Chapter 4

IP Addresses: Classful Addressing

Objectives

Upon completion you will be able to:

- *Understand IPv4 addresses and classes*
- *Identify the class of an IP address*
- *Find the network address given an IP address*
- *Understand masks and how to use them*
- *Understand subnets and supernets*

4.1 INTRODUCTION

The identifier used in the IP layer of the TCP/IP protocol suite to identify each device connected to the Internet is called the Internet address or IP address. An IP address is a 32-bit address that uniquely and universally defines the connection of a host or a router to the Internet. IP addresses are unique. They are unique in the sense that each address defines one, and only one, connection to the Internet. Two devices on the Internet can never have the same address.

The topics discussed in this section include:

Address Space
Notation

Note:

An IP address is a 32-bit address.

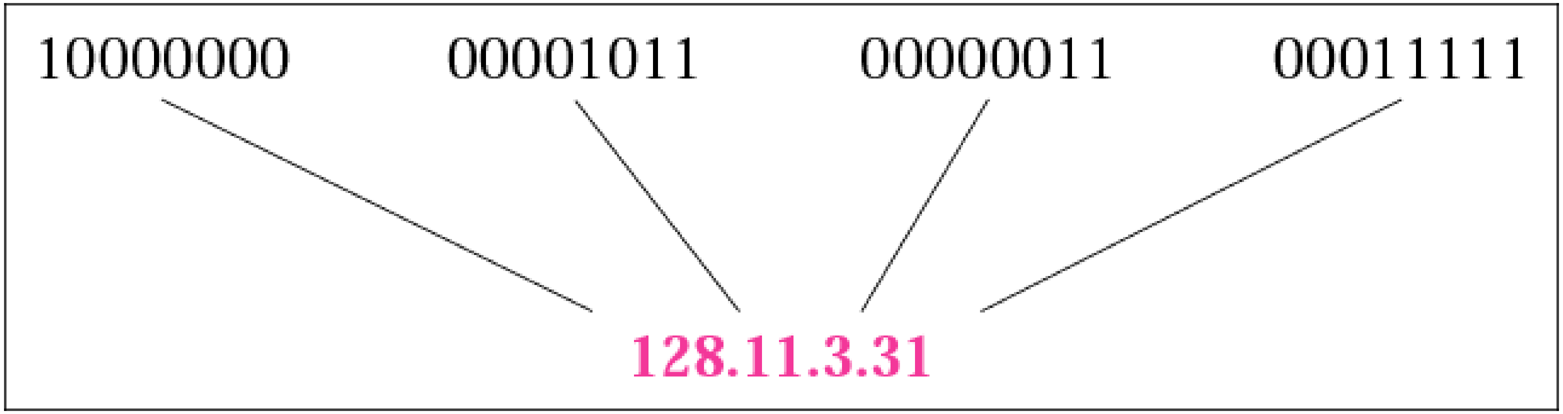
Note:

The IP addresses are unique.

Note:

The address space of IPv4 is
2^{32} or 4,294,967,296.

Figure 4.1 *Dotted-decimal notation*



Note:

The binary, decimal, and hexadecimal number systems are reviewed in Appendix B.

Example 1

Change the following IP 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

Example 1

Change the following IP 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 2

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

a. 111.56.45.78 *b. 221.34.7.82*

c. 241.8.56.12 *d. 75.45.34.78*

Example 2

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

a. 111.56.45.78 *b. 221.34.7.82*

c. 241.8.56.12 *d. 75.45.34.78*

Solution

We replace each decimal number with its binary equivalent:

a. 01101111 00111000 00101101 01001110
b. 11011101 00100010 00000111 01010010
c. 11110001 00001000 00111000 00001100
d. 01001011 00101101 00100010 01001110

Example 3

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

a. 111.56.045.78

b. 221.34.7.8.20

c. 75.45.301.14

d. 11100010.23.14.67

Example 3

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

a. 111.56.045.78

b. 221.34.7.8.20

c. 75.45.301.14

d. 11100010.23.14.67

Solution

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

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

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

d. 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.

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

Example 4

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

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

Solution

We replace each group of 4 bits with its hexadecimal equivalent (see Appendix B). Note that hexadecimal notation normally has no added spaces or dots; however, 0X (or 0x) is added at the beginning or the subscript 16 at the end to show that the number is in hexadecimal.

a. $0X810B0BEF$ *or* $810B0BEF_{16}$

b. $0XC1831BFF$ *or* $C1831BFF_{16}$

4.2 CLASSFUL ADDRESSING

*IP addresses, when started a few decades ago, used the concept of classes. This architecture is called **classful addressing**. In the mid-1990s, a new architecture, called classless addressing, was introduced and will eventually supersede the original architecture. However, part of the Internet is still using classful addressing, but the migration is very fast.*

The topics discussed in this section include:

Recognizing Classes
Netid and Hostid
Classes and Blocks
Network Addresses
Sufficient Information
Mask
CIDR Notation
Address Depletion

