

Chapter 5
IPv4 Address



5.1 Introduction

- ❑ Identifier of each device connected to the Internet : IP Address
- ❑ IPv4 Address : 32 bits
 - ◆ The address space of IPv4 is 2^{32} or 4,294,967,296
- ❑ The IPv4 addresses are unique and universal
 - ◆ Two devices on the Internet can never have the same address at same time
- ❑ Number in base 2, 16, and 256
 - ◆ Refer to Appendix B

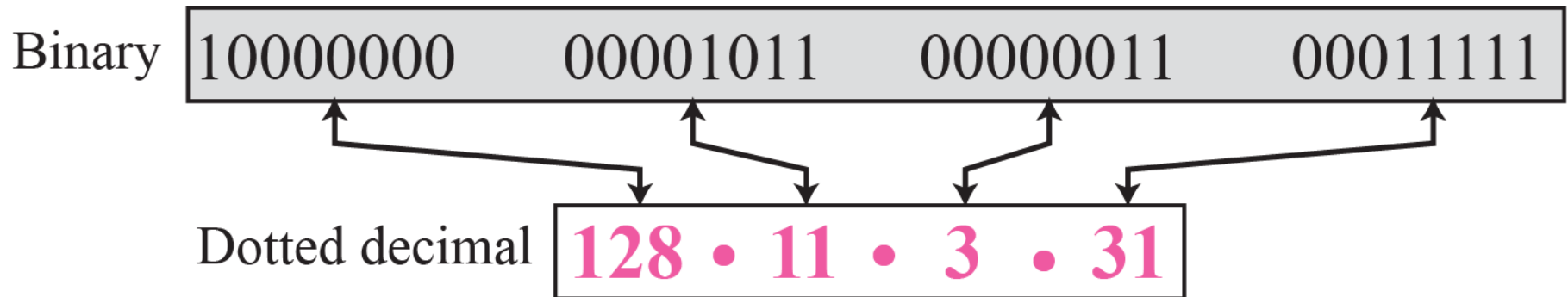
Binary Notation and Dotted-Decimal Notation

❑ Binary notation

01110101 10010101 00011101 11101010

32 bit address, or a 4 octet address or a 4-byte address

❑ Decimal point notation



Notation (cont'd)

□ Hexadecimal Notation

0111 0101 1001 0101 0001 1101 1110 1010

75

95

1D

EA

0x75951DEA

- 8 hexadecimal digits
- Used in network programming



Example 5.1

❑ Change the following IPv4 addresses from binary notation to dotted-decimal notation

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

c. 11100111 11011011 10001011 01101111

d. 11111001 10011011 11111011 00001111

❑ Solution

- ◆ We replace each group of 8 bits with its equivalent decimal number (see Appendix B) and add dots for separation.

a. 129.11.11.239

b. 193.131.27.255

c. 231.219.139.111

d. 249.155.251.15



Example 5.4

❑ Change the following IPv4 address in hexadecimal notation.

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

❑ Solution

- ◆ We replace each group of 4 bits with its hexadecimal equivalent. Note that hexadecimal notation normally has no added spaces or dots; however, 0x is added at the beginning of the subscript 16 at the end

a. 0X810B0BEF or 810B0BEF16

b. 0XC1831BFF or C1831BFF16

Example 5.5

❑ Find the number of addresses in a range if the first address is 146.102.29.0 and last address is 146.102.32.225.

❑ Solution

- ◆ We can subtract the first address from the last address in base 256(see Appendix B). The result is 0.0.3.255 in this base. To find the number of addresses in the range, we convert this number to base 10 and add 1 to the result

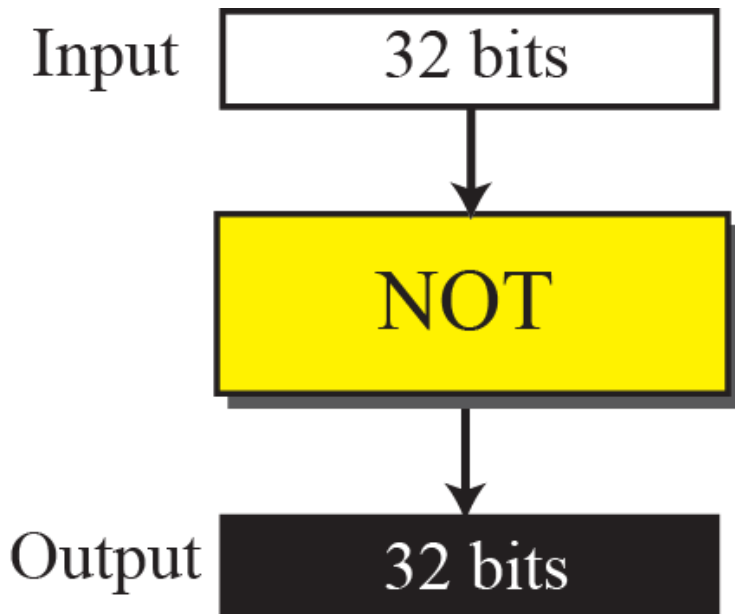
$$\text{Number of addresses} = (0 \times 256^3 + 0 \times 256^2 + 3 \times 256^1 + 255 \times 256^0) + 1 = 1024$$



Operations

- ❑ Need to apply some operations on 32-bit numbers in binary or dotted-decimal notation.

Bitwise NOT operation



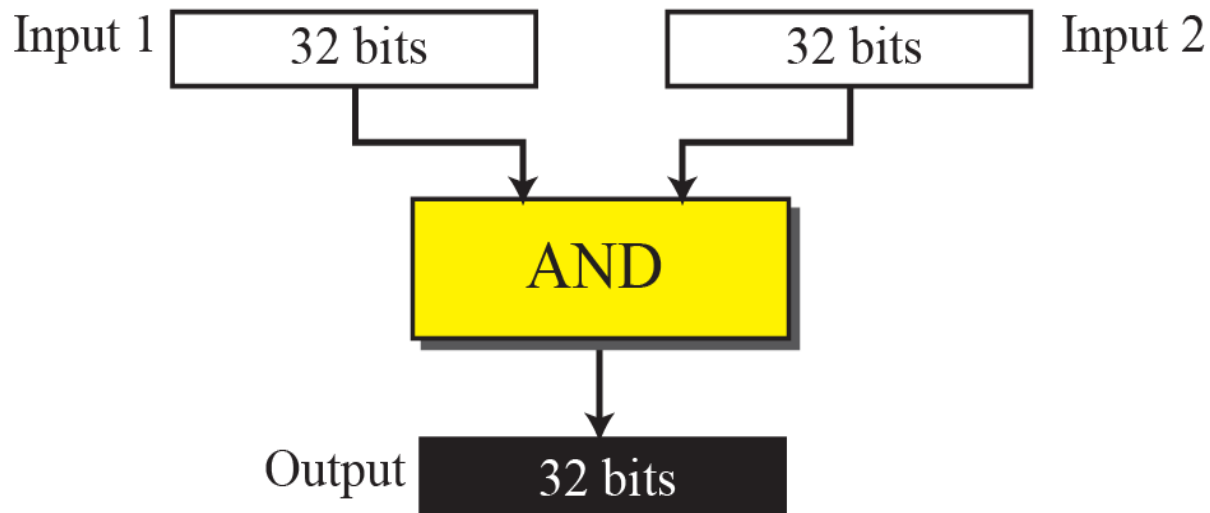
NOT operation

Input	Output
0	1
1	0

Operation for each bit

Operations(con't)

Bitwise AND operation



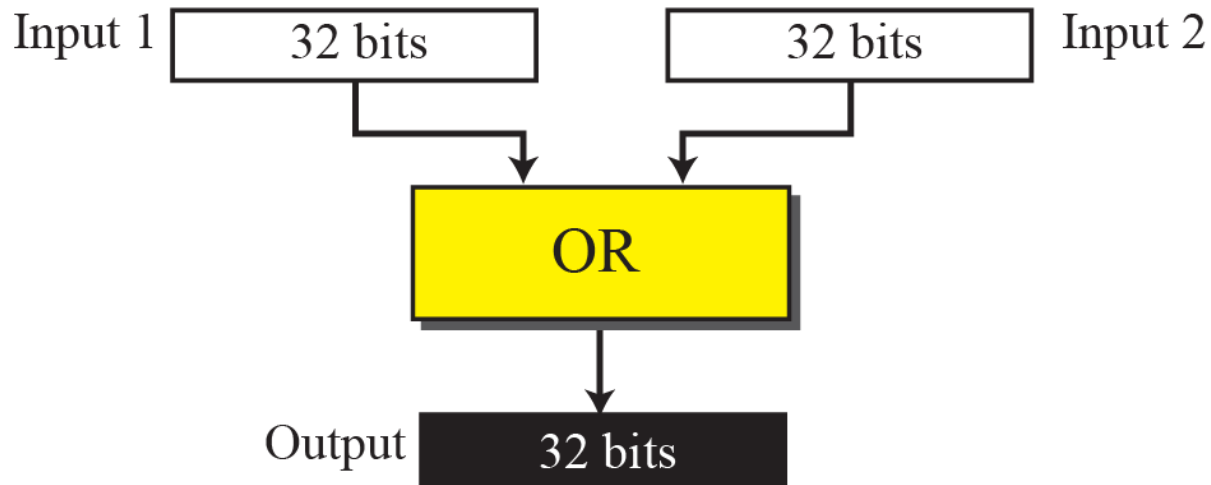
AND		
Input 1	Input 2	Output
0	0	0
0	1	0
1	0	0
1	1	1

Operation for each bit



Operations(cont'd)

Bitwise OR operation



OR		
Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	1

Operation for each bit

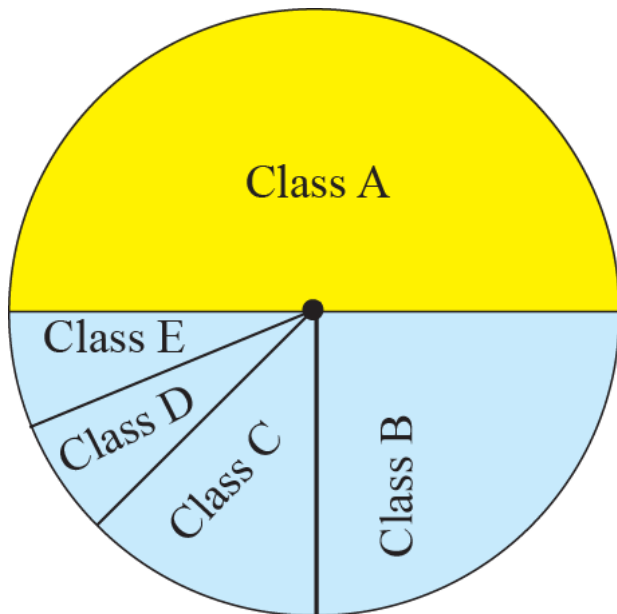


5.2 Classful Addressing

- ❑ IP addresses, when started a few decades ago, used the concept of *classes*
- ❑ In the mid-1990s, a new architecture, called classless addressing, was introduced
- ❑ We will discuss classful addressing in this section, first. Classless addressing will be discussed in next section.

