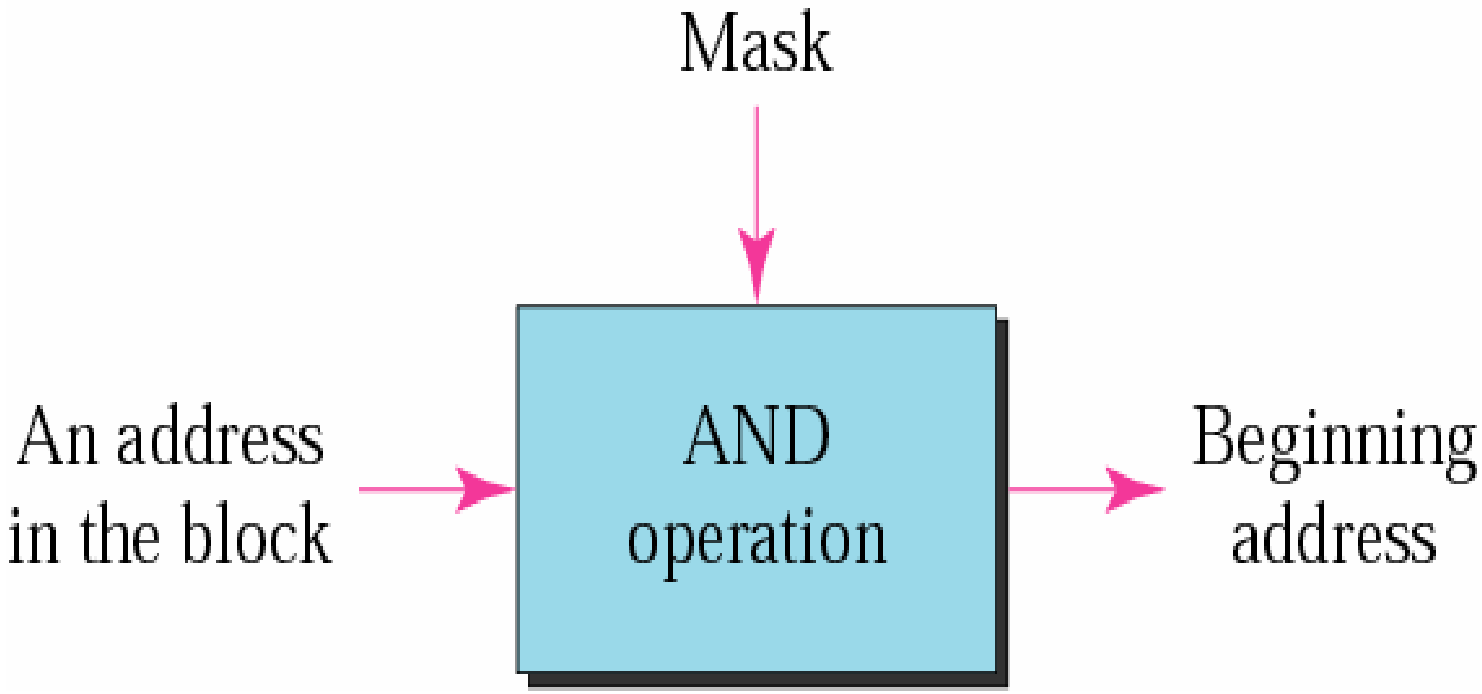
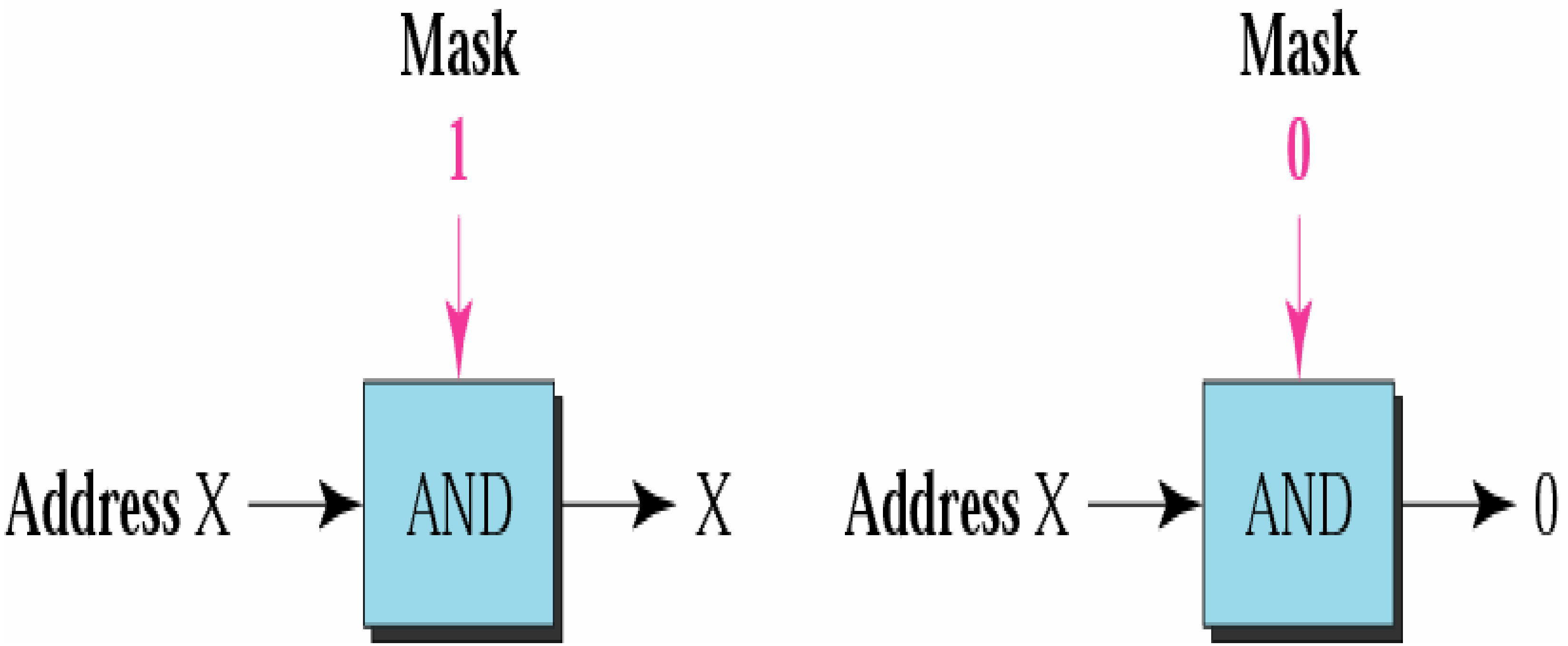


Figure 4.11

AND operation



Default Masks

- Class A
  - Mask in binary: **1111111** 00000000 00000000 00000000
  - Mask in dotted-decimal: **255.**0.0.0
- Class B
  - Mask in binary: **11111111 11111111** 00000000 00000000
  - Mask in dotted-decimal: **255.255.**0.0
- Class C
  - Mask in binary: **11111111 11111111 11111111** 00000000
  - Mask in dotted-decimal: **255.255.255.**0

Note

The network address is the beginning address of each block. It can be found by applying the default mask to any of the addresses in the block (including itself). It retains the netid of the block and sets the hostid to zero.

Example 12

Given the address 23.56.7.91 and the default class A mask, find the beginning address (network address).

Solution

The default mask is 255.0.0.0, which means that only the first byte is preserved and the other 3 bytes are set to 0s. The network address is 23.0.0.0.

Example 13

Given the address 132.6.17.85 and the default class B mask, find the beginning address (network address).

Solution

The default mask is 255.255.0.0, which means that the first 2 bytes are preserved and the other 2 bytes are set to 0s.

The network address is 132.6.0.0.

Example 14

Given the address 201.180.56.5 and the class C default mask, find the beginning address (network address).

Solution

The default mask is 255.255.255.0, which means that the first 3 bytes are preserved and the last byte is set to 0. The network address is 201.180.56.0.