Figure 4.2 *Occupation of the address space*

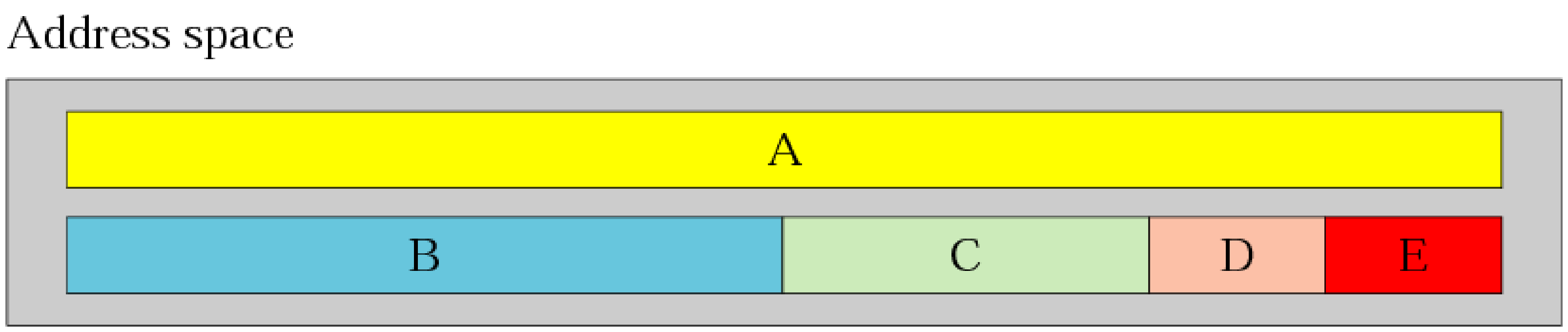


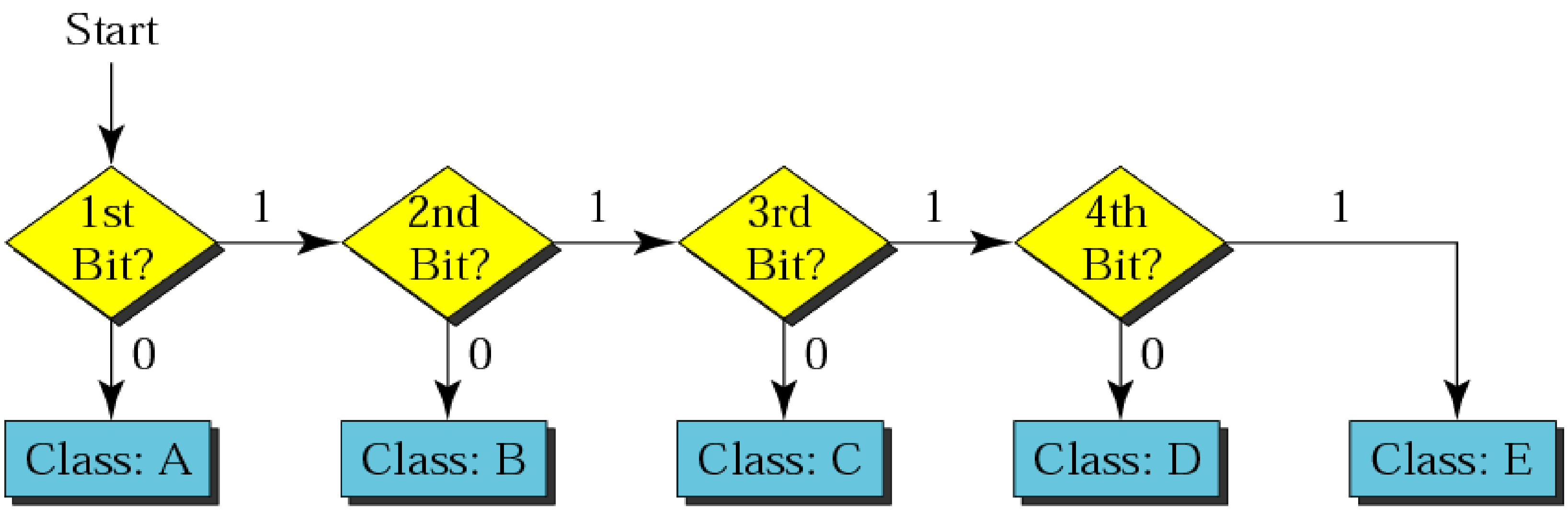
Table 4.1 Addresses per class

Class	*Number of Addresses*	*Percentage*
A	$2^{31} = 2,147,483,648$	50%
B	$2^{30} = 1,073,741,824$	25%
C	$2^{29} = 536,870,912$	12.5%
D	$2^{28} = 268,435,456$	6.25%
E	$2^{28} = 268,435,456$	6.25%

Figure 4.3 *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**			

Figure 4.4 *Finding the address class*



Example 5

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

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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 each address:

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

Example 6

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 4.4.
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 0; the second bit is 1. This is a class B address.
d. The first 4 bits are 1s. This is a class E address..

Figure 4.5 *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 each address:

a. 227.12.14.87 *b.193.14.56.22* *c.14.23.120.8*
d. 252.5.15.111 *e.134.11.78.56*

Example 7

Find the class of each address:

a. 227.12.14.87 b.193.14.56.22 c.14.23.120.8
d. 252.5.15.111 e.134.11.78.56

Solution

a. The first byte is 227 (between 224 and 239); the class is D.
b. The first byte is 193 (between 192 and 223); the class is C.
c. The first byte is 14 (between 0 and 127); the class is A.
d. The first byte is 252 (between 240 and 255); the class is E.
e. The first byte is 134 (between 128 and 191); the class is B.

Example 8

In Example 5 we showed that class A has 2^{31} (2,147,483,648) addresses. How can we prove this same fact using dotted-decimal notation?

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In Example 5 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 need to show that the difference between these two numbers is 2,147,483,648. This is a good exercise because it shows us how to define the range of addresses between two addresses. We notice that we are dealing with base 256 numbers here. Each byte in the notation has a weight. The weights are as follows (see Appendix B):

See Next Slide

Example 8 *(continued)*

$$256^3, 256^2, 256^1, 256^0$$

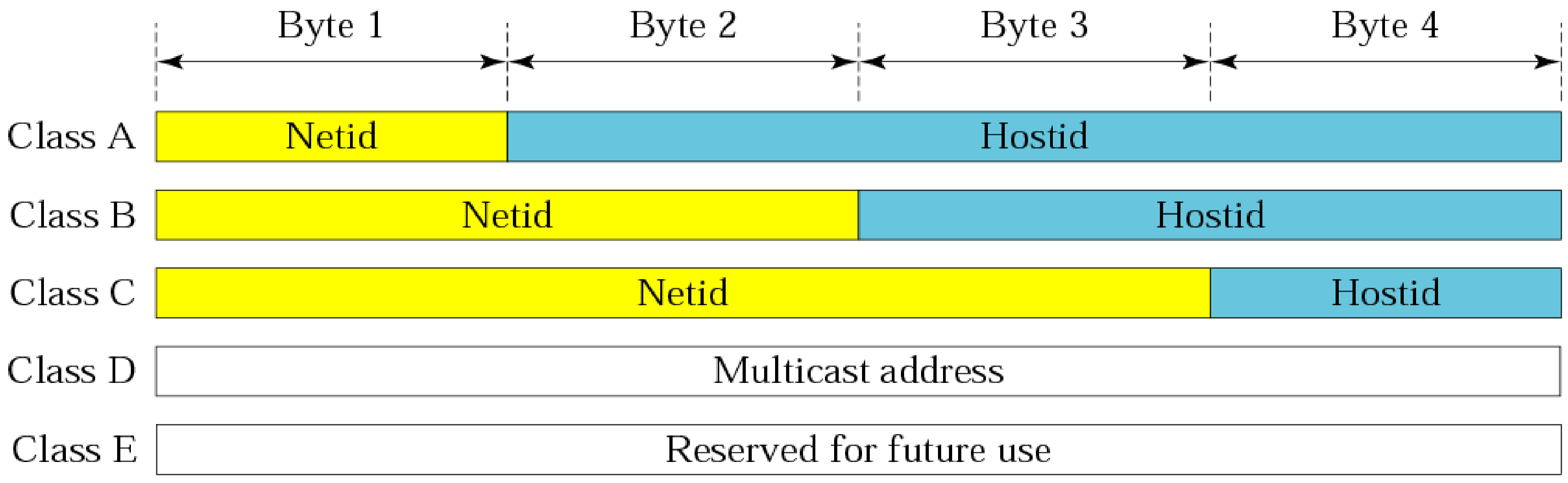
Now to find the integer value of each number, we multiply each byte by its weight:

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

$$\text{First address: } = 0$$

If we subtract the first from the last and add 1 to the result (remember we always add 1 to get the range), we get 2,147,483,648 or 2^{31}.