Occupation of the Address Space

□ Five classes



Class A: $2^{31} = 2,147,483,648$ addresses, 50%

Class B: $2^{30} = 1,073,741,824$ addresses, 25%

Class C: $2^{29} = 536,870,912$ addresses, 12.5%

Class D: $2^{28} = 268,435,456$ addresses, 6.25%

Class E: $2^{28} = 268,435,456$ addresses, 6.25%



Finding the Class of an Address

	Octet 1	Octet 2	Octet 3	Octet 4		Byte 1	Byte 2	Byte 3	Byte 4
Class A	0.....				Class A	0-127			
Class B	10.....				Class B	128-191			
Class C	110.....				Class C	192-223			
Class D	1110....				Class D	224-299			
Class E	1111....				Class E	240-255			

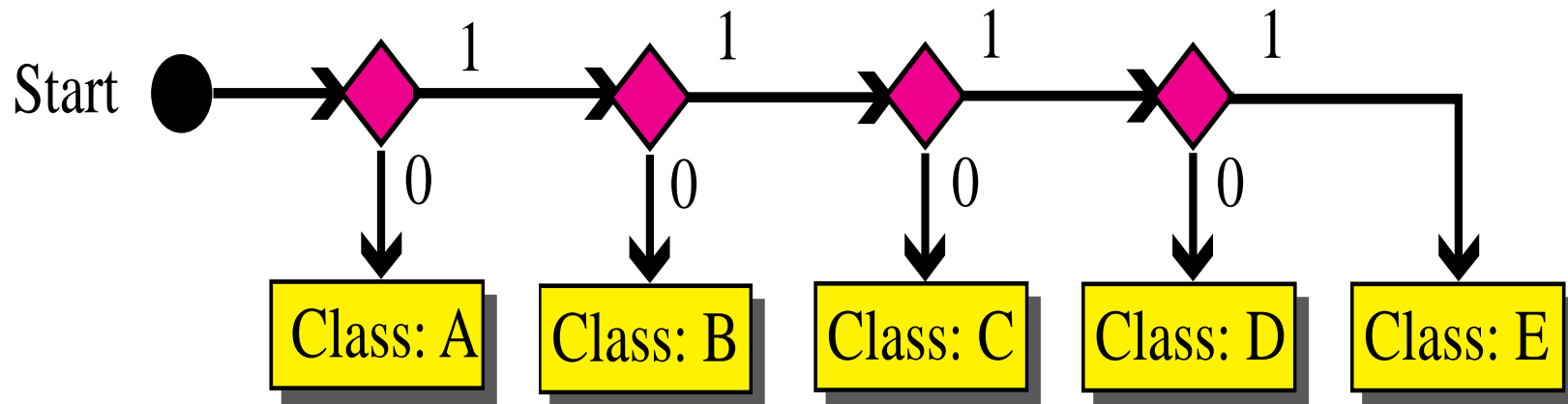
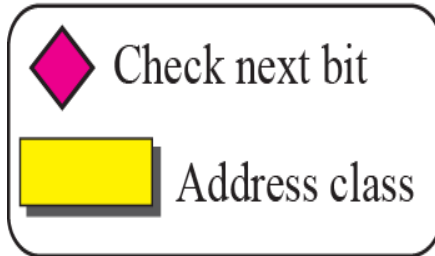
Binary notation

Dotted-decimal notation



Finding the Addresses Class Using Continuous Checking

Legend



Example 5.10

Find the class of each address:

- a. 00000001 00001011 00001011 11101111
- b. 11000001 10000011 00011011 11111111
- c. 10100111 11011011 10001011 01101111
- d. 11110011 10011011 11111011 00001111

Solution

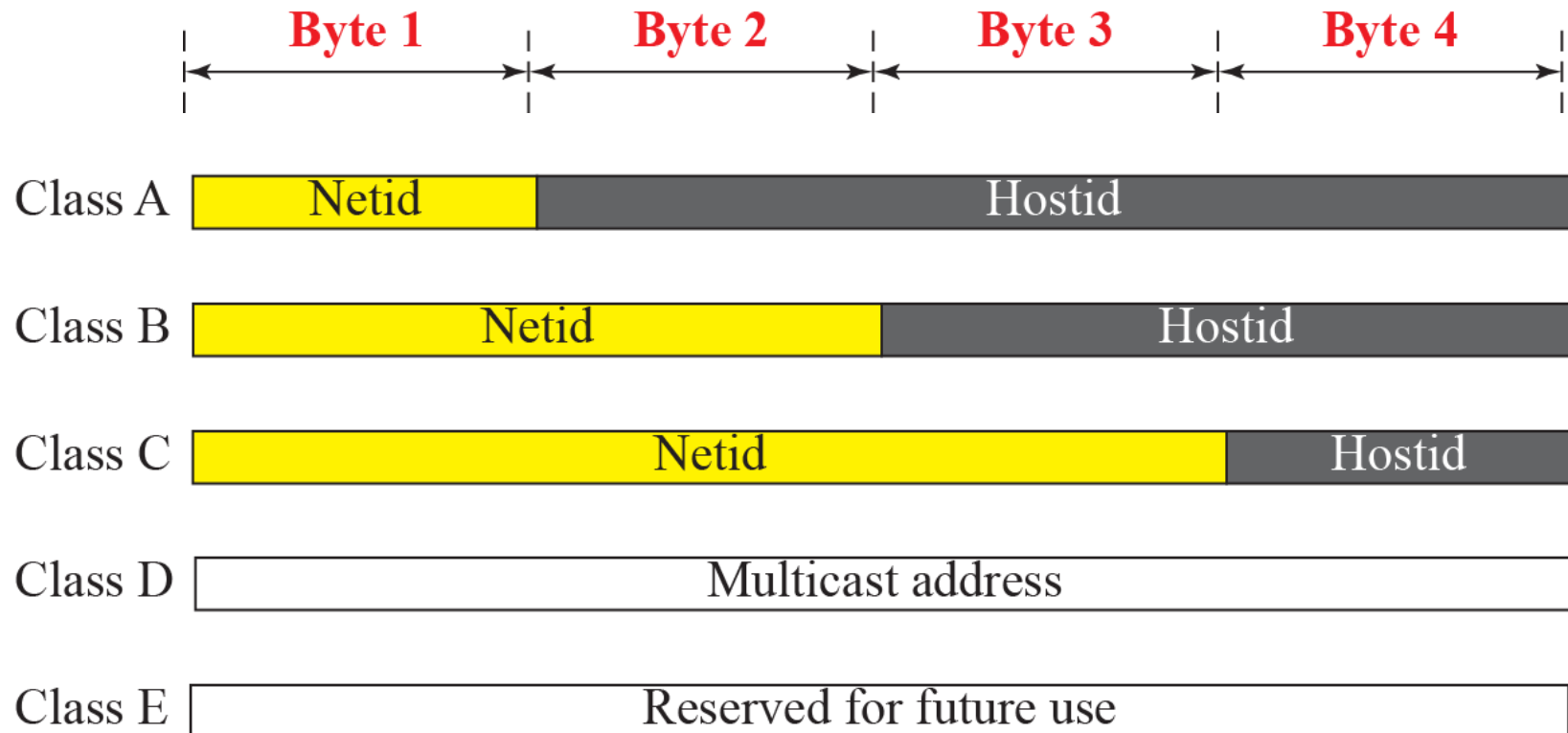
See the procedure in Figure 5.7

- a. The first bit is 0. This is a class A address.
- b. The first 2 bits are 1; the third bit is 0. This is a class C address.
- c. The first bit is 1; the second bit is 0. This is a class B address.
- d. The first 4 bits are 1s. This is a class E address.



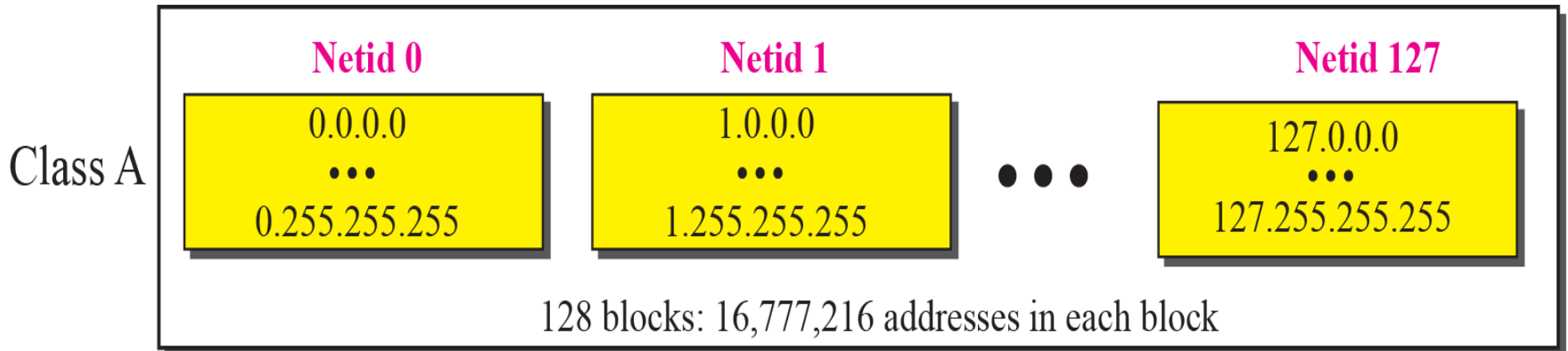
Netid and hostid of A, B, and C Classes

- netid and hostid are of varying lengths, depending on the class of the address



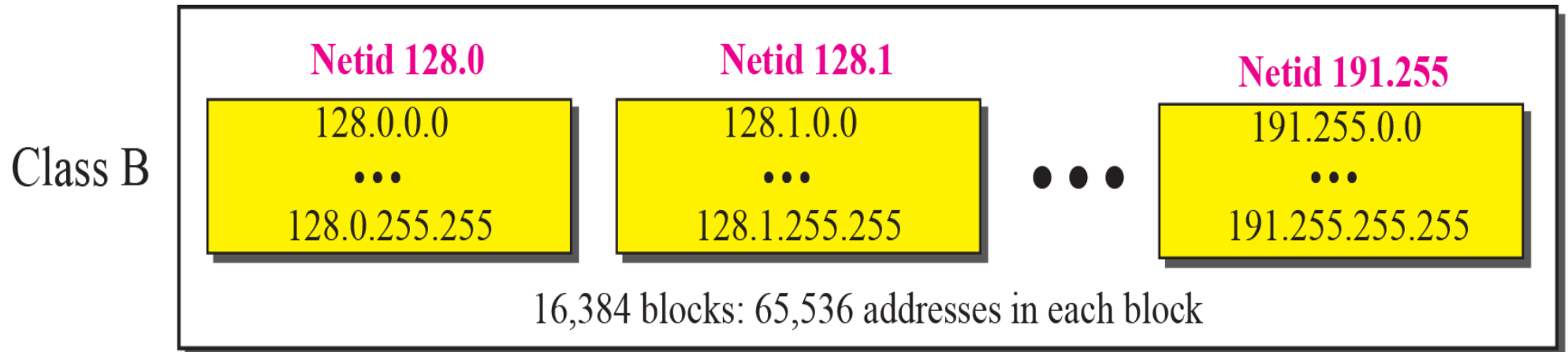
Blocks in Class A

- ❑ Only 1 byte in class A defines the netid
- ❑ The leftmost bit should be '0'
- ❑ Class A is divided into $2^7 = 128$ blocks
- ❑ Each block in class A contains 16,777,216 addresses