CIDR Notation

- It is convenient to explicitly indicate the default mask
- CIDR (classless interdomain routing)
  - The number of 1s in the mask is added after a slash at the end of the address
- Example:
  - Address 18.46.74.10, class A
  - CIDR notation: 18.46.74.10/8
    - Show that there are eight bits in the mask
- CIDR is particular used in classless addressing

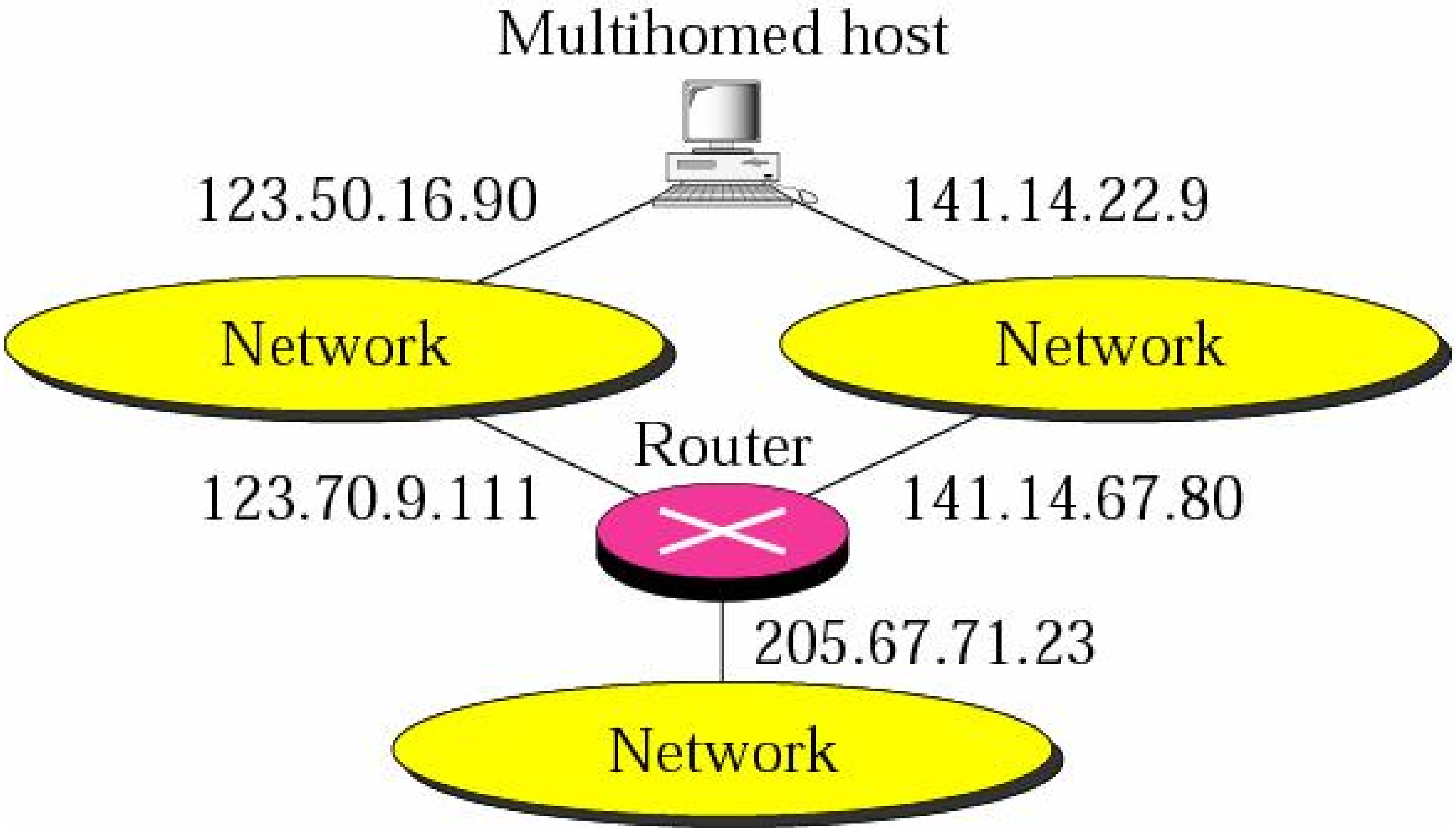
4.13

OTHER ISSUES

Multihomed Devices

- A computer that is connected to different networks is called a ***multihomed*** computer
  - Have more than one address
  - Each possibly belonging to a different class

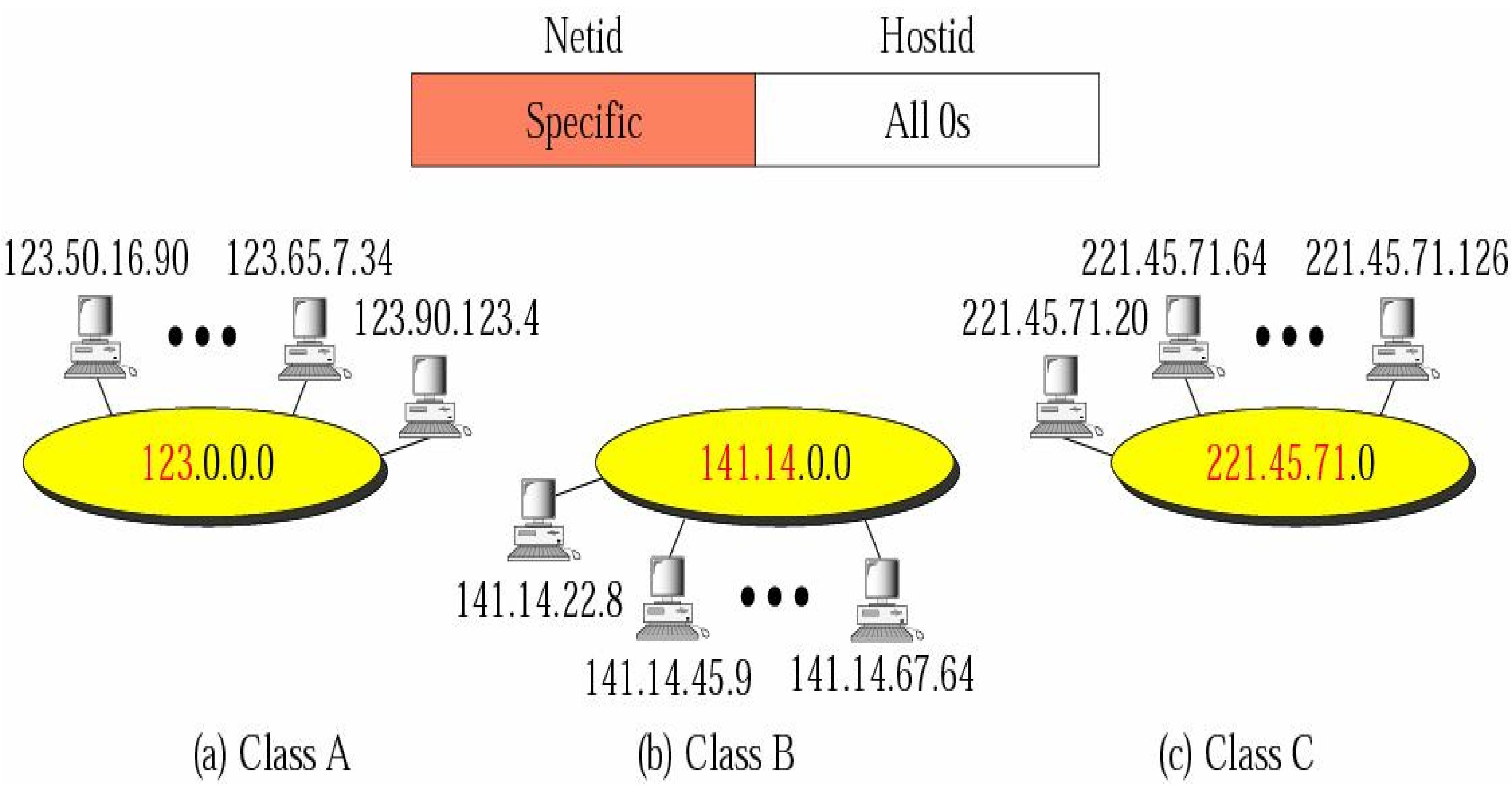
Multihomed Devices



Special Addresses

Special Address	*Netid*	*Hostid*	*Source or Destination*
Network address	Specific	All 0s	None
Direct broadcast address	Specific	All 1s	Destination
Limited broadcast address	All 1s	All 1s	Destination
This host on this network	All 0s	All 0s	Source
Specific host on this network	All 0s	Specific	Destination
Loopback address	127	Any	Destination