Figure 4.6 *Netid and hostid*



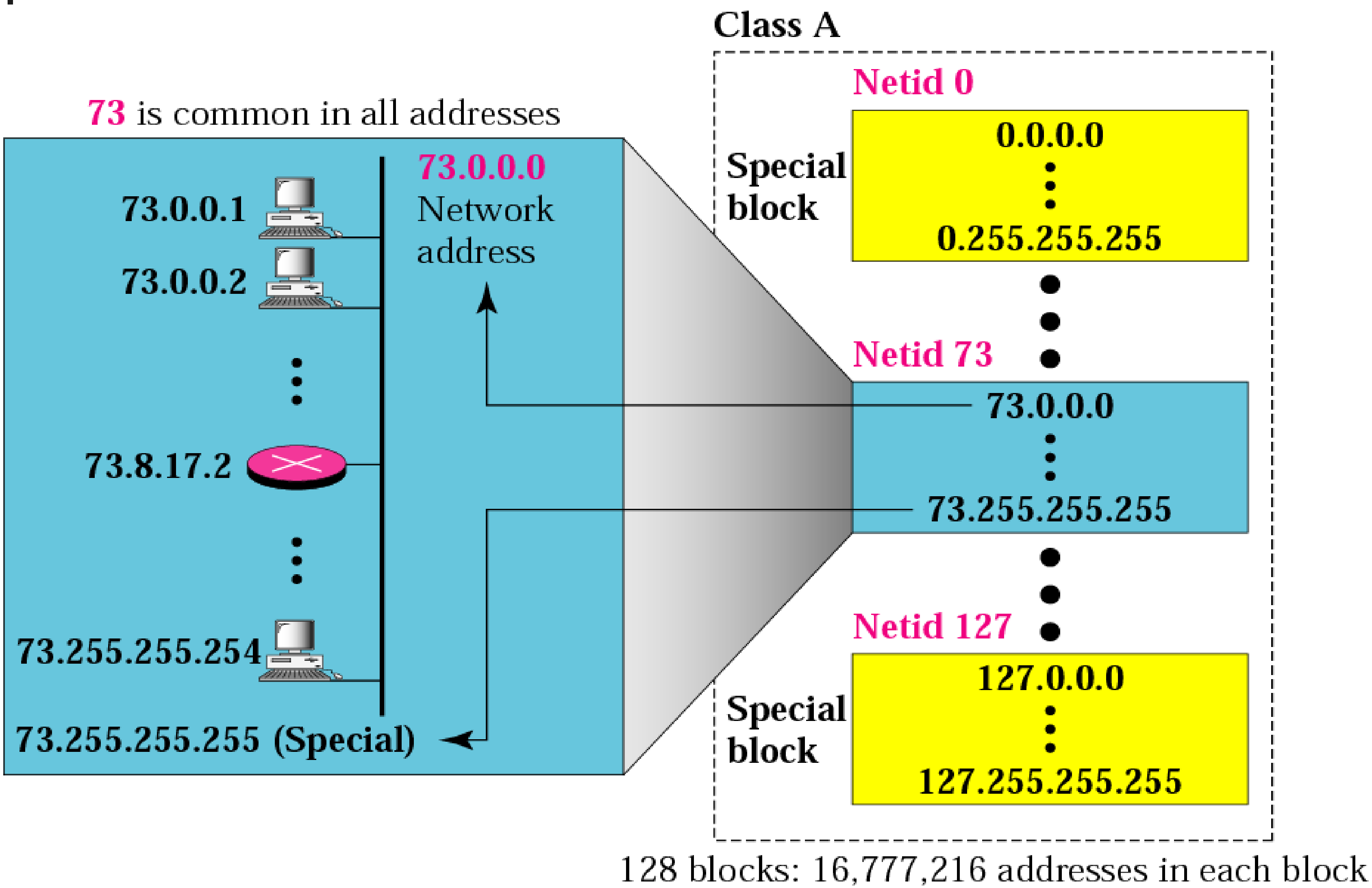
Class A (Classes and Blocks)

- Class A divided into 128 blocks having different netid.
- 1st Block has addresses from 0.0.0.0 to 0.255.255.255 (netid 0)
- For each block of addresses first byte (netid) is same.
- 1st and Last block reserved for future use.
- Netid 10 used for private addresses.
- No. of organizations that can have Class A addresses is 125.
- Each block contains 16,777,216 addresses.

Note:

Millions of class A addresses are wasted.

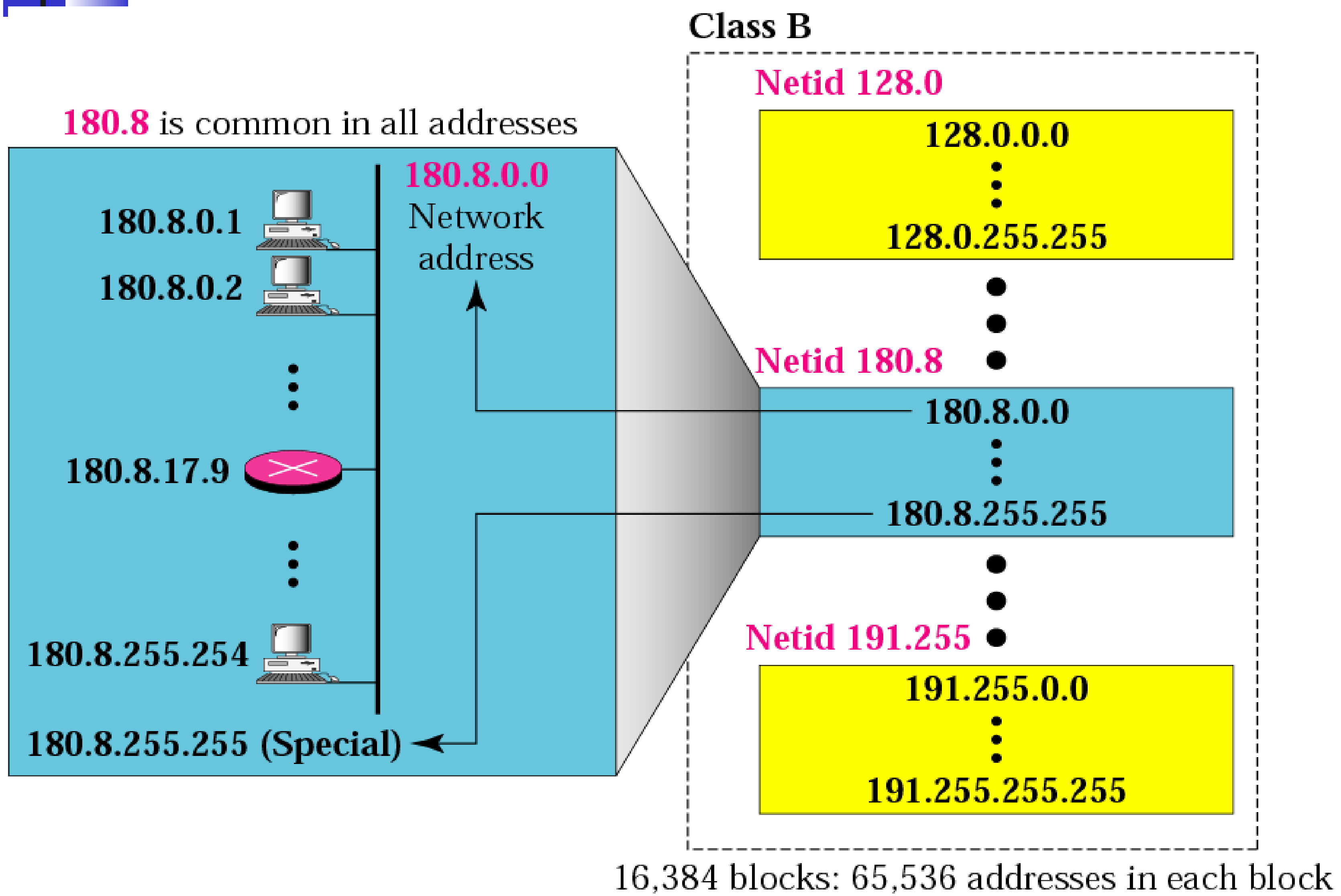
Figure 4.7 *Blocks in class A*



Class B (Classes and Blocks)

- Class B divided into 16,384 blocks having different netid.
- 1st Block has addresses from 128.0.0.0 to 128.0.255.255 (netid 128.0)
- For each block of addresses first two bytes (netid) is same.
- Last block covers from 191.255.0.0 to 191.255.255.255 (netid 191.255)
- Sixteen blocks reserved for private addresses.
- No. of organizations that can have Class B addresses is 16,368.
- Each block contains 65,536 addresses.