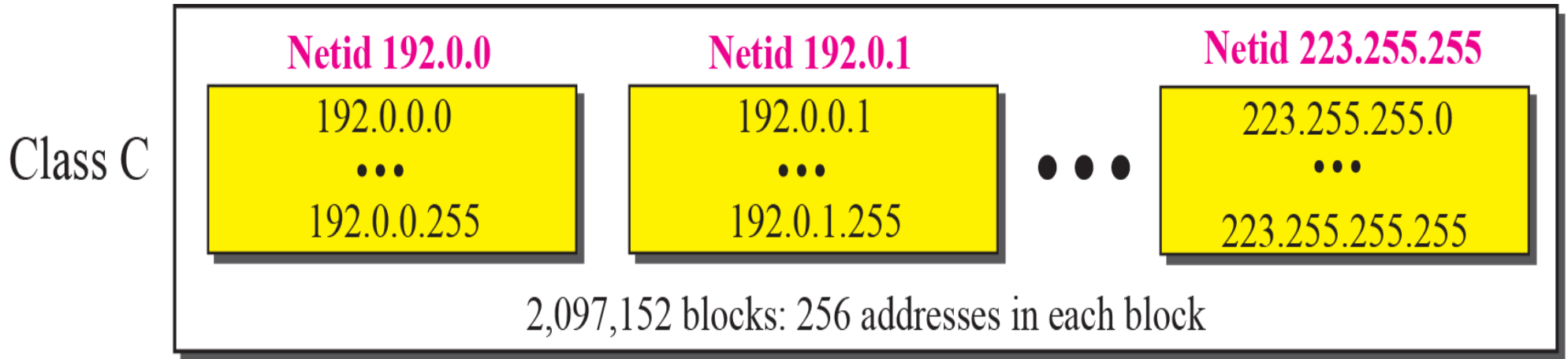
Blocks in Class B

- ❑ 2 bytes in class B define the class
- ❑ The two leftmost bits should be '10'
- ❑ Class B is divided into $2^{14} = 16,384$ blocks
- ❑ Each block in class B contains 65,536 addresses



Blocks in Class C

- ❑ 3 bytes in class C define the class
- ❑ The three leftmost bits should be '110'
- ❑ Class C is divided into $2^{21} = 2,097,152$ blocks
- ❑ Each block in class C contains 256 addresses



The Single Block in Class D and E

□ Class D

- ◆ Class D is designed for multicasting
- ◆ Used to define one group of hosts on the Internet

Class D

224.0.0.0 ... 239.255.255.255

One block: 268,435,456 addresses

□ Class E

- ◆ Reserved for future purposes

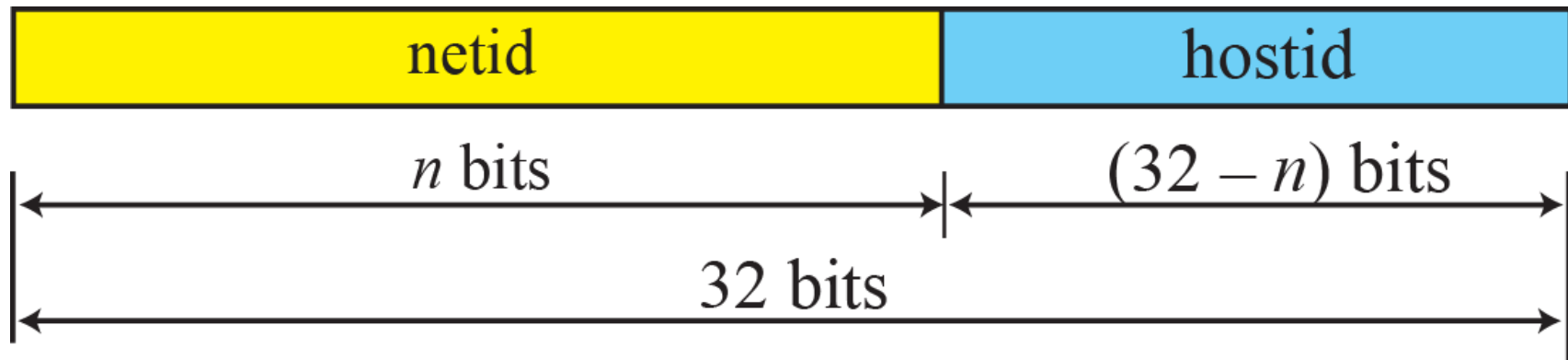
Class E

240.0.0.0 ... 255.255.255.255

One block: 268,435,456 addresses



Two-Level Addressing



Class A: $n = 8$

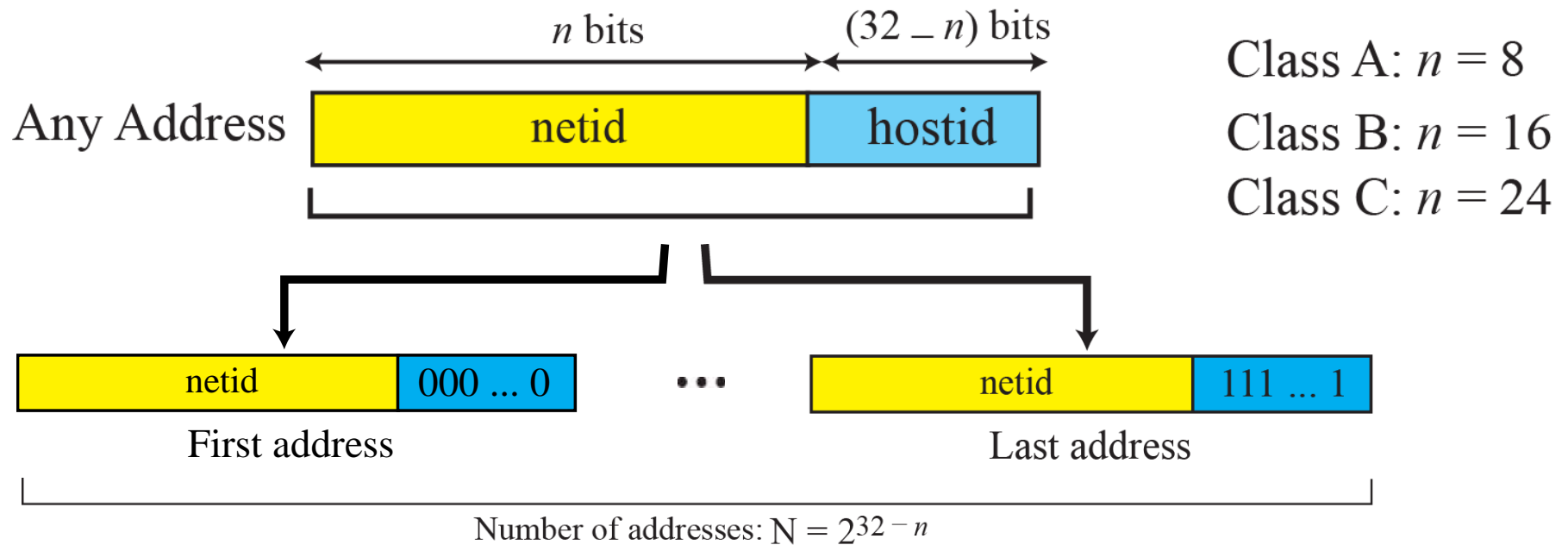
Class B: $n = 16$

Class C: $n = 24$



Information Extraction in Classful Addressing

- ❑ The number of addresses
- ❑ The first address
- ❑ The last address



Example 5.13

An address in a block is given as 73.22.17.25. Find the number of addresses in the block, the first address, and the last address

Solution

1. The number of addresses in this block is

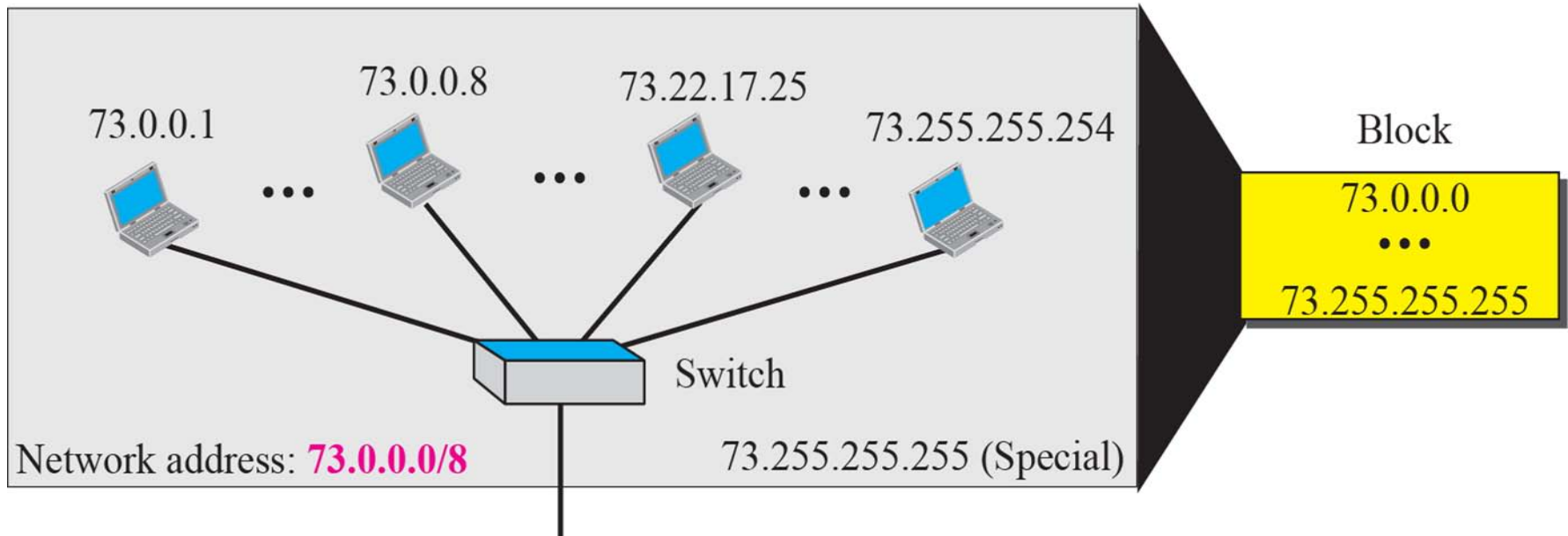
$$N = 2^{32-n} = 2^{24} = 16,777,216$$

2. To find the first address, we keep the left most 8 bits and set the rightmost 24 bits all to 0s. The first address is 73.0.0.0/8 in which 8 is the value of n .
3. To find the last address, we keep the leftmost 8 bits and set the rightmost 24 bits all to 1s. The last address is 73.255.255.255