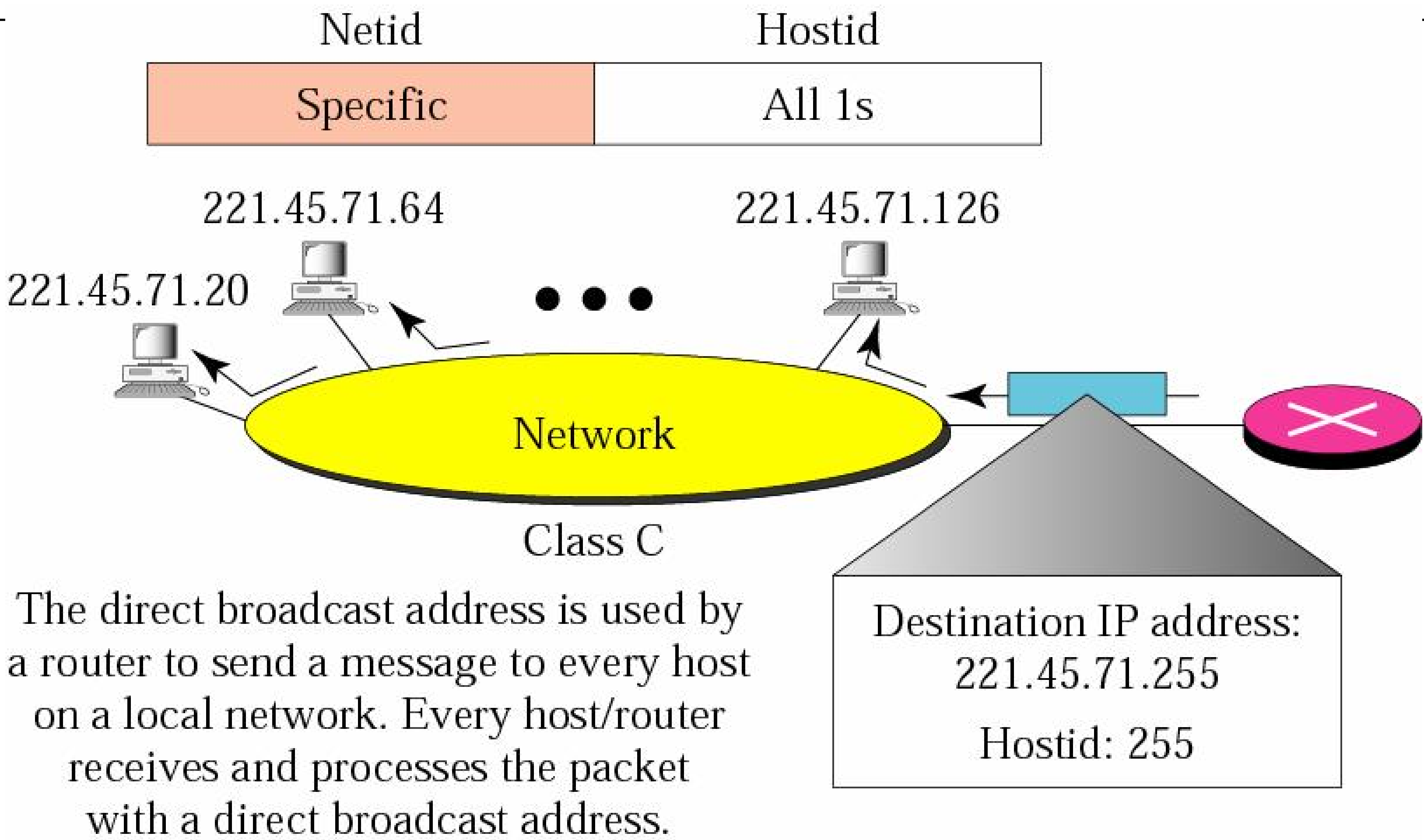
Network Addresses



Direct Broadcast Address

- The *hostid* is all *1s* in classes A, B, and C
- Used by a router to send a packet to all hosts in a specific network
- Can only be used as a destination address

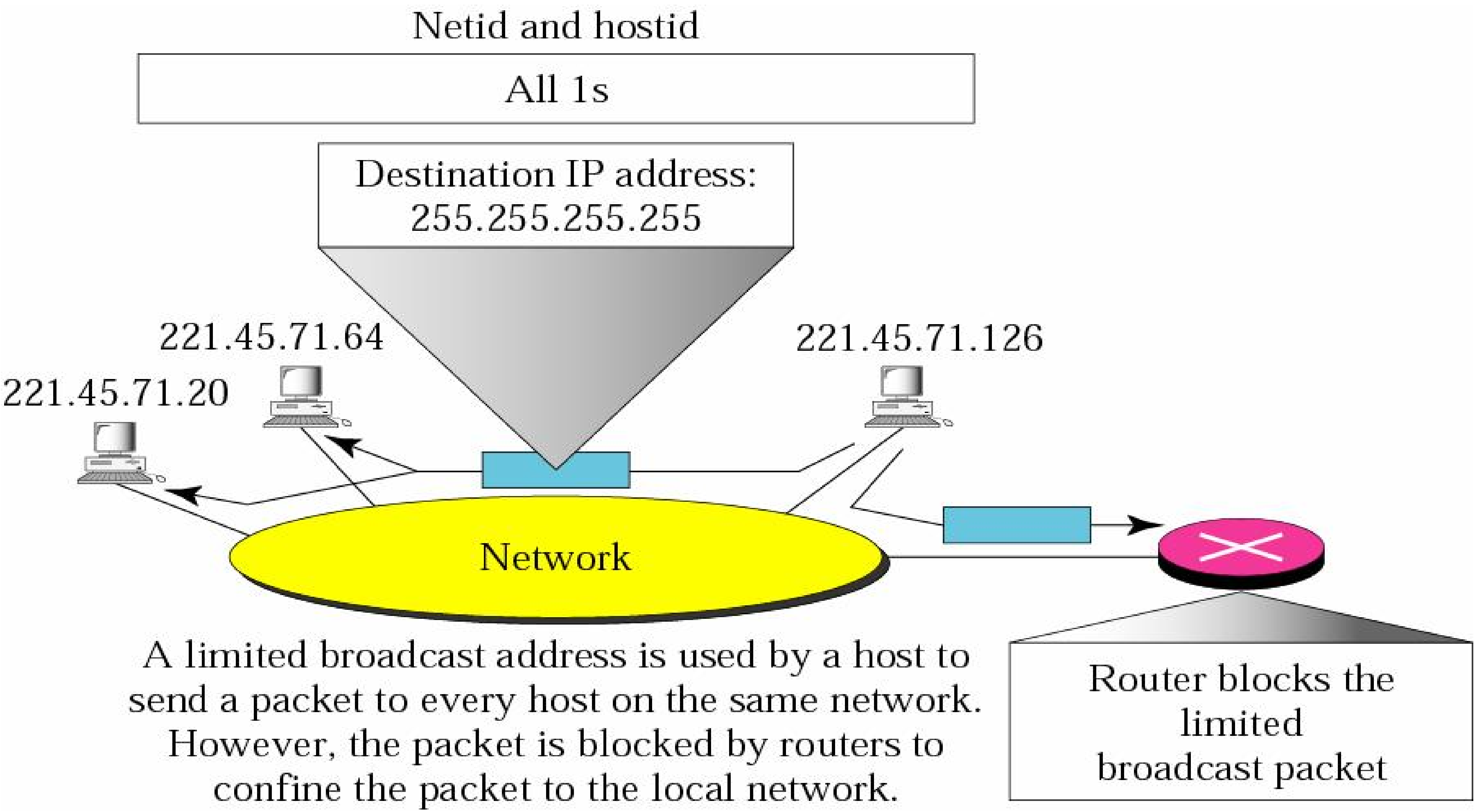
Example of Direct Broadcast Address



Limited Broadcast Address

- An address with all *1s* for the *netid* and *hostid* in classes A, B, and C
- Used by a host to send a packet to every other host in a network
- Routers will block a packet having this type of address to other networks
- Limited broadcast address belongs to class E