Figure 4.8 *Blocks in class B*



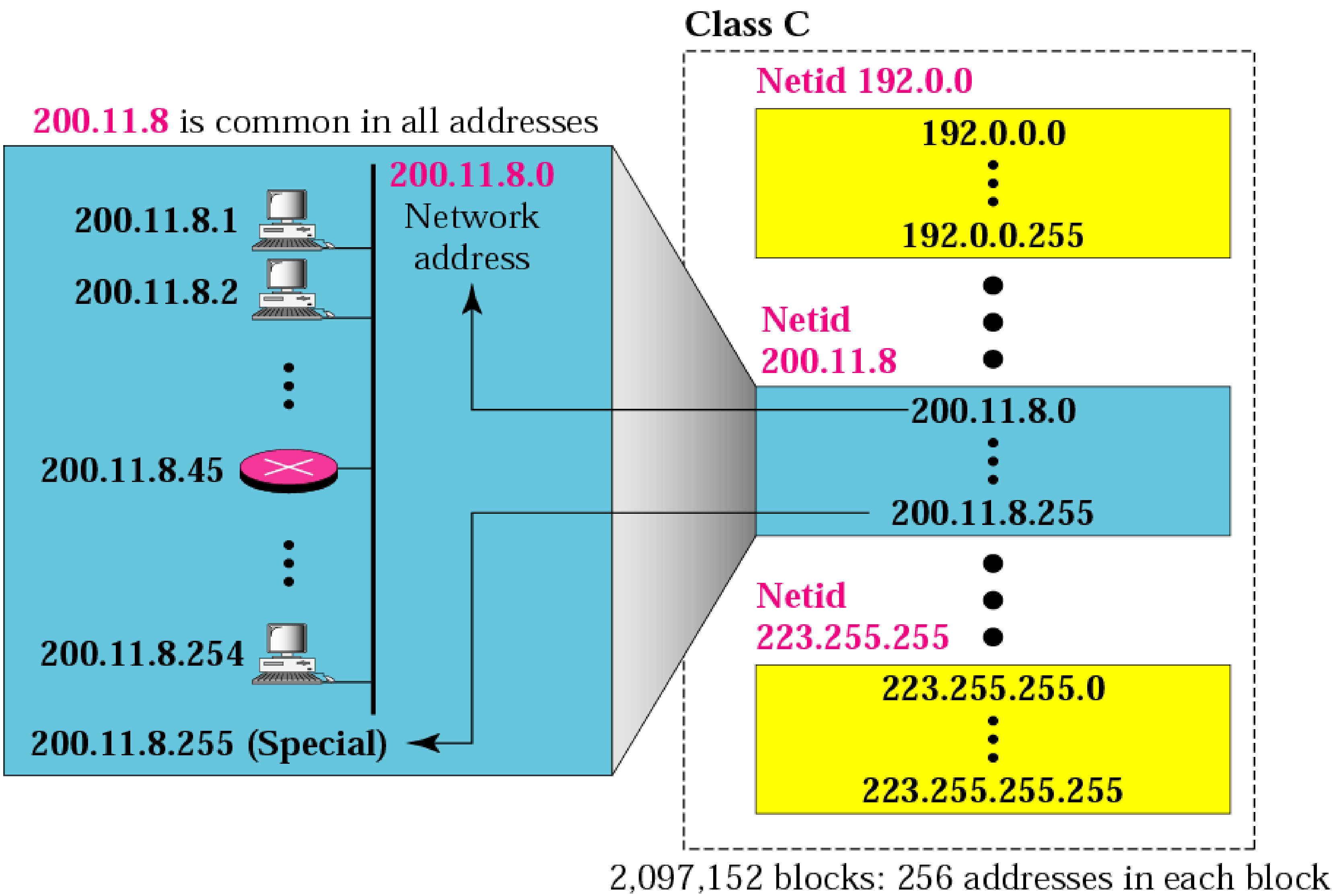
Note:

Many class B addresses are wasted.

Class C (Classes and Blocks)

- Class C divided into 2,097,152 blocks having different netid.
- 1st Block has addresses from 192.0.0.0 to 192.0.0.255 (netid 192.0.0)
- For each block of addresses first three bytes (netid) is same.
- Last block covers from 223.255.255.0 to 223.255.255.255 (netid 223.255.255)
- 256 blocks reserved for private addresses.
- No. of organizations that can have Class C addresses is 2,096,896.
- Each block contains 256 addresses.

Figure 4.9 *Blocks in class C*



Note:

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

Note:

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

Note:

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

Note:

In classful addressing, the network address (the first address in the block) is the one that is assigned to the organization. The range of addresses can automatically be inferred from the network address.

Network Addresses

- First address in the block
- Defines network to rest of the Internet
- Routers route the packet based on network address.
- Given the network address, we can find the class of the address, the block and range of addresses in the block.

Example 9

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

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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.

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.

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.

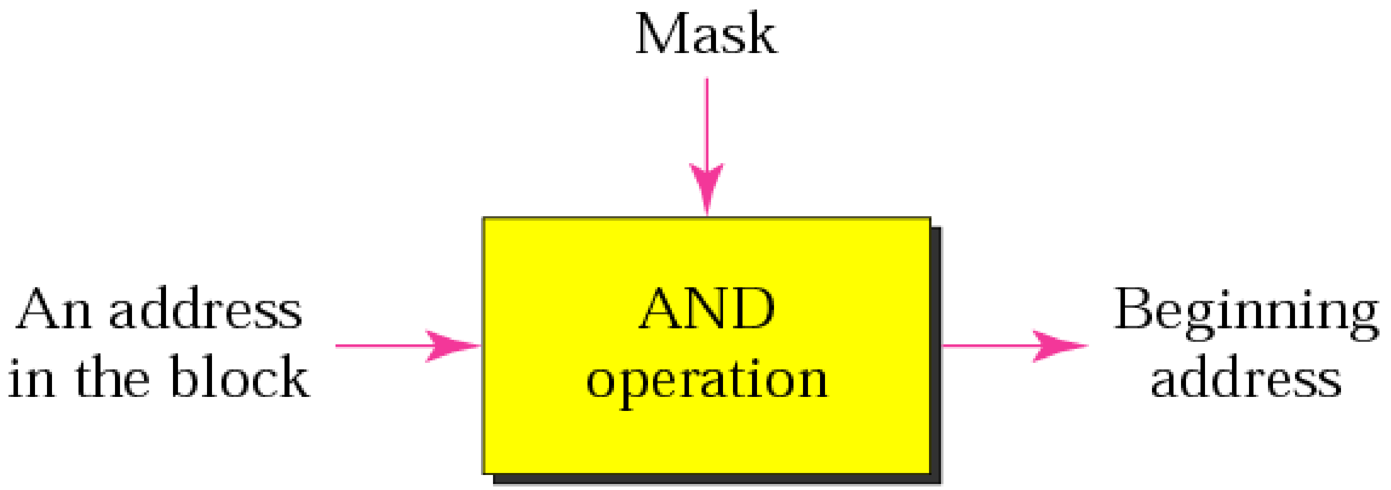
Mask

- If address is given can we find the network address?
- Because router needs to extract network address from destination address.
- First find the class of address and the netid.
- Then set hostid to zero to find network address.
- Ex. IP given is: 134.45.78.2, we can find that Class is B, so netid is 134.45 and network address comes to 134.45.0.0

Mask

- *A mask is 32-bit number that gives first address in the block (i.e. A network address) when bitwise ANDed with an address in the block.*
- *See fig.*