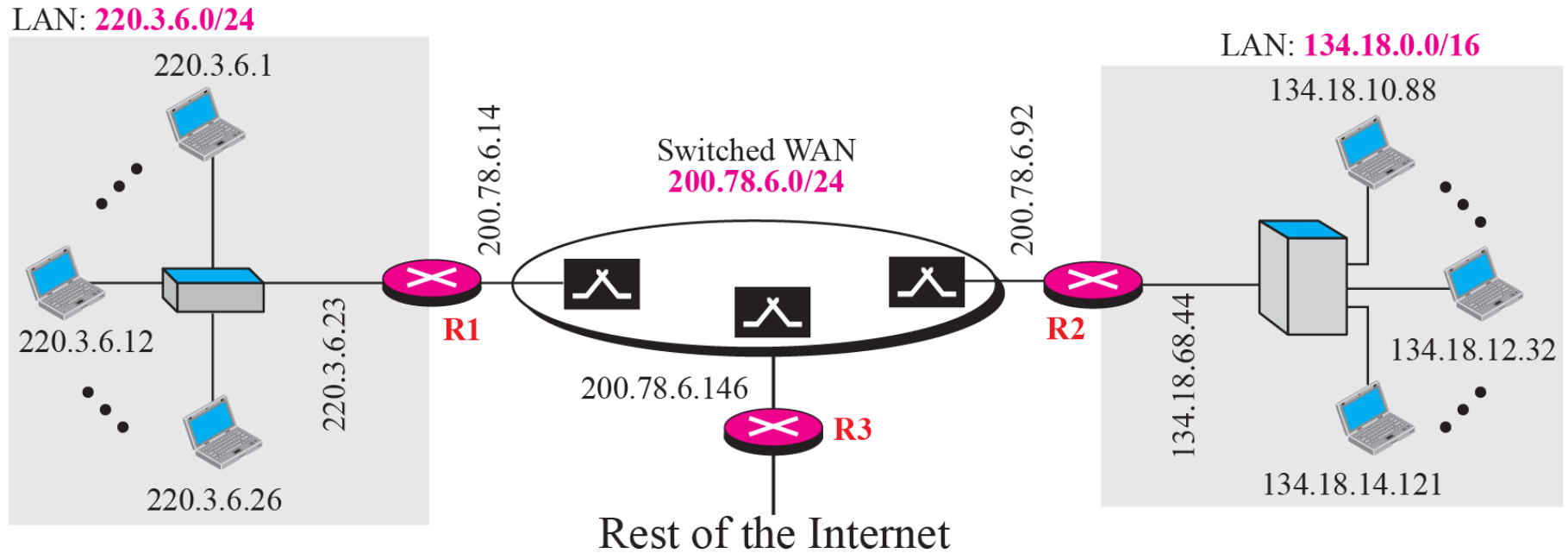


Solution of Example 5.13

Netid 73: common in all addresses



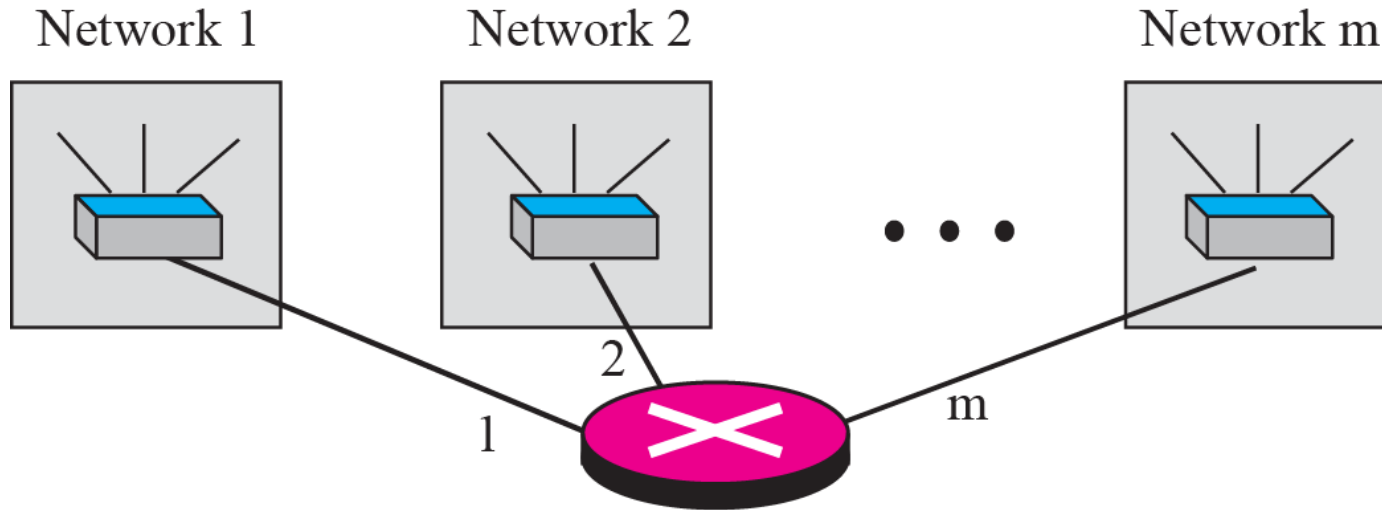
Sample Internet



Network Address

- ❑ The first address of block is network address
- ❑ Used in routing a packet to its destination network
- ❑ The network address is the identifier of a network

Network Address



Routing Process

Destination address

Find Network address

Routing Table

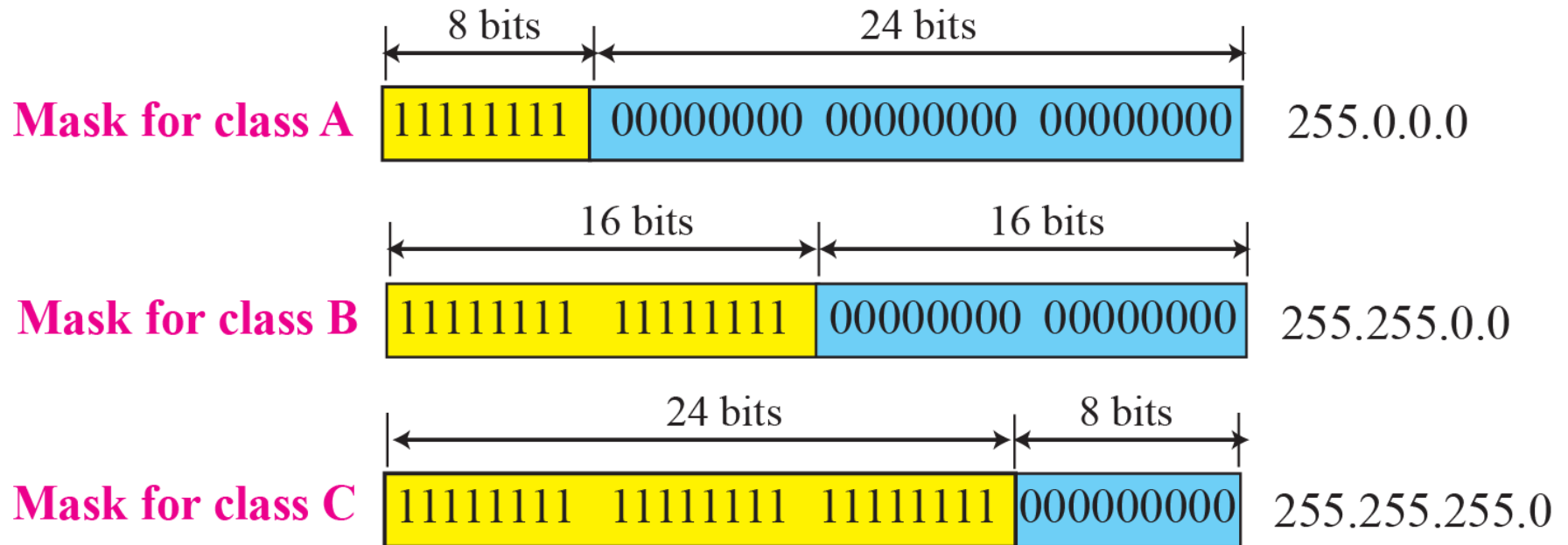
Network address	Interface
$b_1 \cdot c_1 \cdot d_1 \cdot e_1$	1
$b_2 \cdot c_2 \cdot d_2 \cdot e_2$	2
...	...
$b_m \cdot c_m \cdot d_m \cdot e_m$	m

Interface number

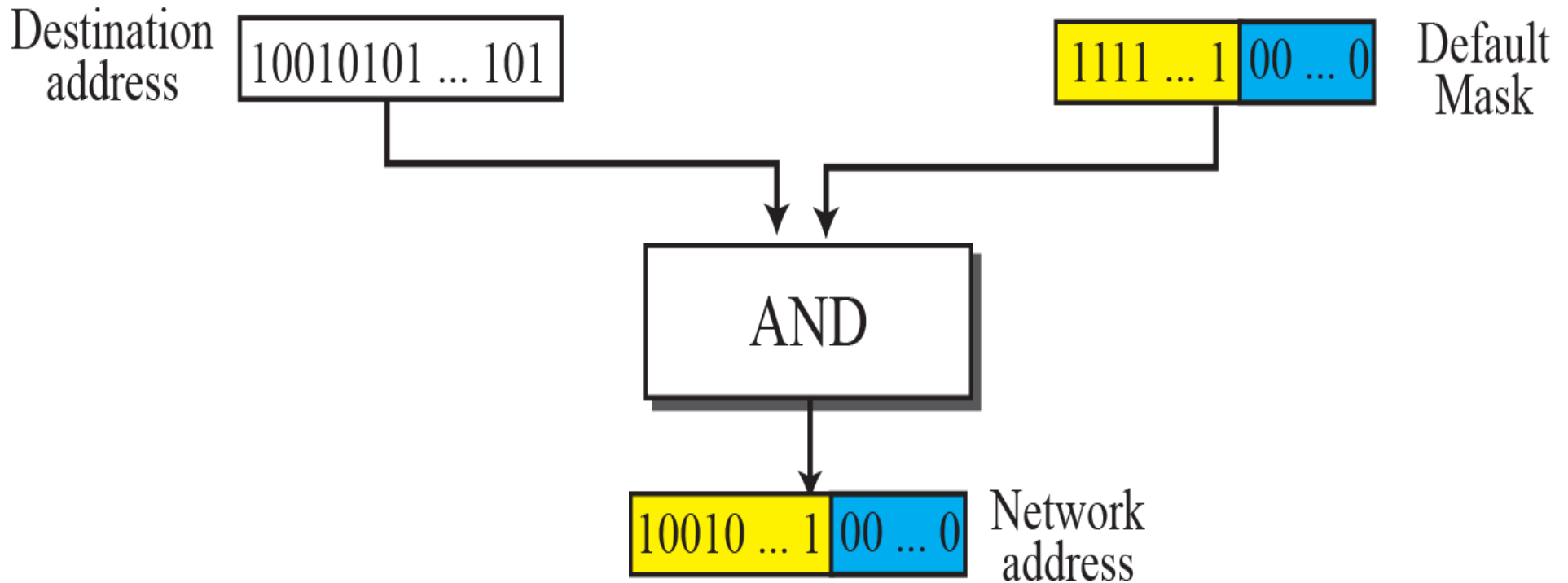


Network Mask

- ❑ Used to extract the network address from the destination address of a packet
- ❑ Called a default mask



Finding a Network Address using the Default Mask



Example 5.16

A router receives a packet with the destination address 201.24.67.32. Show how the router finds the network address of the packet.

Solution

Since the class of the address is B, we assume that the router applies the default mask for class B, 255.255.0.0 to find the network address.