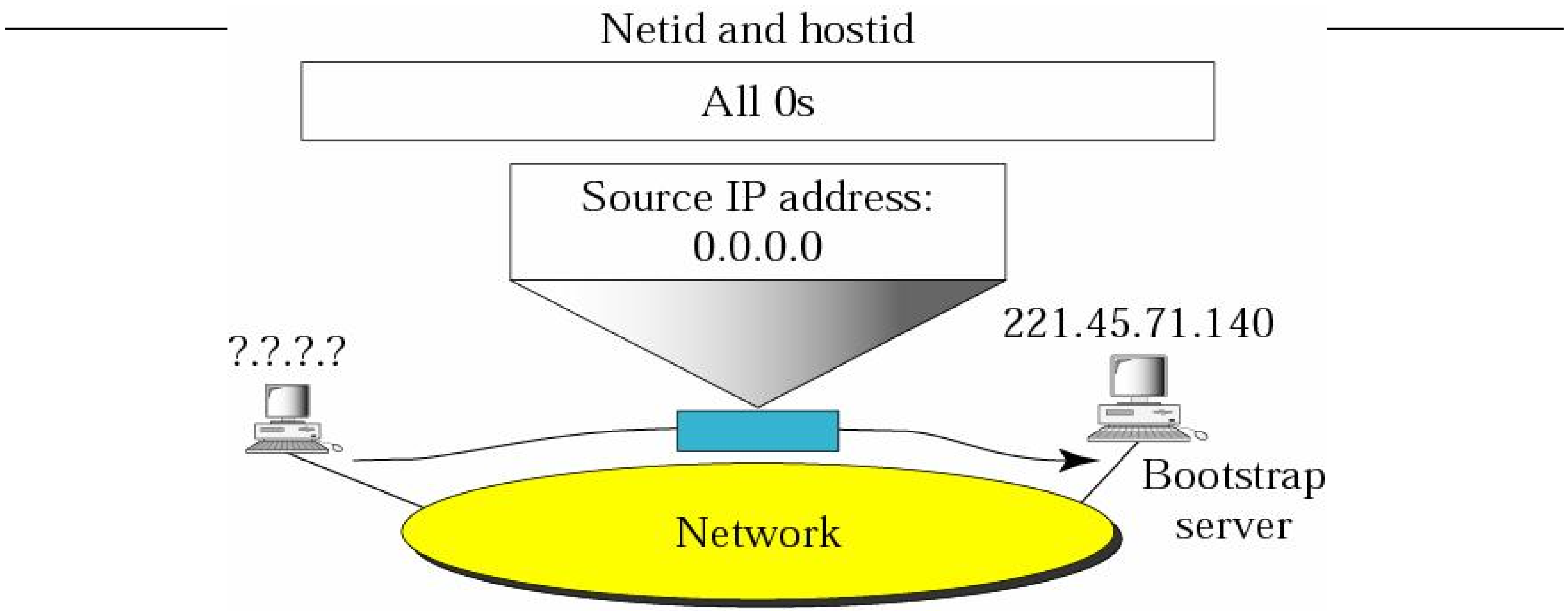
Example of Limited Broadcast Address



This Host on This Network

- An IP address is composed of all 0s
- Used by a host at bootstrap time when it does not know its IP address
  - Source address: all 0s
  - Destination address: limited broadcast address

Example of This Host on This Network



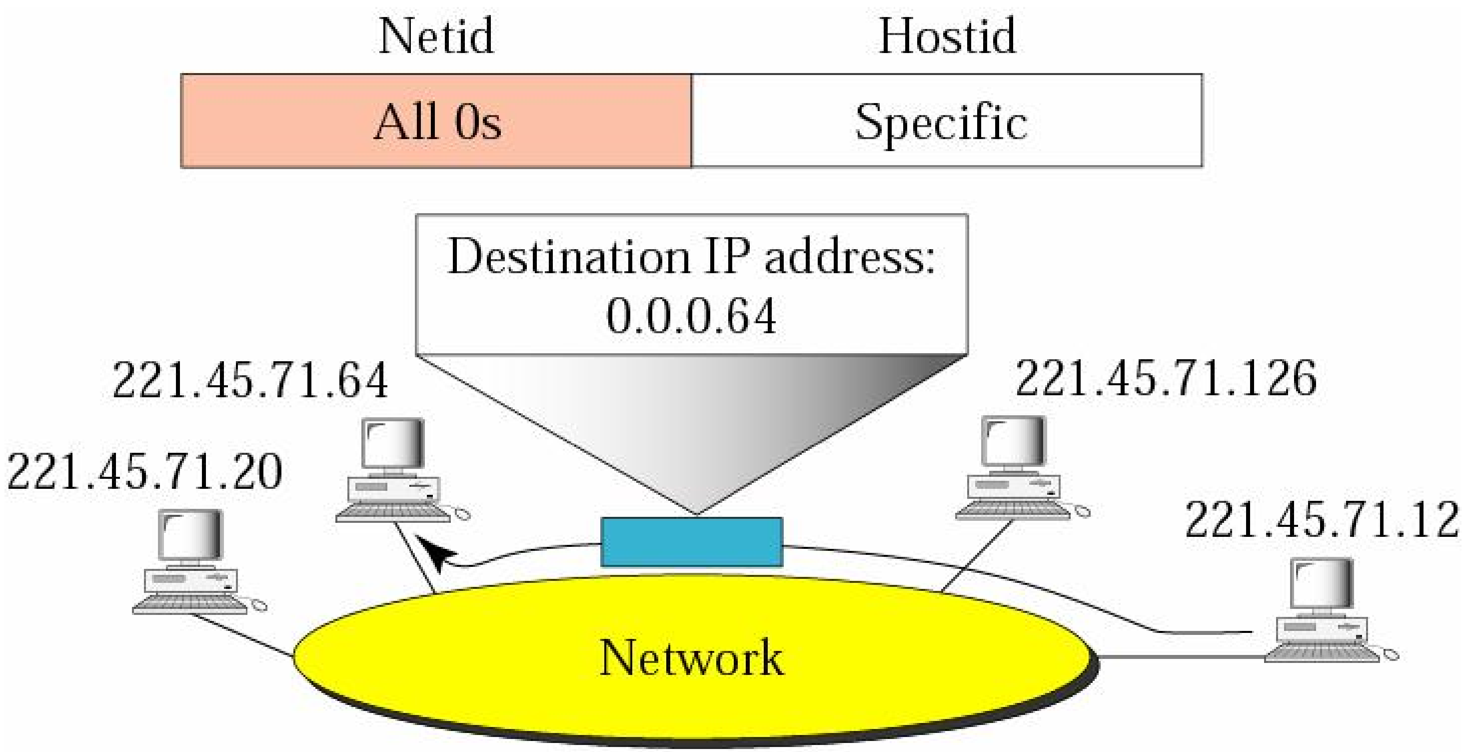
A host that does not know its IP address uses the IP address 0.0.0.0 as the source address and 255.255.255.255 as the destination address to send a message to a bootstrap server.

Specific Host on This Network

- An IP address with a *netid* of all *0s*
- Used by a router or host to send a packet to another host *on the same network*
- Router will block this packet to other networks
- Only used for a destination address

Figure 4.17

Example of Specific Host on This Network



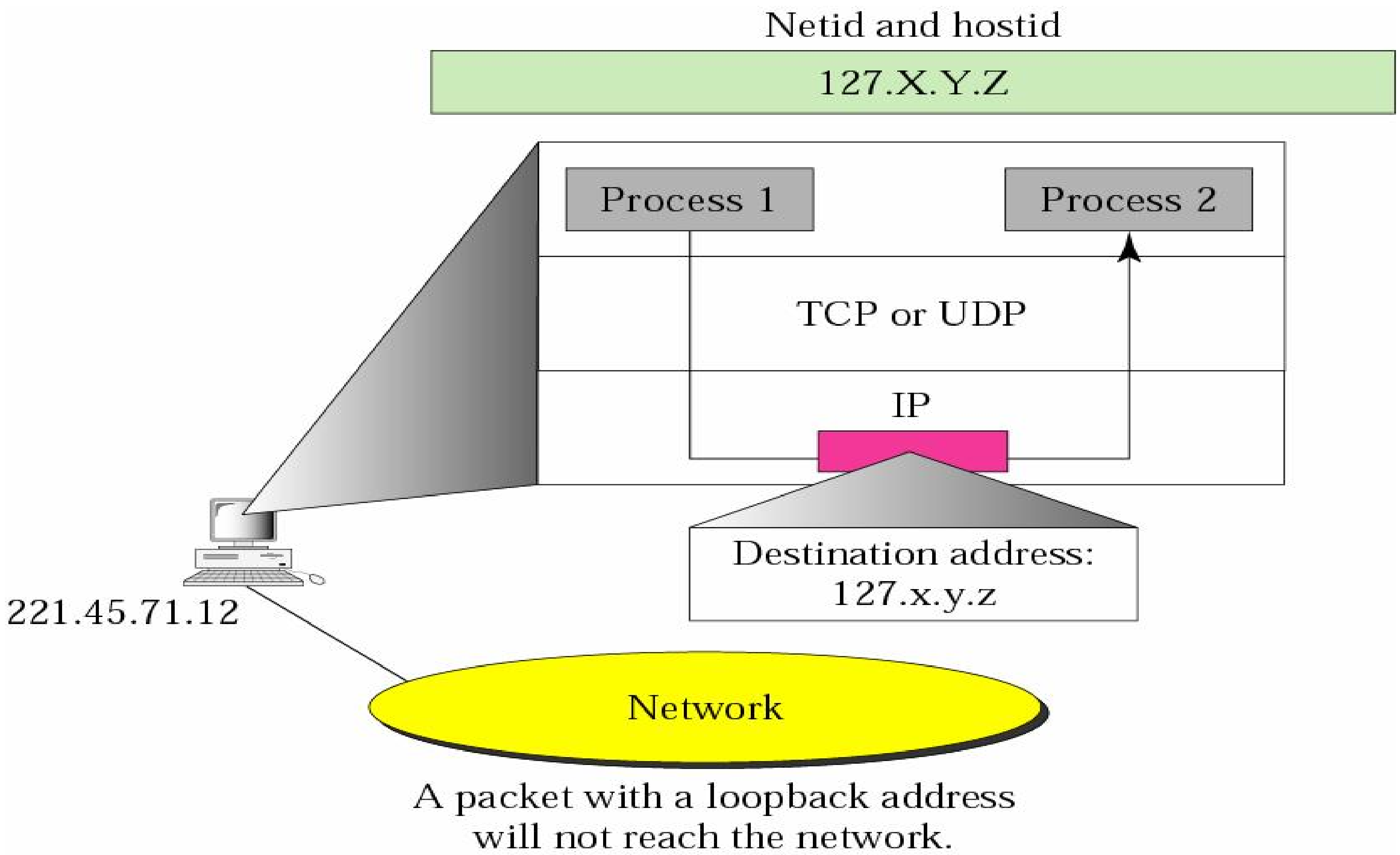
This address is used by a router or host
to send a message to a specific host on the same network.