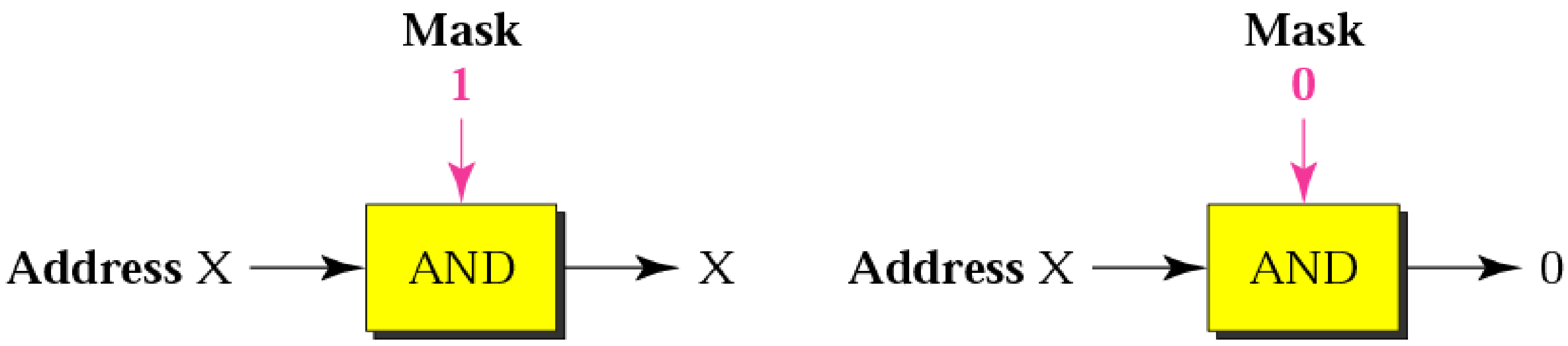
Figure 4.10 *Masking concept*



Mask

- Masking uses a bitwise AND operation.
- Operation is applied bit by bit to the address and the mask.
- AND operation does the following
  - If bit in mask is 1, it is retained in output.
  - If the bit in mask is 0, a 0 bit in output is result.
- See fig.

Figure 4.11 *AND operation*



Three masks, one for each class.
The 1s preserve the NetId.

Table 4.2 Default masks for each class

Class	*Mask in binary*	*Mask in dotted-decimal*
A	**11111111** 00000000 00000000 00000000	**255.**0.0.0
B	**11111111 11111111** 00000000 00000000	**255.255.**0.0
C	**11111111 11111111 11111111** 00000000	**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, find the beginning address (network address).

Example 12

Given the address 23.56.7.91, 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, find the beginning address (network address).

Example 13

Given the address 132.6.17.85, 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, find the beginning address (network address).

Example 14

Given the address 201.180.56.5, 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.

Note:

Note that we must not apply the default mask of one class to an address belonging to another class.

4.3 OTHER ISSUES

In this section, we discuss some other issues that are related to addressing in general and classful addressing in particular.

The topics discussed in this section include:

Multihomed Devices
Location, Not Names
Special Addresses
Private Addresses
Unicast, Multicast, and Broadcast Addresses

Multihomed Devices

- Any device connected to more than one network must have more than one internet Address.
- Computer connected to different networks is called multihomed computer.
- Multihomed computer has more than one address, belonging to different class.
- Router must be connected and has more than one IP address.
- Ex. fig. One multihomed computer and one router. (Router has 3 IP addresses.)

Figure 4.12 *Multihomed devices*

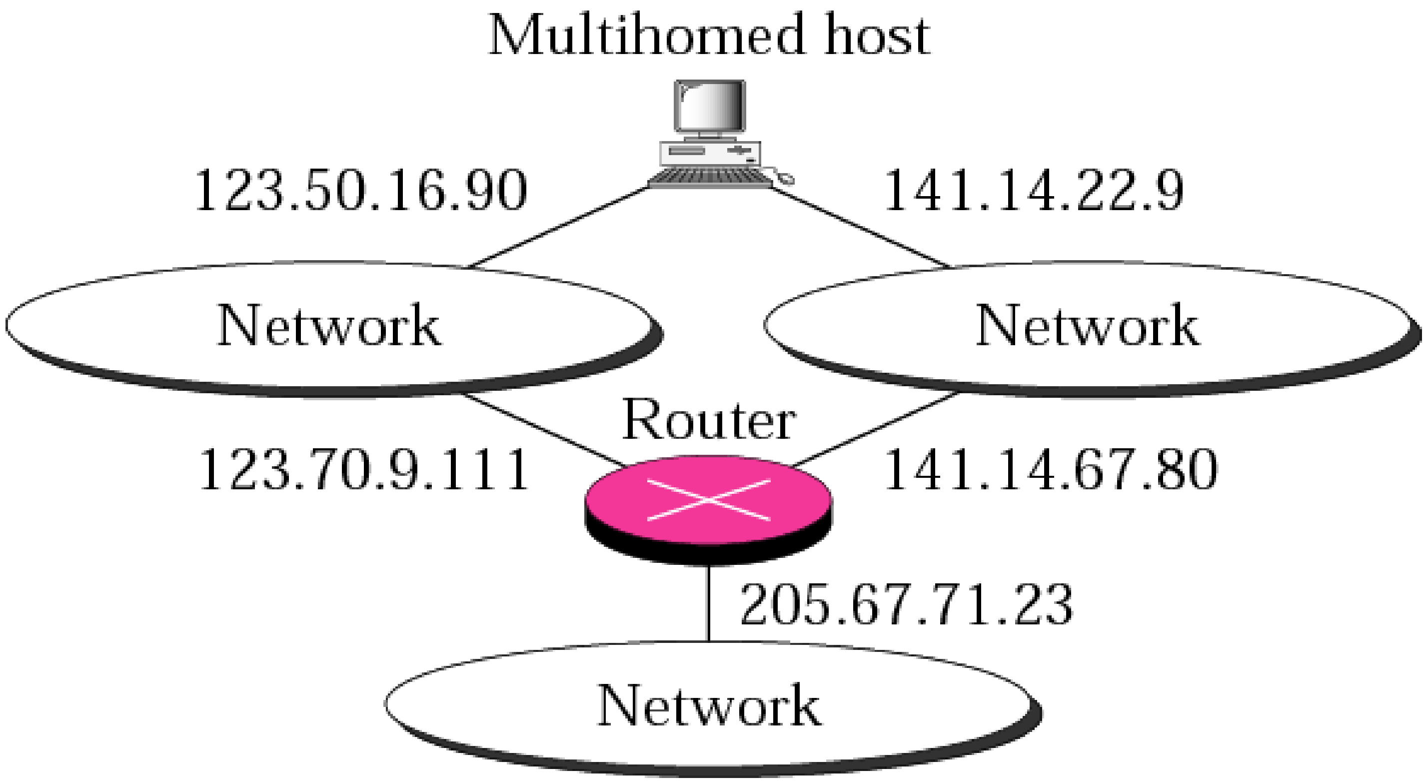
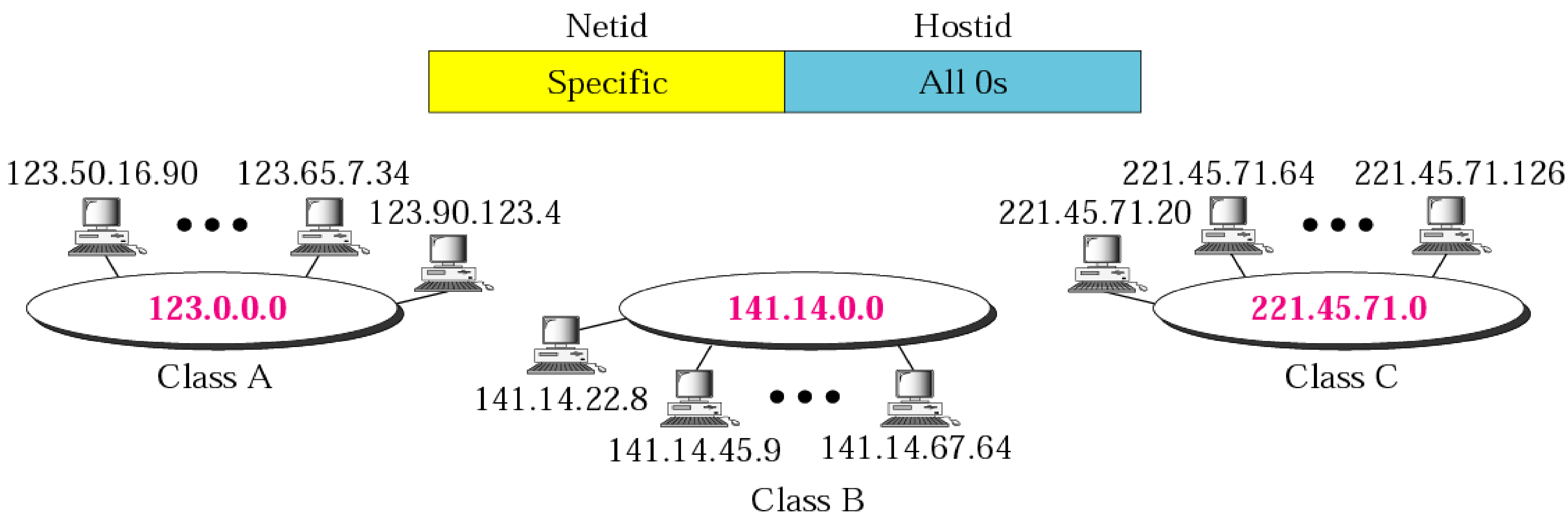