Destination address ->	201	.	24	.	67	.	32
Default mask ->	255	.	255	.	0	.	0
Network address ->	201	.	24	.	0	.	0

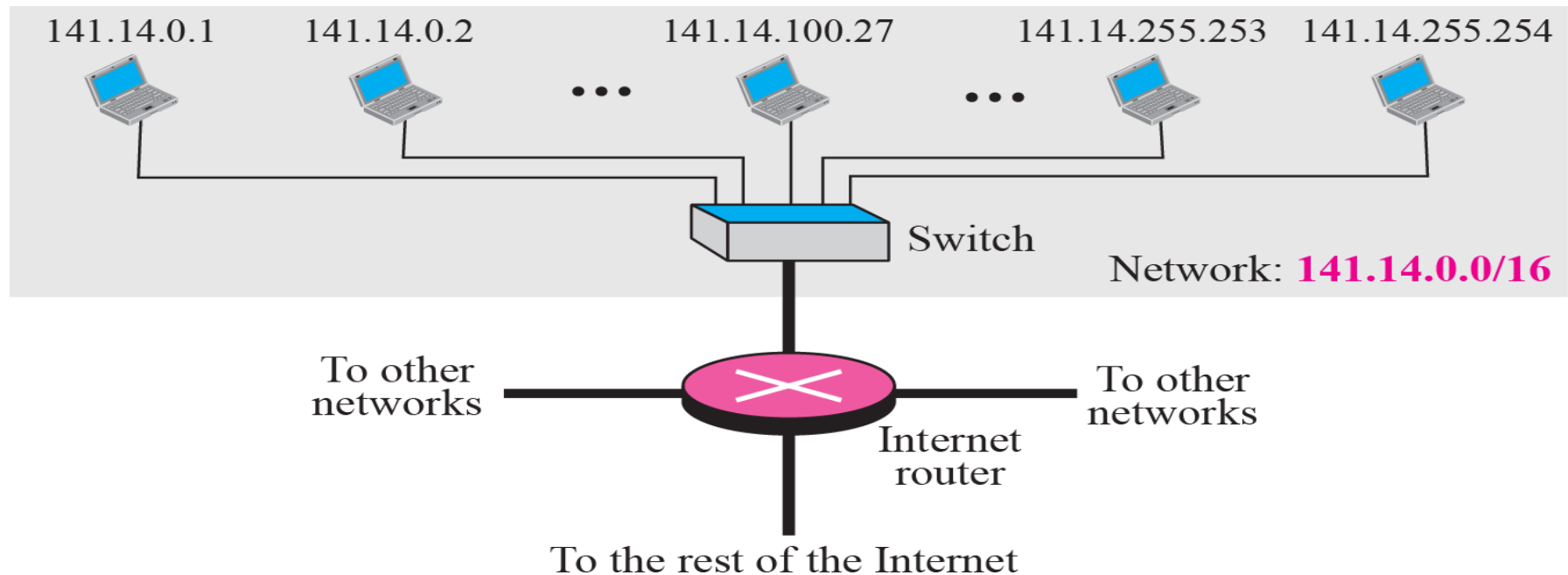


Three-Level Addressing : Subnetting

- ❑ The organization that was granted a block in class A or B needed to divide its large network into several subnetworks for better security and management
- ❑ In subnetting, a network is divided into several smaller subnetworks with each subnetwork having its own subnetwork address

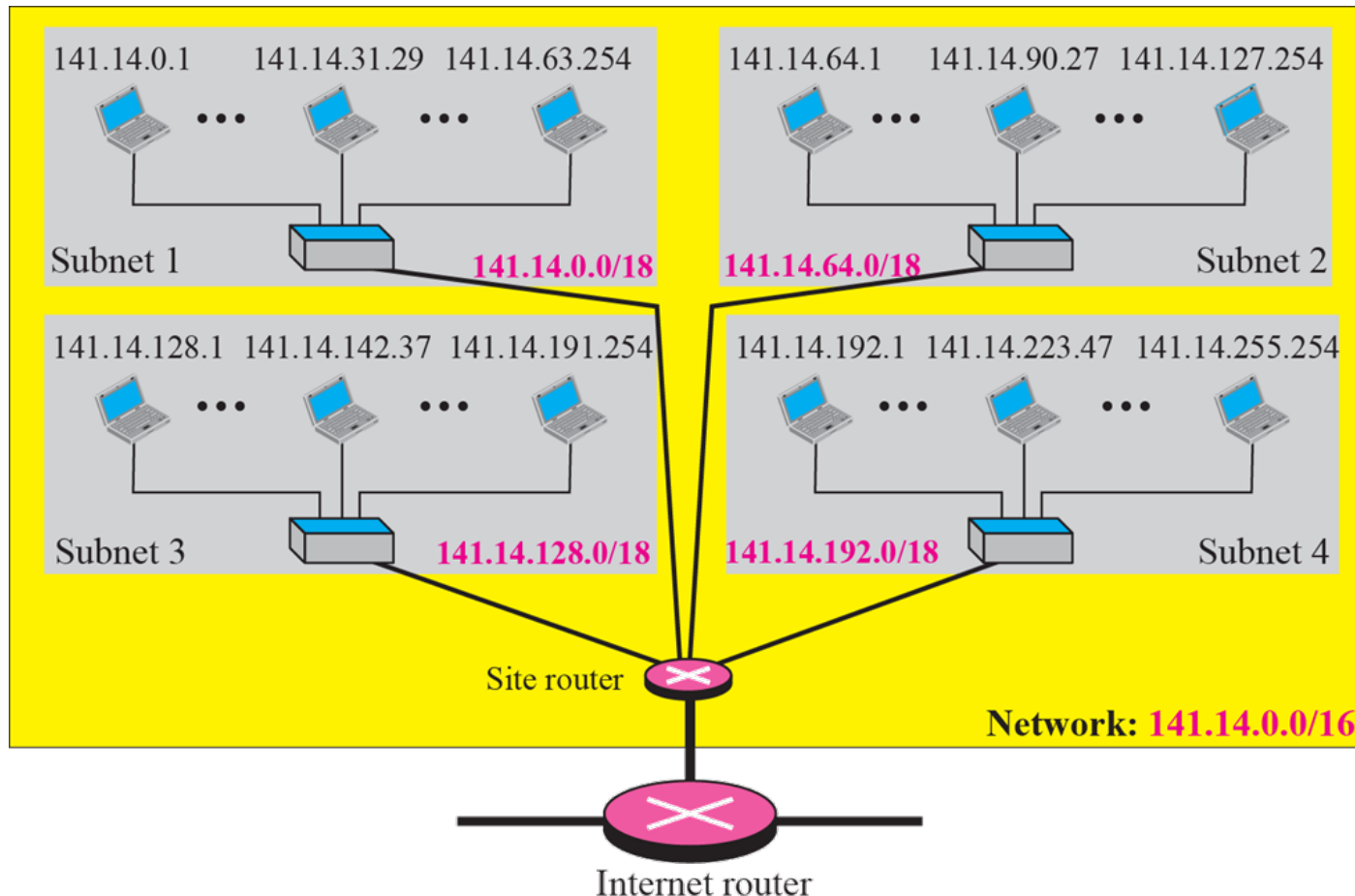
Example 5.18

- ❑ The next figure shows a network using class B addresses before subnetting. We have just one network with almost 216 hosts. The whole network is connected, through one single connection, to one of the routers in the Internet. Note that we have shown /16 to show the length of the netid (class B)

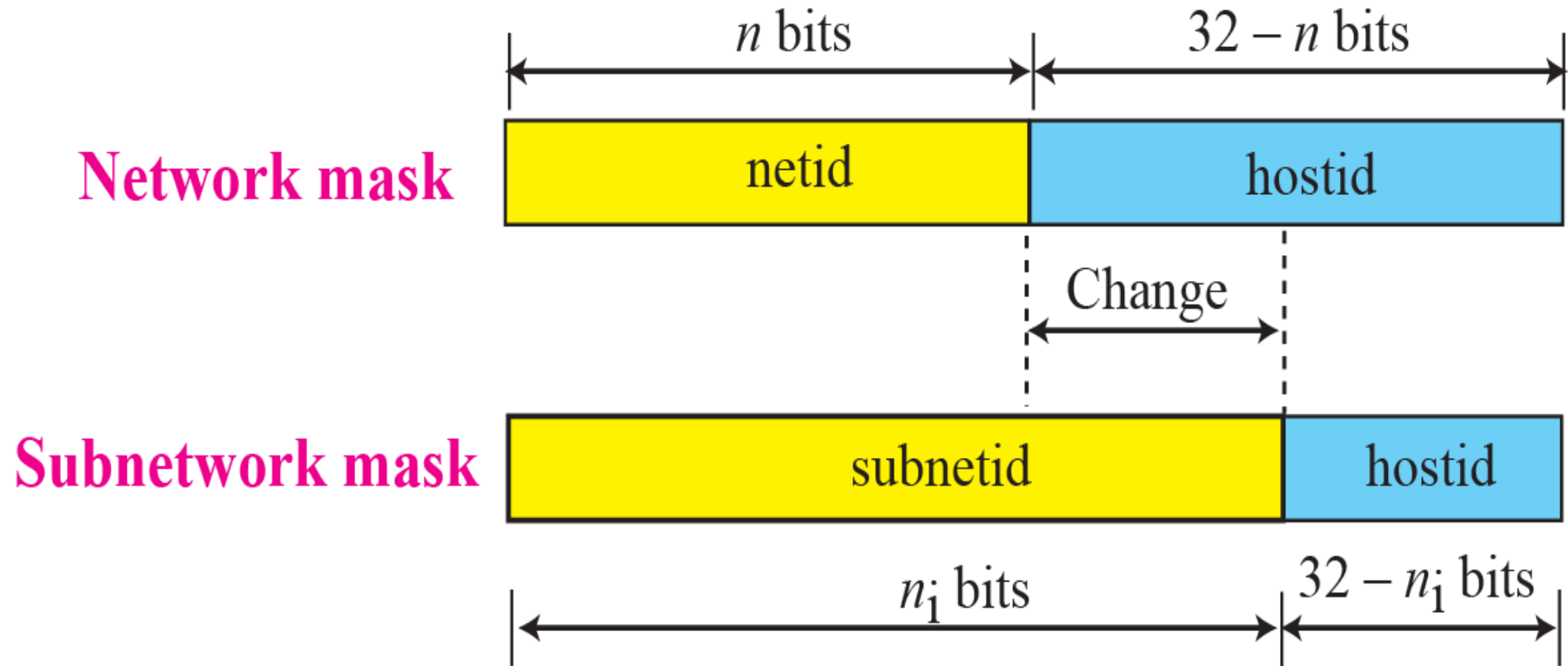


Example 5.19

- The next figure shows same network in example 5.18 after subnetting.



Network Mask and Subnet Mask



Supernetting

- ❑ **Combine several class C blocks to create a larger range of address**
 - ◆ **An organization that needs 1000 addresses can be granted four class C blocks.**

- ❑ **Supernet mask is the reverse of a subnet mask**

Comparison of Subnet, Default, and Supernet masks

Divide 1 class C block into 8 subblocks

Subnet mask  $n_{\text{subnet}} = 24 + 3 = 27$



Default mask  $n = 24$



Supernet mask  $n_{\text{supernet}} = 24 - 3 = 21$

Combine 8 class C blocks into 1 superblock



5.3 Classless Addressing

- ❑ **Classful address did not solve the address depletion problem**
 - ◆ **Distribution of addresses and the routing process more difficult**

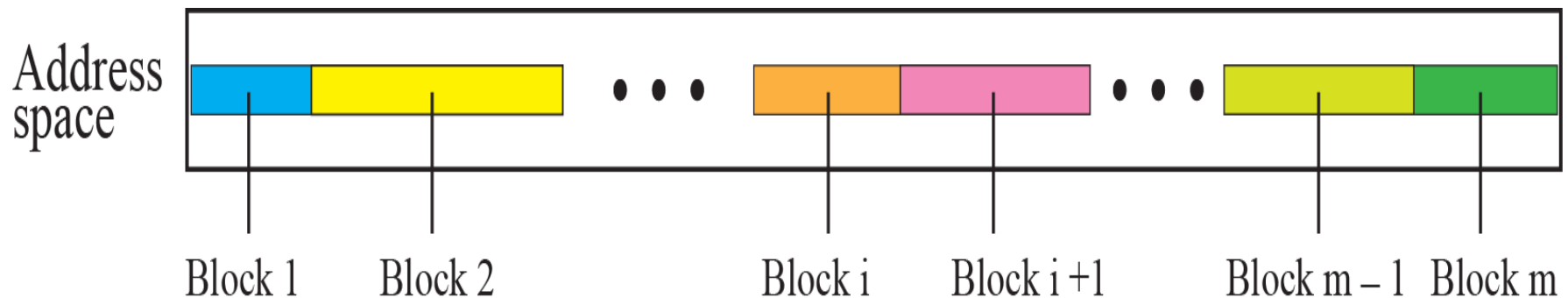
- ❑ **With the growth of the Internet, a larger address space was needed as a long-term solution**