Loopback Address

- An IP address with the first byte equal to 127
- This packet never leaves the machine
- Used only as a destination address

Figure 4-18

Example of Loopback Address



Private Addresses

- A number of blocks in each class are assigned for private use and not recognized globally.
- Used in
  - Isolation
  - In connection with network address translation

Class	*Netid*	*Blocks*
A	10.0.0	1
B	172.16 to 172.31	16
C	192.168.0 to 192.168.255	256

Unicast, Multicast, and Broadcast Addresses

Unicast communication is *one-to-one*.

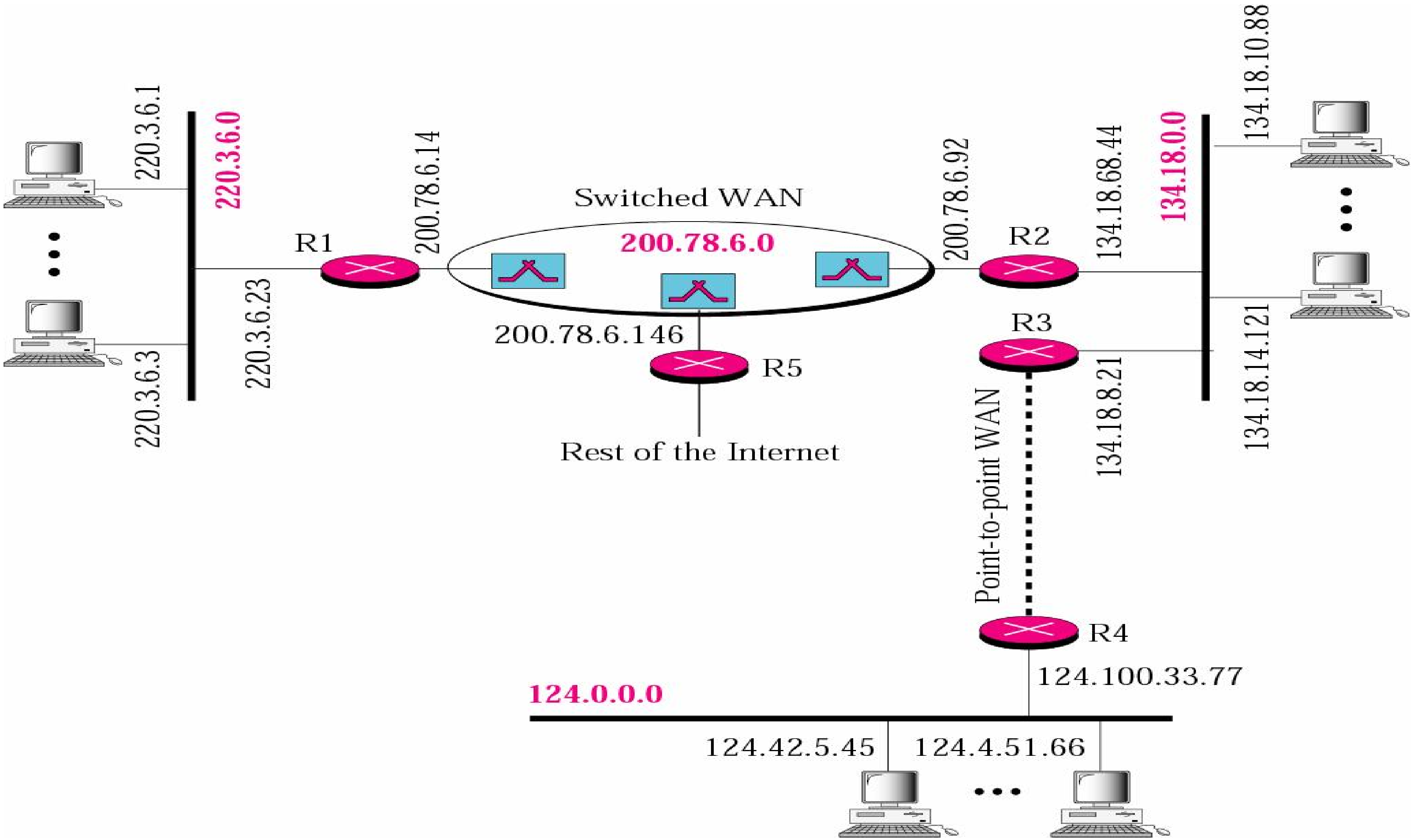
Multicast communication is *one-to-many*.

Broadcast communication is *one-to-all*.

Example: Sample internet

- A LAN: 220.3.6.0: Class C
- An LAN: 134.18.0.0: Class B
- An LAN: 124.0.0.0: Class A
- A point-to-point WAN, for example a T-1 line
  - Just connect two routers and no hosts
  - To save addresses, no IP address is assigned
- A switch WAN, e.g., Frame Relay or ATM
  - Connect to three network via three routers