Table 4.3 Special addresses

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

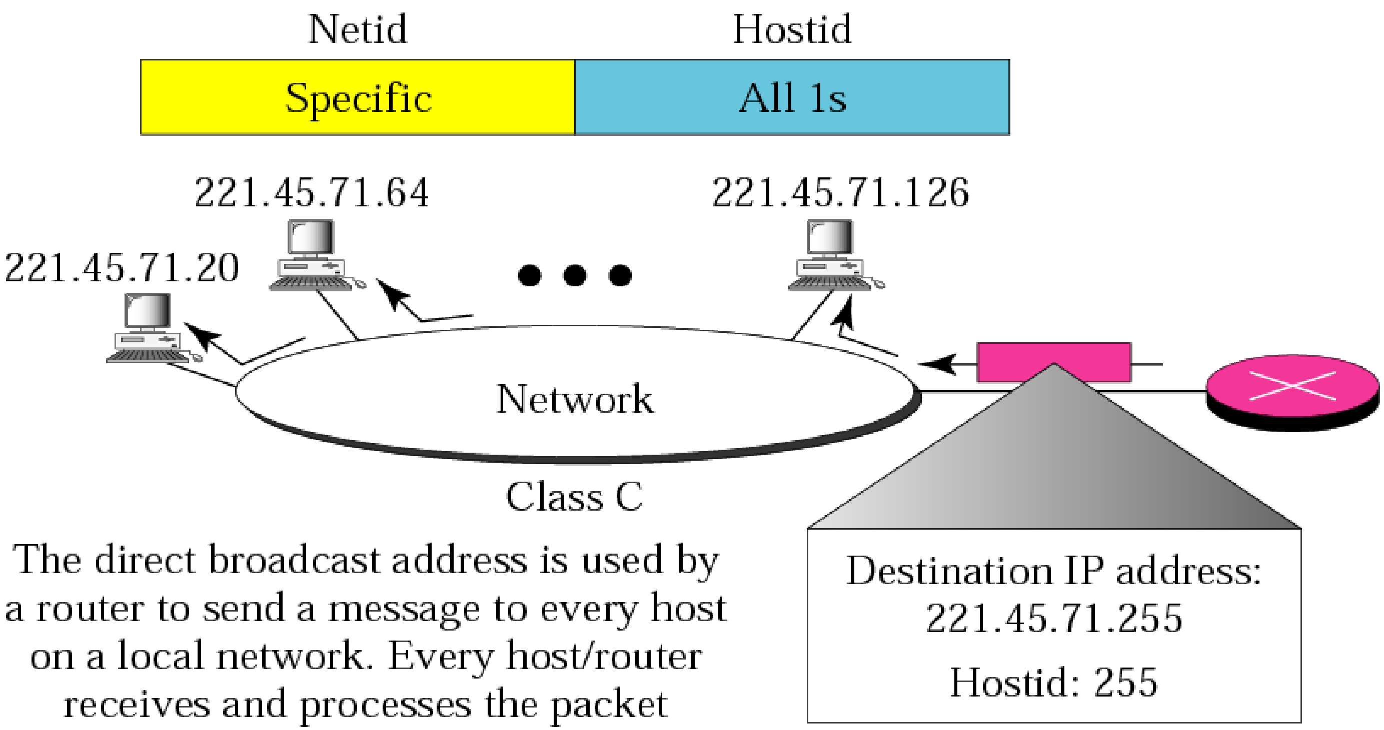
Figure 4.13 *Network address*



Direct Broadcast Address

- If hostid is all 1's.
- Used by router to send packet to all hosts in the network.
- All hosts accept this packet.
- Reduces number of available hostids for each netid in class A,B,C.
- Ex.: Router sends a Datagram using destination IP Addr. With hostid all 1's.