- ❑ **Although the long-range solution has already been devised and is called IPv6, a short-term solution was also devised to use the same address space but to change the distribution of addresses**
 - ◆ **Classless addressing**



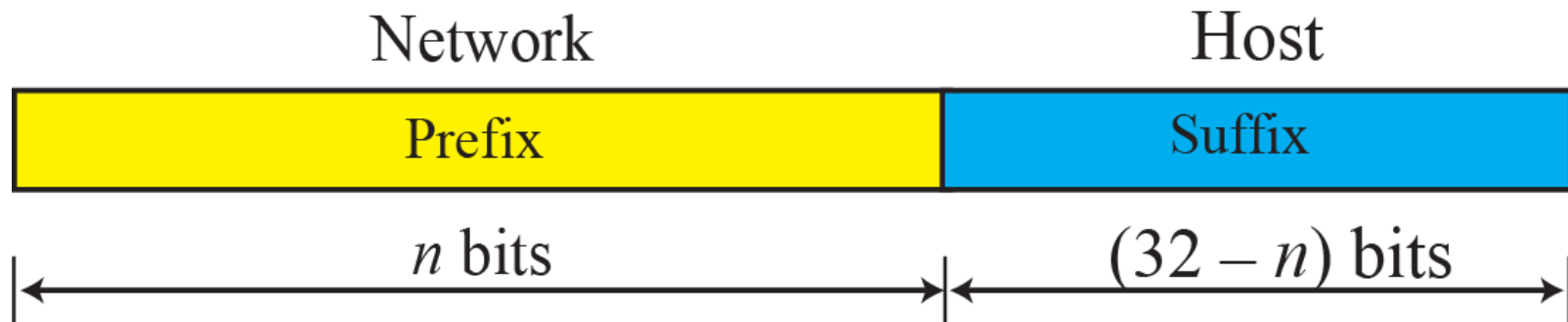
Variable-length blocks in Classless Addressing

- ❑ In classless addressing, whole address space is divided into variable length blocks
 - ◆ Theoretically, we can have a block of $2^0, 2^1, 2^2, \dots, 2^{32}$ addresses



Prefix and Suffix

- ❑ Prefix : play the same role as the netid
- ❑ Suffix : play the same role as the hostid



- ❑ The prefix length in classless addressing can be 1 to 32

Example 5.22

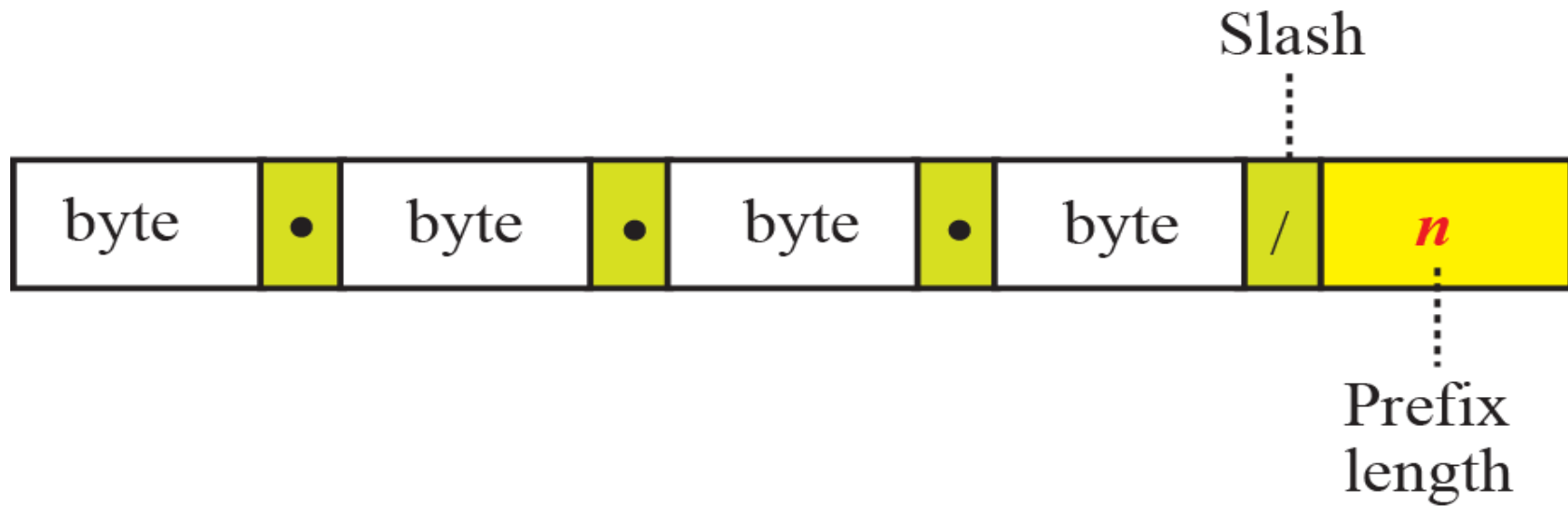
What is the prefix length and suffix length if the whole Internet is considered as one single block with 4,294,967,296 addresses?

Solution

In this case, the prefix length is 0 and suffix length is 32. All 32 bits vary to define $2^{32} = 4,294,967,296$ hosts in this single block

Slash Notation

- Notation of address including length of prefix



- In classless addressing, we need to know one of the addresses in the block and the prefix length to define the block

Example 5.25

- ❑ In classless addressing, an address cannot per se define the block the address belongs to. For example, the address 230.8.24.56 can belong to many blocks some of them are shown below with the value of the prefix associated with that block :

Prefix length:16	→	Block:	230.8.0.0	to	230.8.255.255
Prefix length:20	→	Block:	230.8.16.0	to	230.8.31.255
Prefix length:26	→	Block:	230.8.24.0	to	230.8.24.63
Prefix length:27	→	Block:	230.8.24.32	to	230.8.24.63
Prefix length:29	→	Block:	230.8.24.56	to	230.8.24.63
Prefix length:31	→	Block:	230.8.24.56	to	230.8.24.57

Example 5.27

One of the address in a block is 167.199.170.82/27. To find the number of addresses in the network, the first address, and the last address.

Solution

The value of n is 27. The network mask has twenty-seven 1s and five 0s. It is 255.255.255.240.

- a. The number of addresses in the network is $2^{32-n} = 2^5 = 32$
- b. We use the AND operation to find the first address. The first address is 167.199.170.64/27

Address in Binary	10100111	11000111	10101010	01010010
Network mask	11111111	11111111	11111111	11100000.
First address	10100111	11000111	10101010	01000000



Example 5.27(cont'd)

C. To find the last address, we first find the complement of the network mask and the OR it with the given address : the last address is 167.199.170.95/27

Address in Binary	10100111	11000111	10101010	01010010
Network mask	0000000	00000000	00000000	00011111
Last address	10100111	11000111	10101010	01011111

Extracting Block Information

- ❑ The number of addresses in the block can be found as

$$N = 2^{32-n}$$

- ❑ The first address in the block can be found by ANDing the address with the network mask

First address = (any address) AND (network mask)

- ❑ The last address in the block can be found by either adding the first address with the number of addresses or, directly, by ORing the address with complement (NOTing) of the network mask

Last address = (any address) OR [NOT (network mask)]

Block Allocation

- ❑ The ultimate responsibility of block allocation is given to a global authority called ICANN(Internet Corporation for Assigned Names and Address)
- ❑ Assign a large block of addresses to an ISP (Internet Service Provider)
- ❑ For the proper operation of the CIDR, there are three restrictions
 - ◆ The number of requested addresses, N , needs to be power of 2.
 - ◆ The value of prefix length can be found from the number of addresses in the block
 - ◆ The requested block needs to be allocated where there are a contiguous number of unallocated addresses in the address space



Example 5.30

An ISP has requested a block of 1000 addresses. The following block is granted.

- a. Since 1000 is not a power of 2, 1024 addresses are granted
- b. The prefix length for the block is calculated as $n = 32 - \log_2 1024 = 22$
- c. The beginning address is chosen as 18.14.12.0

The granted block is 18.14.12.0/22. The first address is 18.14.12.0/22 and the last address is 18.14.15.255/22

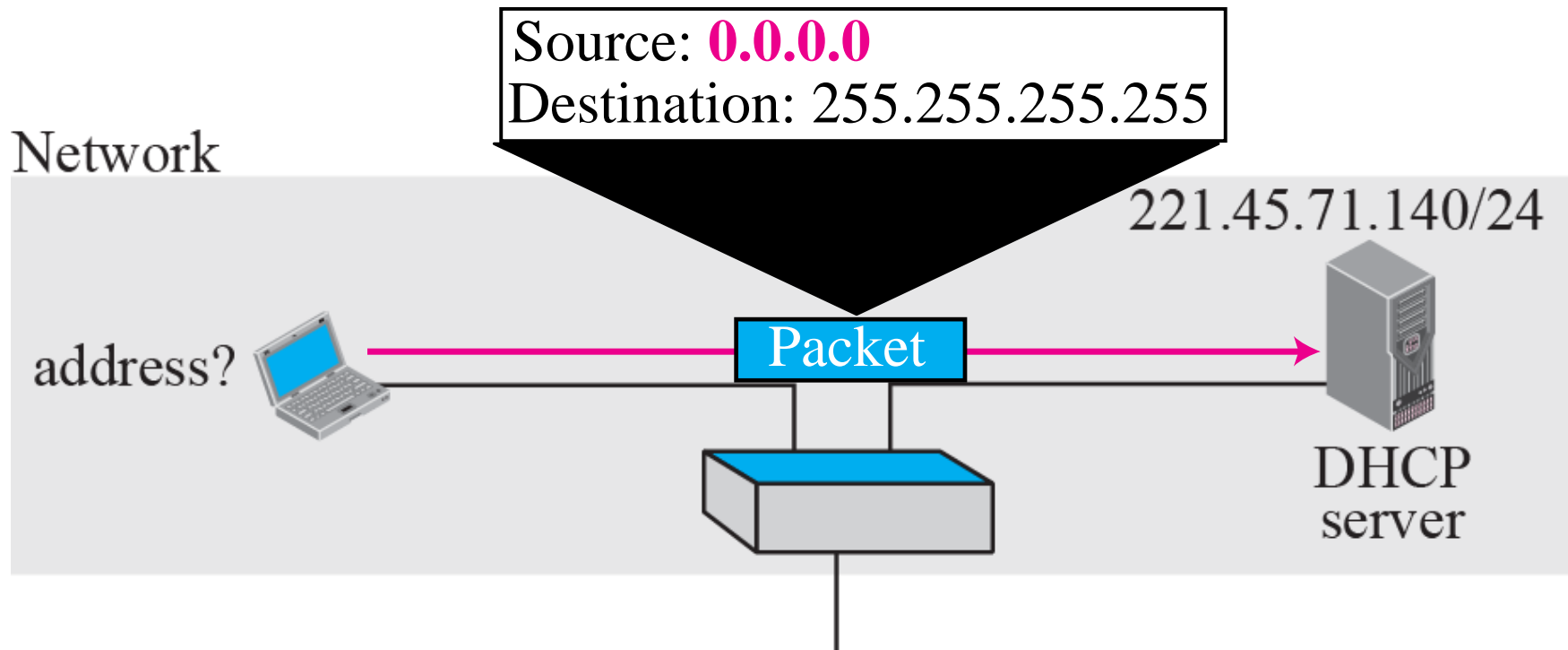
5.4 Special Addresses

- ❑ In classful addressing some addresses were reserved for special purposes. The classless addressing scheme inherits some of these special addresses from classful addressing
- ❑ Special block
 - ◆ All-Zero Address
 - ◆ All-One Address
 - ◆ Loopback Address
 - ◆ Private Address
 - ◆ Multicast Address
- ❑ Special address in each block
 - ◆ Network Address
 - ◆ Direct broadcast address