Sample internet



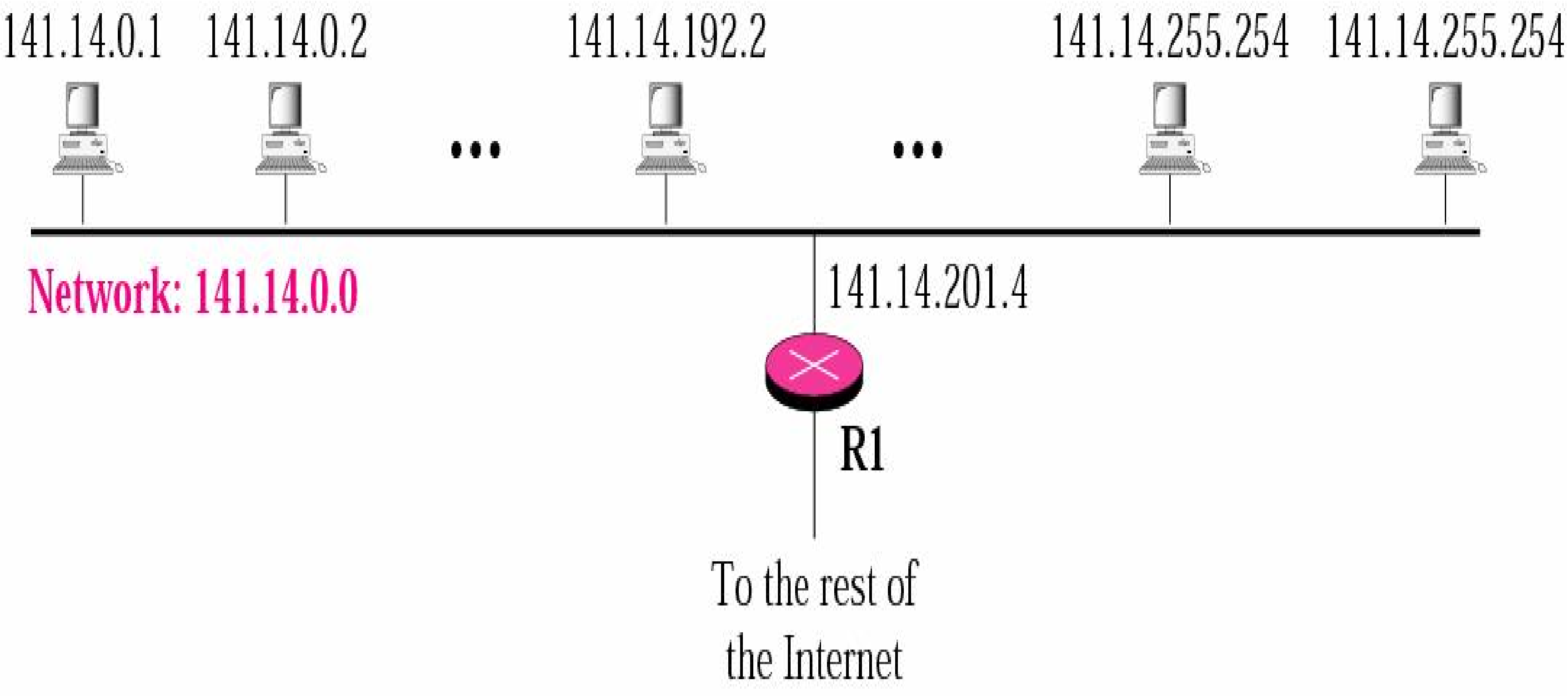
4.4

SUBNETTING AND SUPERNETTING

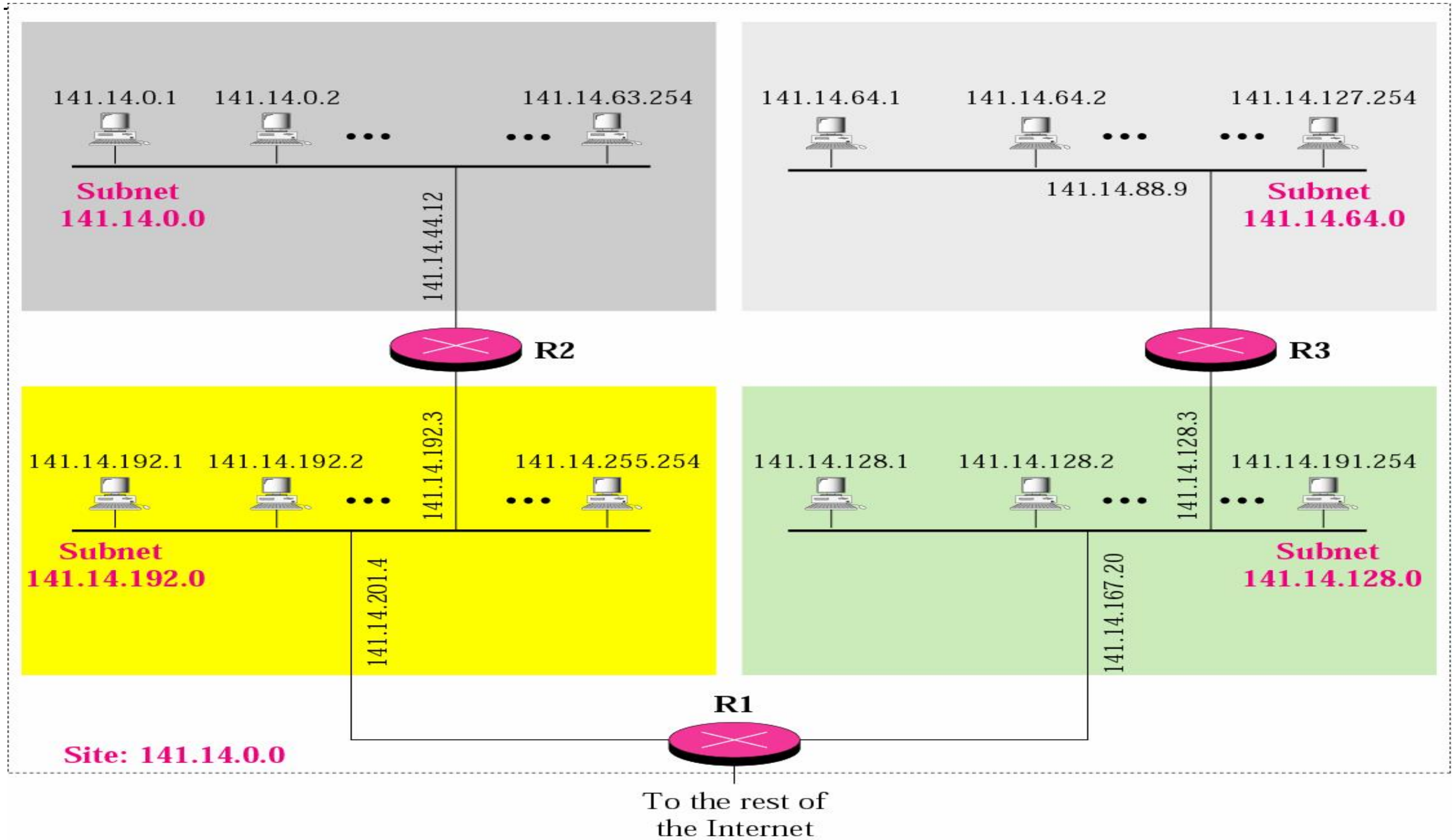
Subnetting

- IP addresses are designed with two level of hierarchy
  - Two levels of hierarchy is not enough
- Solution: ***subnetting***
  - A network is divided into several smaller networks
  - Each smaller network is called a *subnetwork* or a *subnet*

A Network with Two Levels of Hierarchy (not Subnetted)



A Network with Three Levels of Hierarchy (Subnetted)



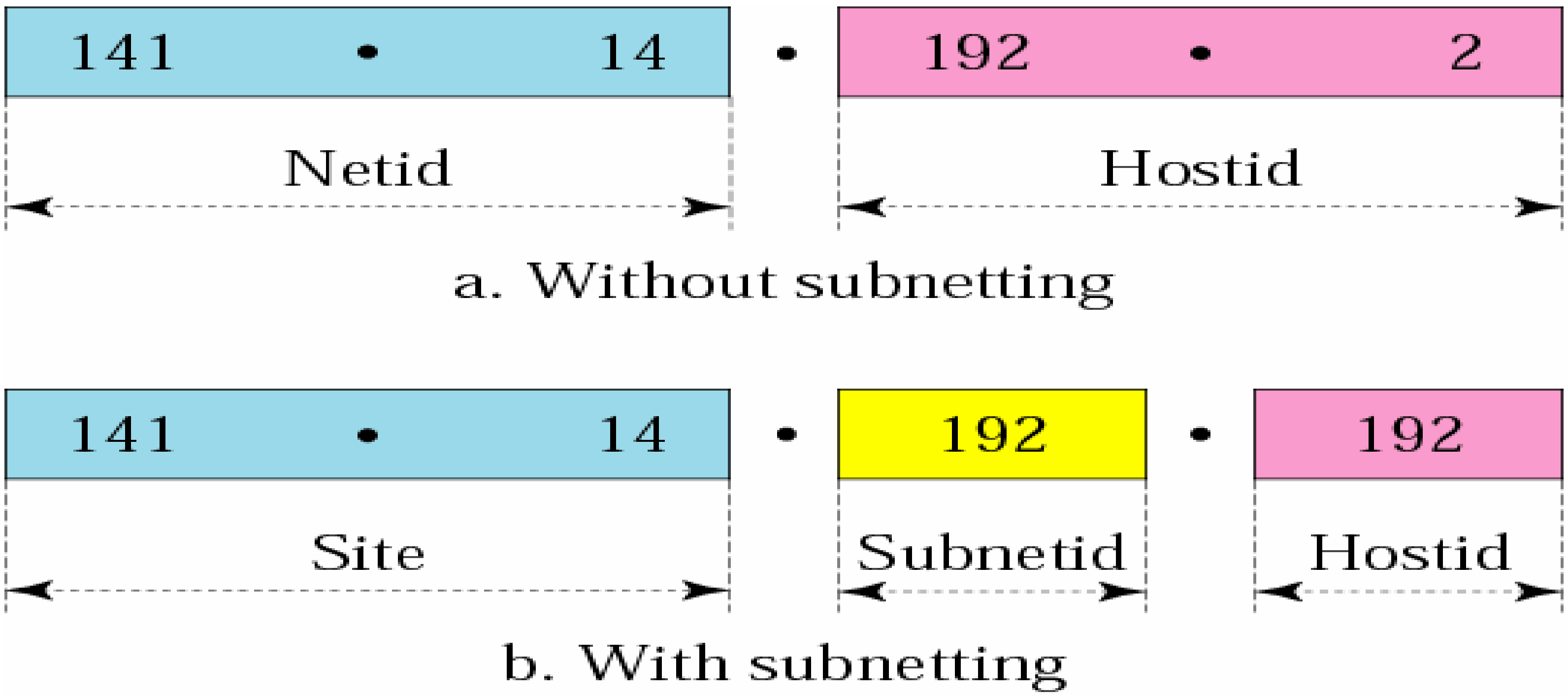
Subnetting (Cont.)