Figure 4.14 *Example of direct broadcast address*

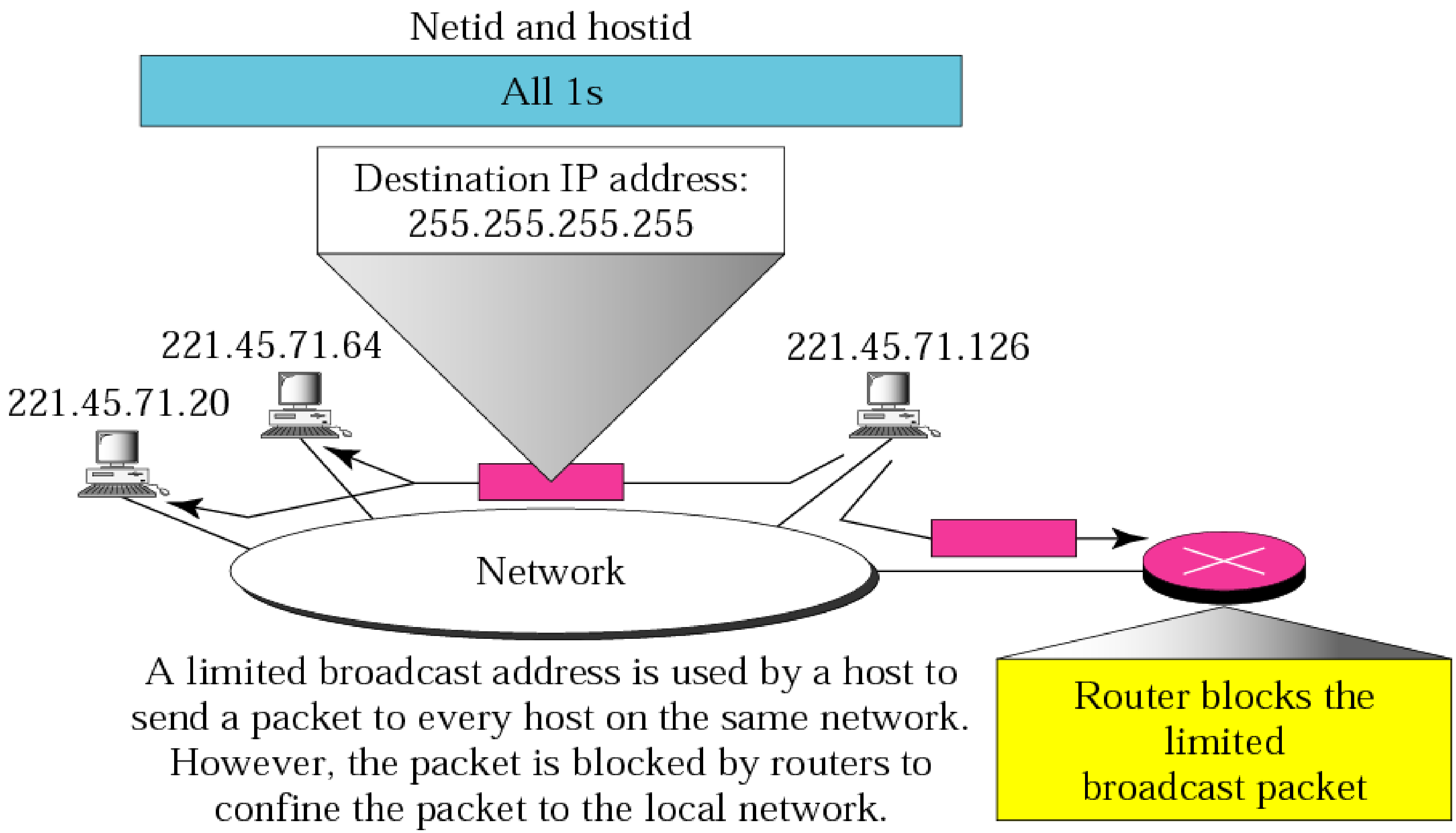


The direct broadcast address is used by a router to send a message to every host on a local network. Every host/router receives and processes the packet with a direct broadcast address.

Limited Broadcast Address

- If all 1's for netid and hostid.
- Used by hosts to send message to every other hosts in the network.
- Router blocks this packet from going outward.
- Address belongs to **Class E**
- All hosts accept this packet.
- Ex.: Host sends a Datagram using destination IP Addr. all 1's i.e. 255.255.255.255

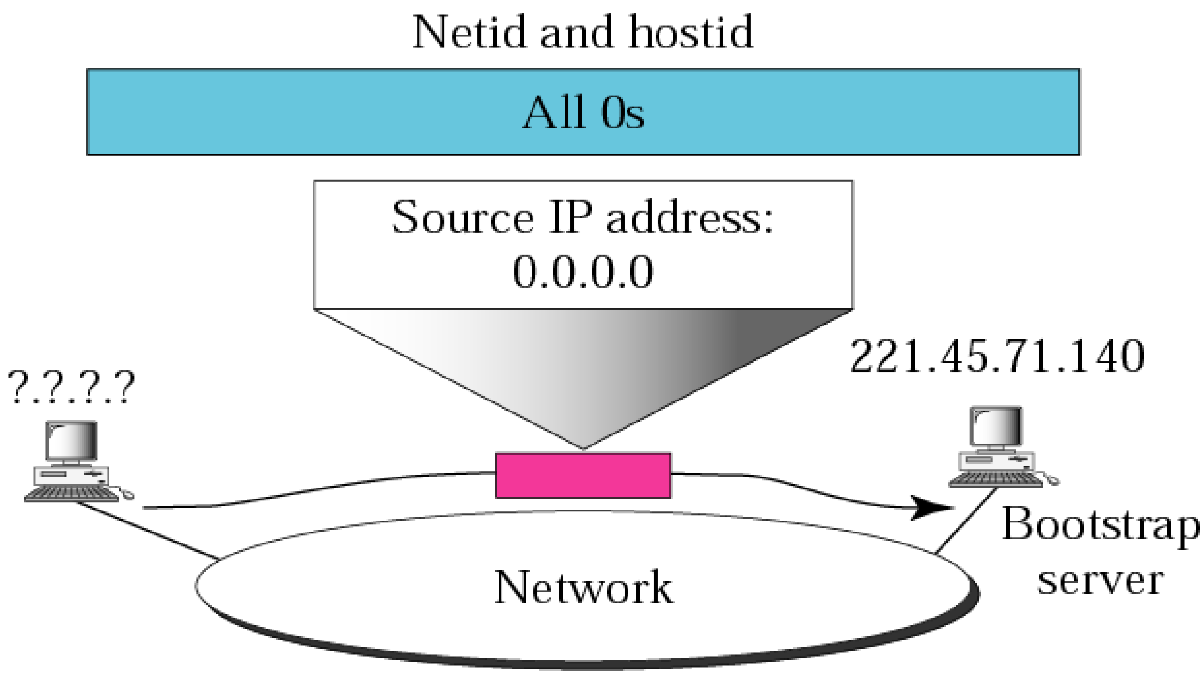
Figure 4.15 *Example of limited broadcast address*



This host on this network

- Ip addr. Composed of all 0s means this host on this network.
- When a host does not know its ip.
- Sends a packet to bootstrap server using this ip as src and limited broadcast ip as dst addr.
- It is always a class A addr regardless of network.

Figure 4.16 *Examples of “this host on this network”*

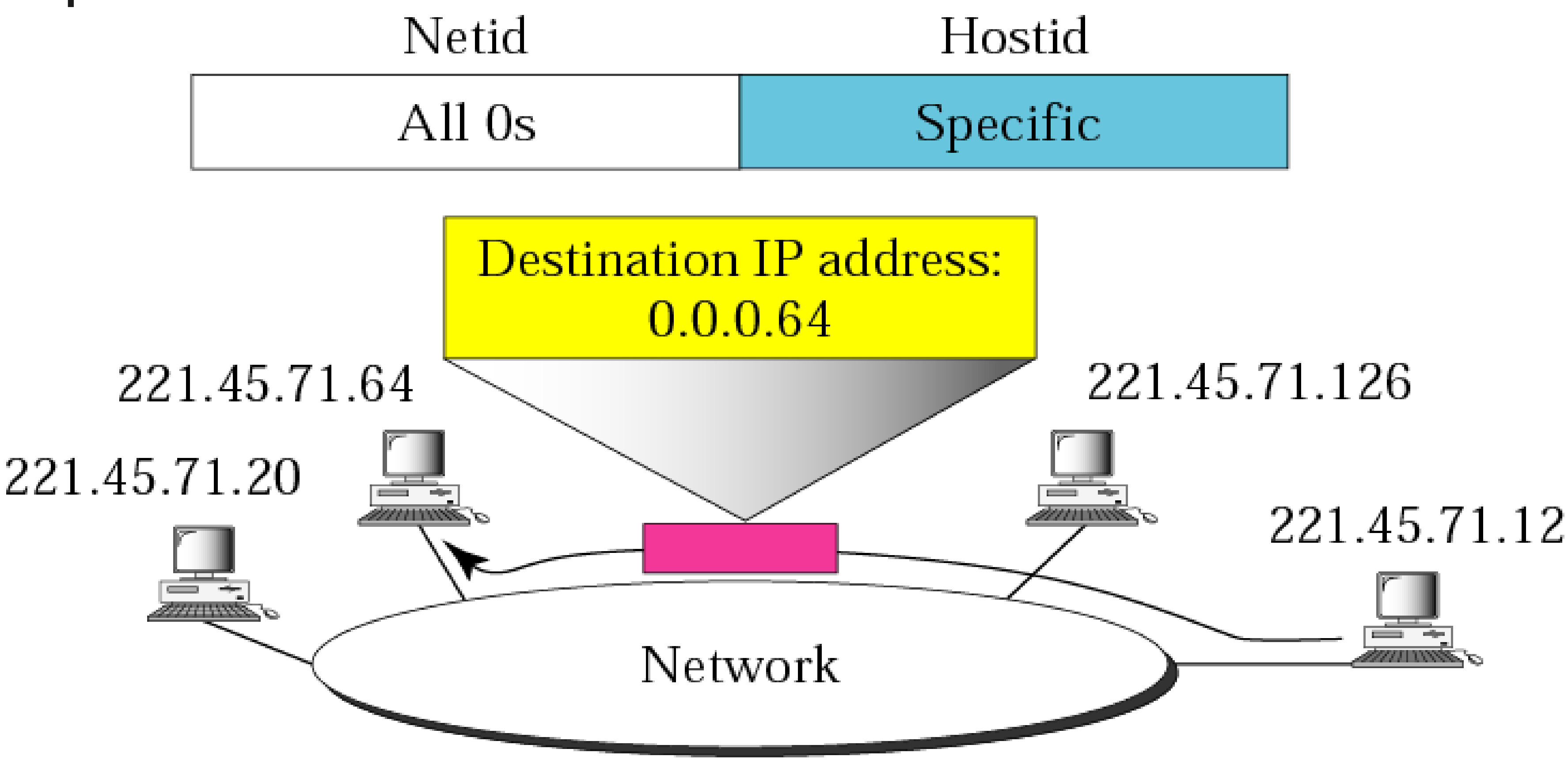


A host that does not know its IP address uses the IP address 0.0.0.0 as the source address and 255.255.255.255 as the destination address to send a message to a bootstrap server.