Example of using the all-zeros address

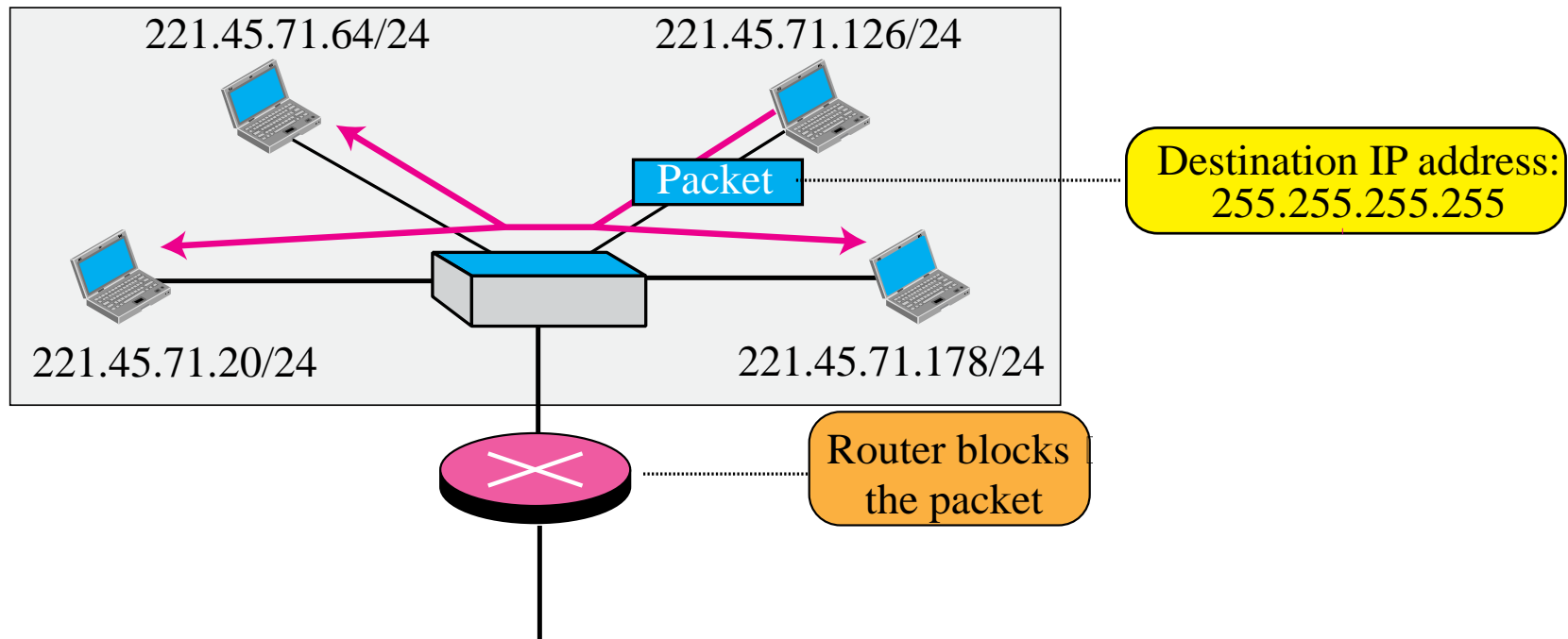
- When a host needs to send an IPv4 packet but it does not know its own address



Example of Limited Broadcast Address

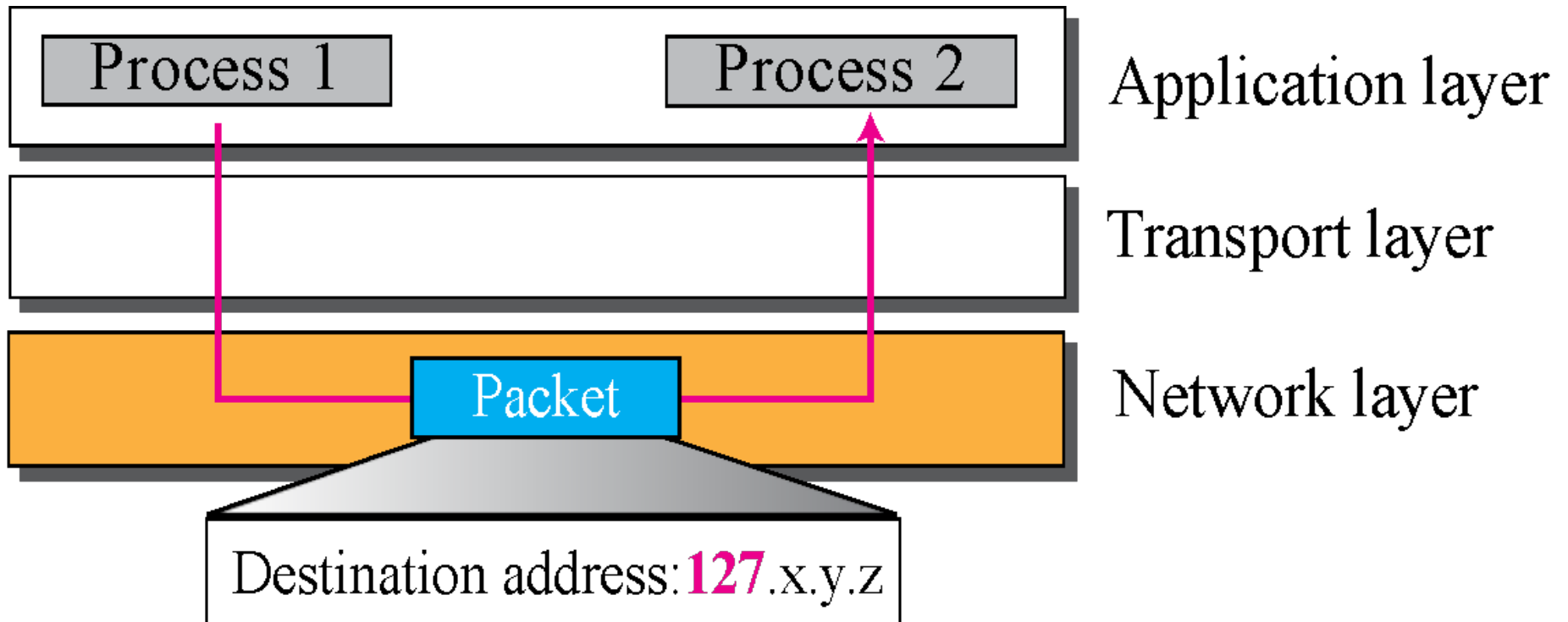
- ❑ All-One Address
- ❑ A host that wants to send a message to every other host can use

Network



Example of Loopback Address

- ❑ Used to test the software on a machine



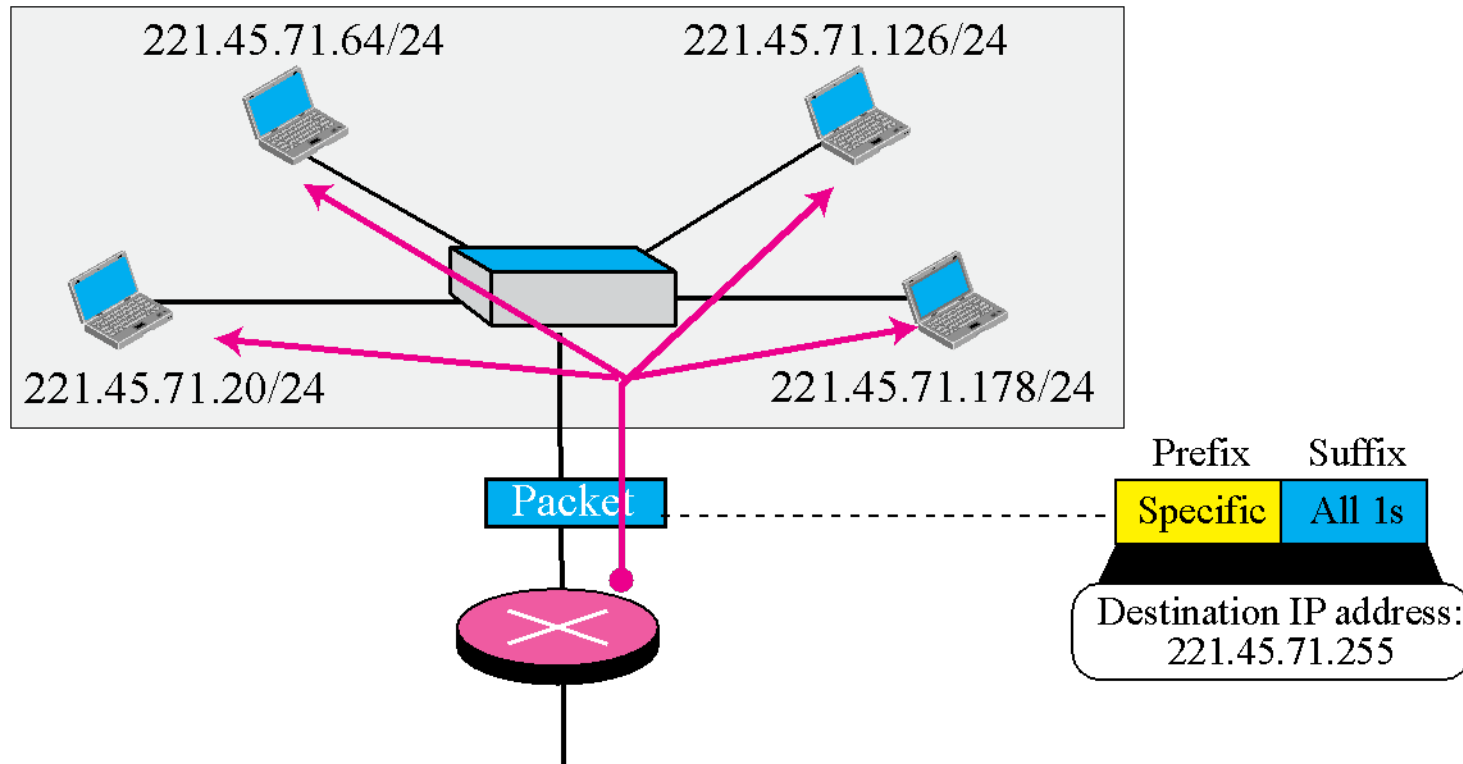
Private address

- ❑ Not recognize globally
- ❑ Used either in isolation or in connection with network address translation technique

Block	Number of addresses	Block	Number of address
10.0.0.0/8	16,777,216	192.168.0.0/16	65,536
172.16.0.0/12	1,047,584	169.254.0.0/16	65,536