- The subnetworks still appear as a single network to the rest of the Internet
- For example, a packet destined for host 141.14.192.2 still reaches router R1
- However, R1 knows the network 141.14 is physically divided into subnetworks
  - It deliver the packet to subnetwork 141.14.192.0

Three Levels of Hierarchy

- Three levels
  - Site, subnet, and host
- The routing of an IP datagram now involves three steps
  - Delivery to the *site*
  - Delivery to the *subnetwork*
  - Delivery to the *host*

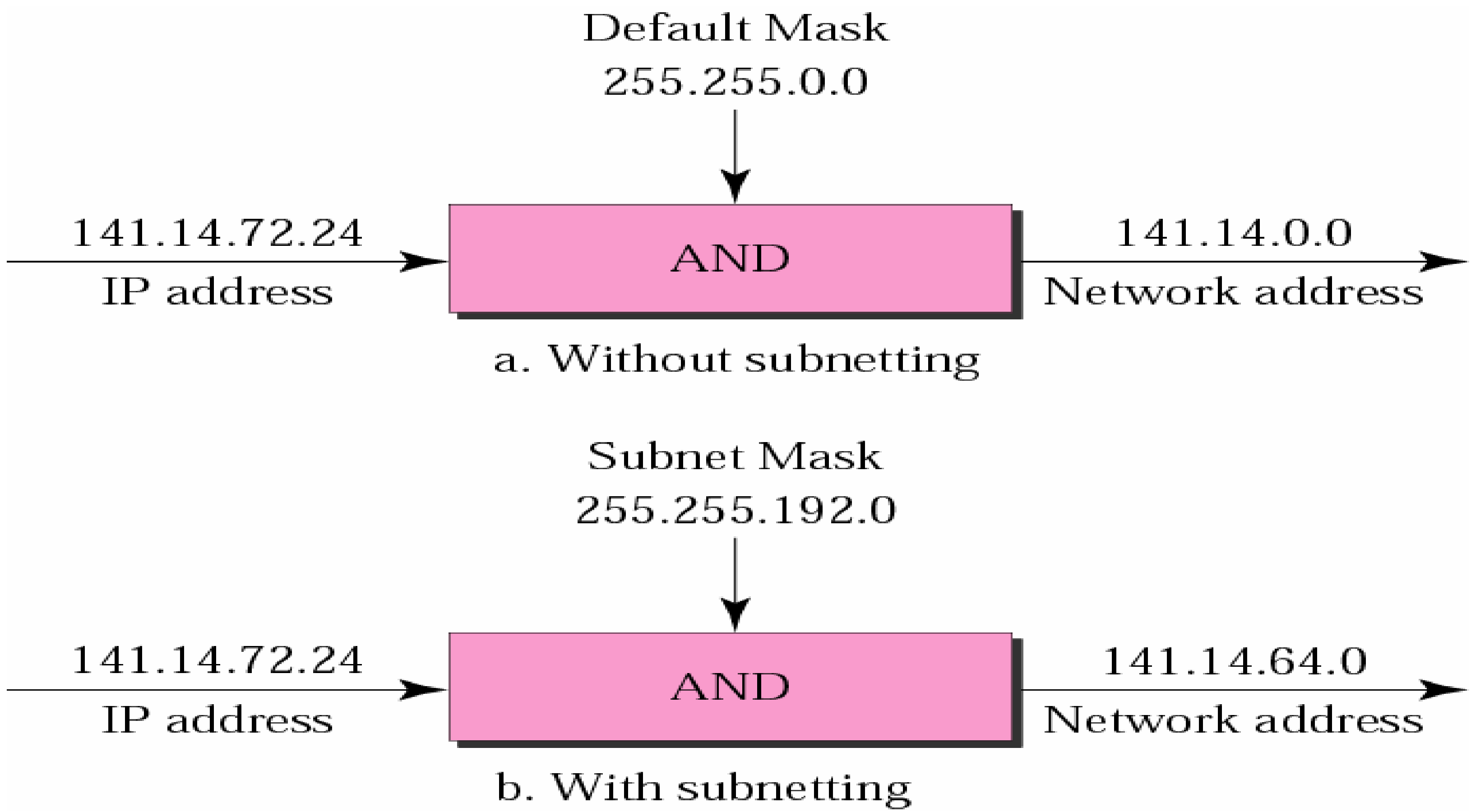
Addresses in a Network with and without Subnetting



Subnet Mask

- The network mask create the network address
- The subnet mask create the subnetwork address
- Subnet Mask
  - Noncontiguous: a mixture of 0s and 1s
    - Out-of-day
  - Contiguous: a run of 1s followed by a run of 0s
    - In use

Default Mask and Subnet Mask



Finding the Subnet Address

- Given an IP address, we can find the *subnet address* in the same way as we found the *network address*
  - Apply the mask to the address

Example 15

What is the subnetwork address if the destination address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Solution

11001000 00101101 00100010 00111000

11111111 11111111 1111**0000** **00000000**

11001000 00101101 0010**0000** **00000000**

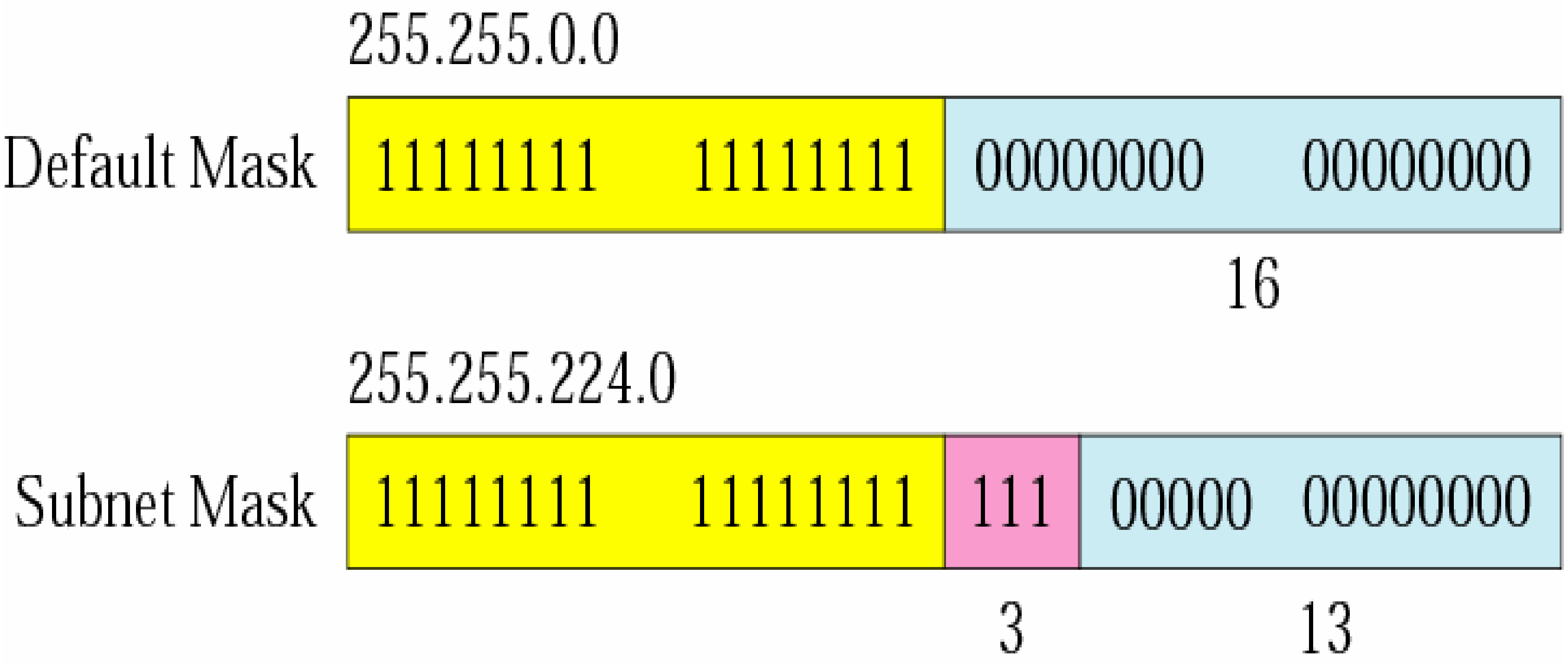
The subnetwork address is **200.45.32.0**.

Default Mask and Subnet Mask

- The number of *1s* in a default mask is perdetermined
  - 8, 16, or 24

- But, in a subnet mask, the number of 1s is more than the number of 1s in the corresponding default mask

Comparison of a Default Mask and a Subnet Mask



Number of Subnetworks

- Found by counting the number of extra bits that are added to the default mask in a subnet mask

- For example, in above figure
  - The number of extra 1s is 3
    - The length of subnetid = 3
  - The number of subnets is 2^3 = 8

Number of Addresses per Subnet

- Found by counting the number of *0s* in the subnet mask

- For example, in above figure
  - The number of 0s is 13
    - The length of hostid = 13
  - The number of addresses in each subnet is 2^13 = 8192

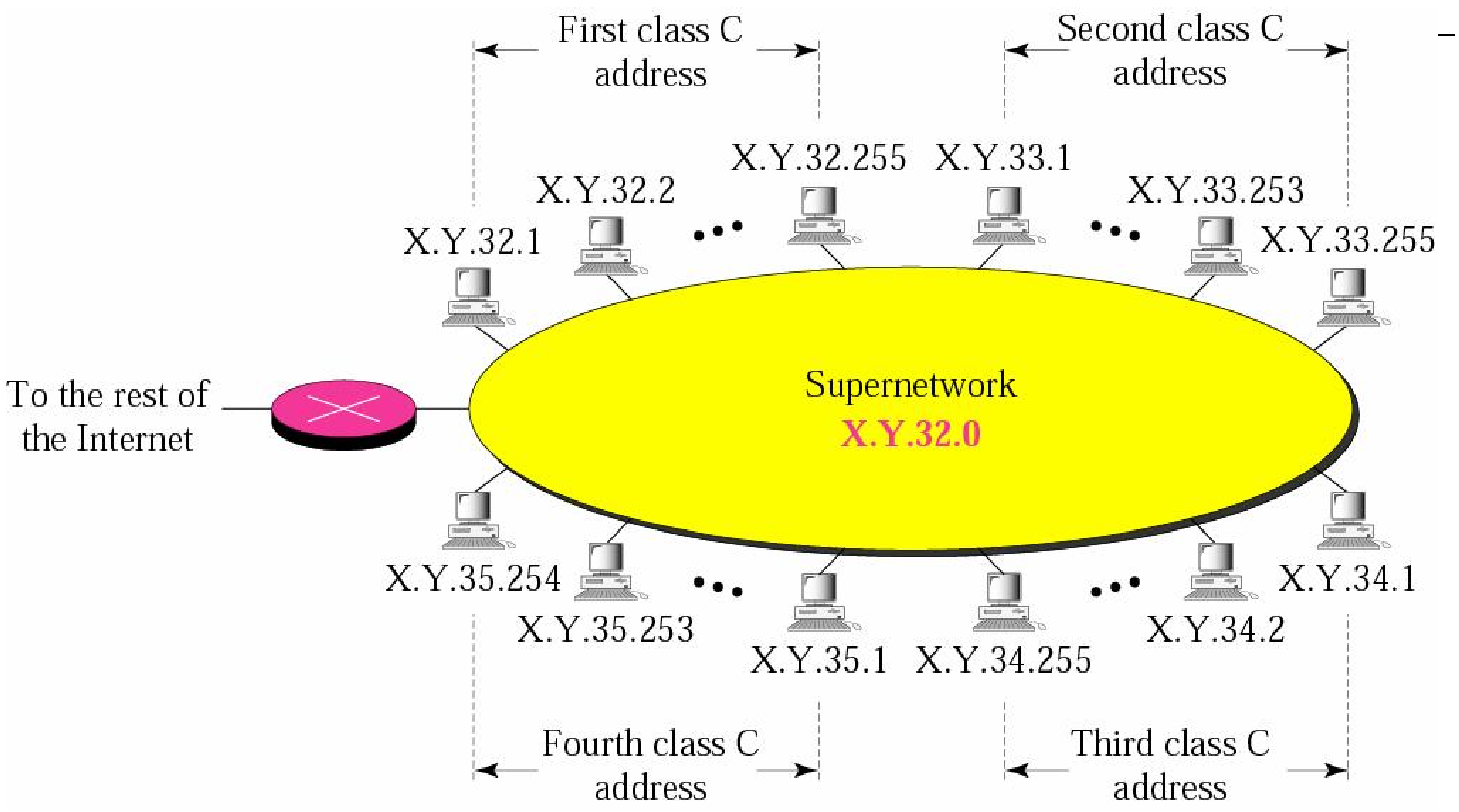
CIDR Notation

- An address in a subnet can be easily defined using CIDR notation
- Example:
  - Address: 141.14.192.3/16
    - A class B address
  - Address: 141.14.192.3/18
    - The address belongs to the subnet with mask 255.255.192.0

Supernetting

- Class A and B addresses are almost depleted. However, class C addresses are still available
- But, the size of class block, 256, is too small
- Solution: ***supernetting***
  - Combine several class C blocks to create a larger range of addresses

A Supernetwork



Supernet Mask

- In original block of addresses, we know the range of addresses from the first address
  - Since the mask is perdefined (default mask)

- In subnetting or supernetting, the first address alone cannot derive the range of addresses
  - We need to know the *mask*, subnet mask or supernet mask, as well.

Note

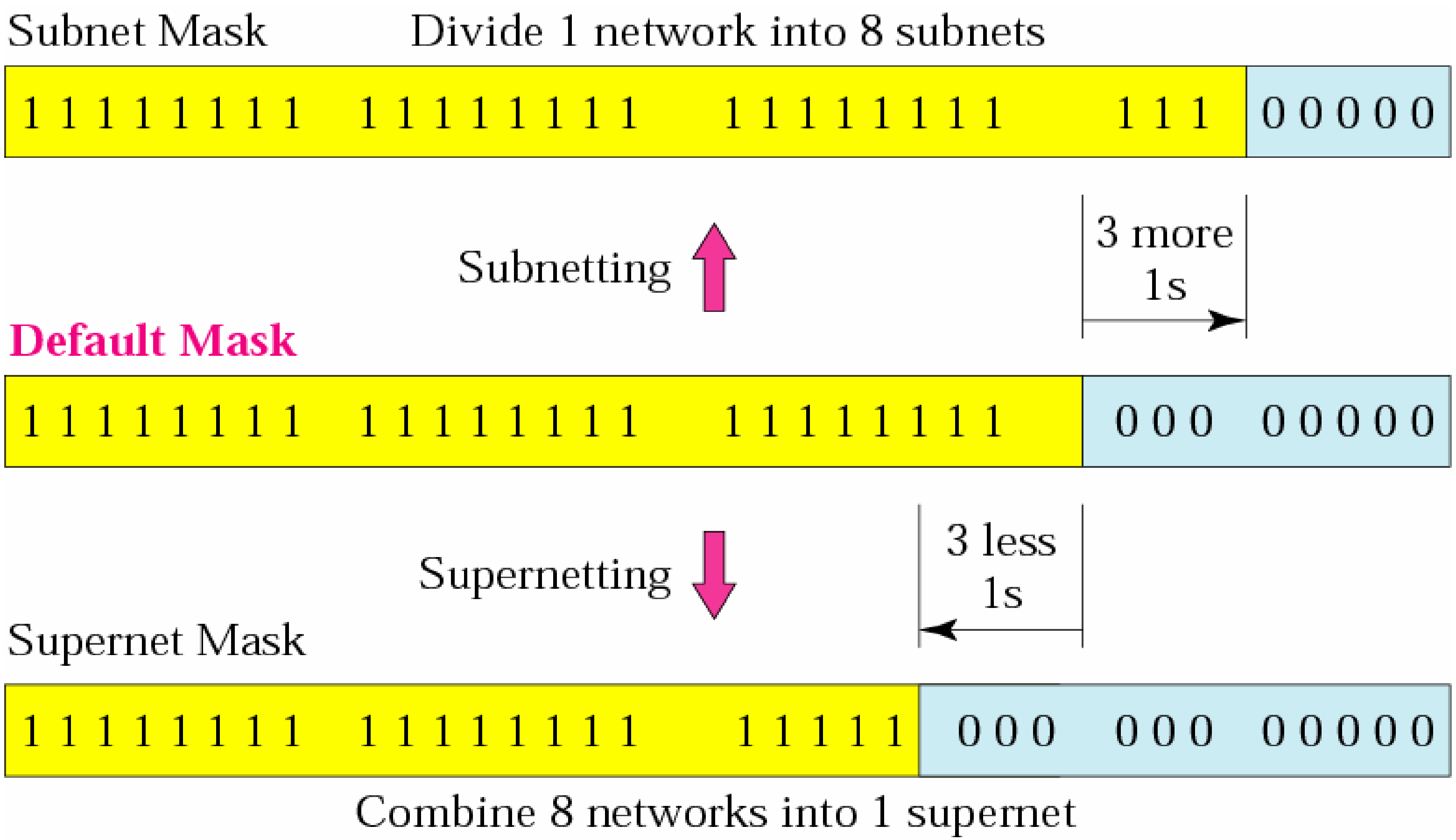
In subnetting, we need the first address of the subnet and the subnet mask to define the range of addresses.

In supernetting, we need the first address of the supernet and the supernet mask to define the range of addresses.

Supernet Mask (Cont.)

- A supernet mask is the reverse of a subnet mask
  - A subnet mask has more 1s than the default mask
  - A supernet mask has less 1s than the default mask

Comparison of Subnet, Default, and Supernet Masks



Obsolescence

- With the advent of classless addressing
  - The idea of subnetting and supernetting of classful addressing is almost obsolete