Example of Directed Broadcast Address

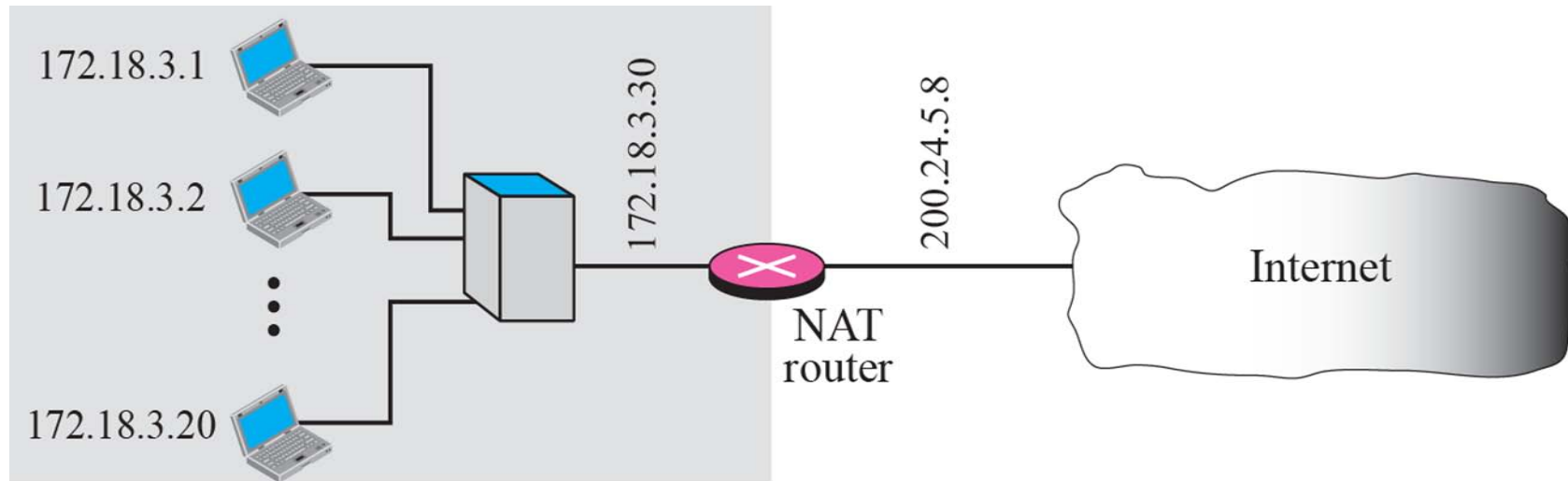
Network: **221.45.71.0/24**



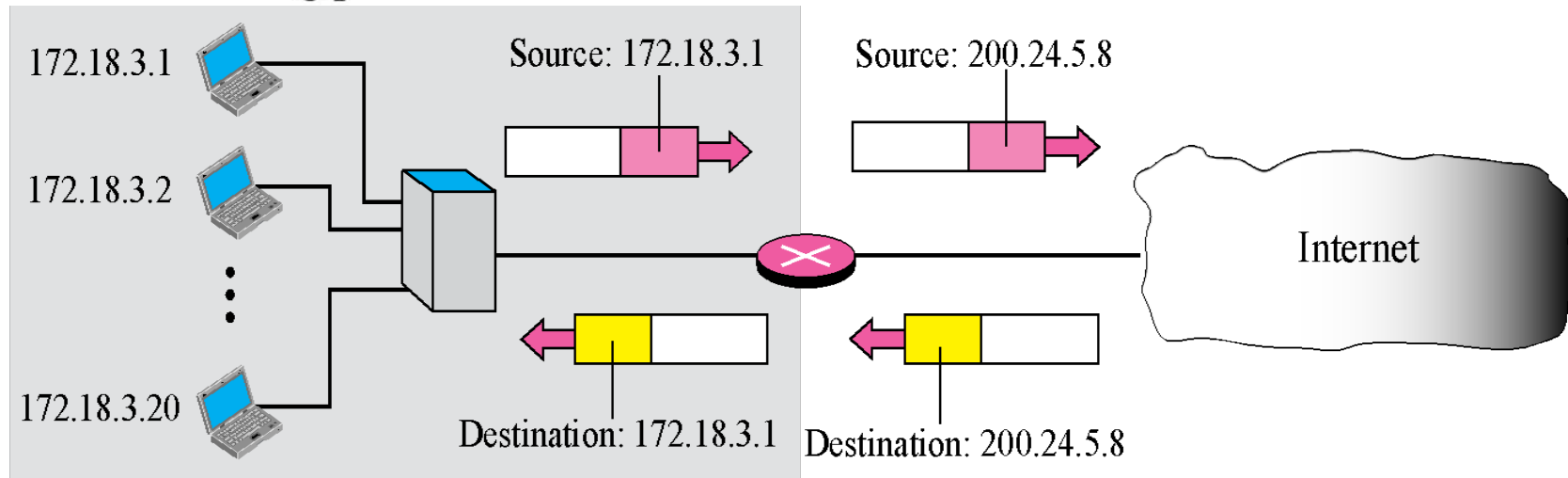
5.5 NAT

- ❑ **The distribution of addresses through ISPs has created a new problem**
 - ◆ **ISP cannot rearrange the range of addresses**
- ❑ **But in most situation, only a portion of computers in a small network need access to the Internet simultaneously**
 - ◆ **The number of allocated addresses does not have to match the number of computers in the network**
- ❑ **A technology that can provide the mapping between the private and universal addresses, and at the same time, support virtual private networks is NAT(Network Address Translation)**

Example of NAT and Address Translation



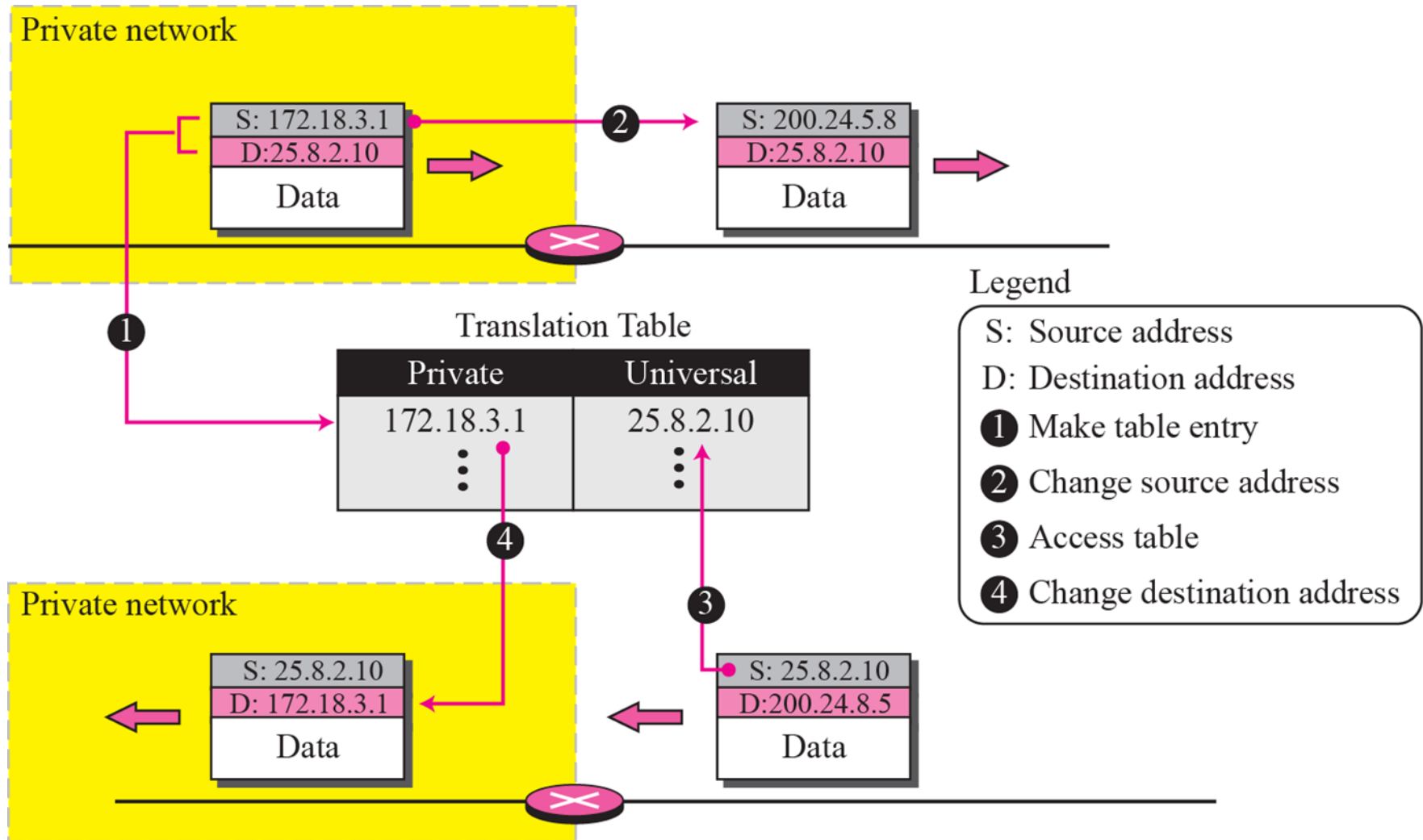
Site using private addresses



Site using private addresses



Using One IP Address



Example of NAT

❑ Using a pool of IP address

- ◆ Using one global address by the NAT router allows only one private-network host to access the same external host

- ❑ To remove this restriction, NAT router can use a pool of global addresses

❑ Using both IP addresses and port addresses

- ◆ To allow a many-to-many relationship

Private Address	Private Port	External Address	External Port	Transport Protocol
172.18.3.1	1400	25.8.3.2	80	TCP
172.18.3.2	1401	25.8.3.2	80	TCP
...

Summary

- ❑ The identifier used in the IP layer of the TCP/IP layer of the TCP/IP protocol suite is called the Internet address or IP address. An IPv4 address is 32 bits long. An address space is the total number of addresses used by the protocol. The address space of IPv4 is 2^{32} or 4,294,967,296.
- ❑ In classful addressing, the IPv4 address space is divided into five classes: A, B, C, D, and E. An organization is granted a block in one of the three classes, A, B, or C. Classes D and E is reserved for special purpose. An IP address in classes A, B, and C is divided into netid and hostid.
- ❑ In classful addressing, the first address in the block is called the network address. It defines the network to which an address belongs. The network address is used in routing a packet to its destination network.
- ❑ A network mask or a default mask in classful addressing is a 32-bit number with n leftmost bits all set to 1s and (32 – n) rightmost bits all set to 0s. It is used by a router to find the network address from the destination address of a packet.
- ❑ The idea of splitting a network into smaller subnetworks is called subnetting. A subnetwork mask, like a network mask, is used to find the subnetwork address when a destination IP address is given. In supernetting, an organization can combine several class C blocks to create a larger range of addresses.

Summary

- ❑ In 1996, the Internet authorities announced a new architecture called classless addressing, or CIDR that allows an organization to have a block addresses of any size as long as the size of the block is a power of two.
- ❑ The address in classless addressing is also divided into two parts: the prefix and the suffix. The prefix plays the same role as the netid; the suffix plays the same role as the hostid. All addresses in the block have the same prefix; each address has a different suffix
- ❑ Some of the blocks in IPv4 are reserved for special purpose. In addition, some addresses in a block are traditionally used for special addresses. These addresses are not assigned to any host.
- ❑ To improve the distribution of addresses, NAT technology has been created to allow separation of private addresses in a network from the global addresses used in the Internet. A translation table can translate the private addresses, selected from the blocks allocated for this purpose, to global addresses. The translation table also translates the IP addresses as well as the port number for mapping from the private to global addresses and vice versa.

Q and A