Specific host on this network

- Netid Composed of all 0s means this host on this network.
- Used by host to send a message to another host on same network.
- Packet is blocked by router.
- Used only for dst addr.
- Always a class A addr regardless of network.

Figure 4.17 *Example of "specific host on this network"*

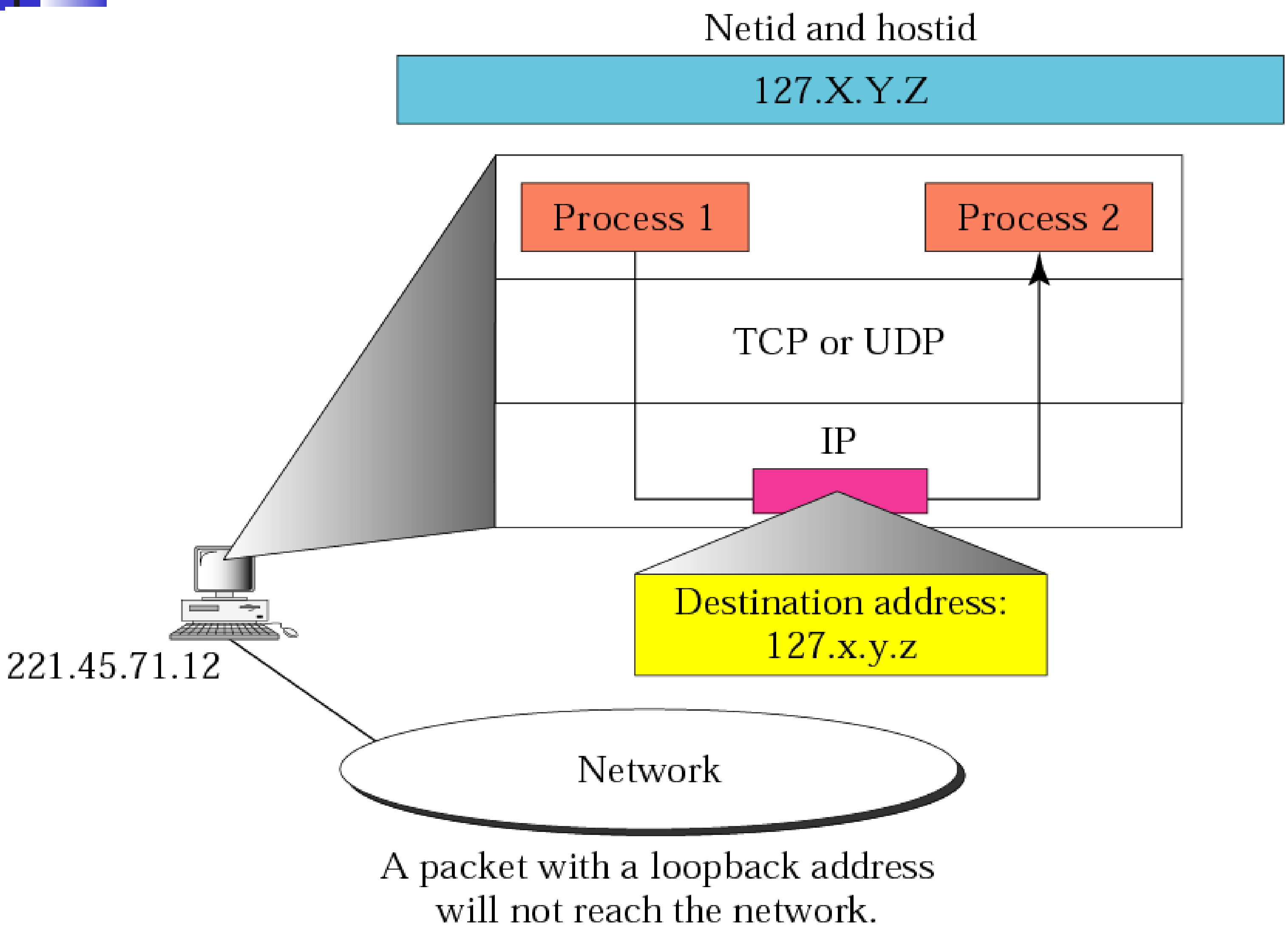


This address is used by a router or host to send a message to a specific host on the same network.

Loopback address

- IP addr. With first byte equal to 127 is used for loopback addr.
- Used to test software on a machine.
- Packet never leaves machine, only returns to protocol software.
- Can be used by client process to send a message to server process on same machine.
- Used only as dst addr.
- It is a Class A addr.

Figure 4.18 *Example of loopback address*



Private Addresses

- Number of blocks in each class are assigned for private use.

Table 4.5 Addresses for private networks

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

Unicast Addresses

- Unicast communication is one-on-one.
- Packet sent from individual src to individual dst.
- Unicast addresses belongs to Class A, B or C.

Multicast Addresses

- Multicast communication is one-on-many.
- Packet sent from individual src to group of dst.
- It is a class D addr.
- Entire address defines a groupid.
- If a system has 7 multicast addr. , says it belongs to seven different groups.
- Used only as dst.
- Can be on local level or global level.

Note:

Multicast delivery will be discussed in depth in Chapter 15.

Table 4.5 Category addresses

Address	*Group*
224.0.0.0	Reserved
224.0.0.1	All SYSTEMS on this SUBNET
224.0.0.2	All ROUTERS on this SUBNET
224.0.0.4	DVMRP ROUTERS
224.0.0.5	OSPFIGP All ROUTERS
224.0.0.6	OSPFIGP Designated ROUTERS
224.0.0.7	ST Routers
224.0.0.8	ST Hosts
224.0.0.9	RIP2 Routers
224.0.0.10	IGRP Routers
224.0.0.11	Mobile-Agents

Table 4.6 Addresses for conferencing

Address	*Group*
224.0.1.7	AUDIONEWS
224.0.1.10	IETF-1-LOW-AUDIO
224.0.1.11	IETF-1-AUDIO
224.0.1.12	IETF-1-VIDEO
224.0.1.13	IETF-2-LOW-AUDIO
224.0.1.14	IETF-2-AUDIO
224.0.1.15	IETF-2-VIDEO
224.0.1.16	MUSIC-SERVICE
224.0.1.17	SEANET-TELEMETRY
224.0.1.18	SEANET-IMAGE

Broadcast Addresses

- Broadcast communication is one-on-all.
- Only on local level.
- Two types: Limited, Direct
- No broadcasting allowed at global level.

4.4 SUBNETTING AND SUPERNETTING

In the previous sections we discussed the problems associated with classful addressing. Specifically, the network addresses available for assignment to organizations are close to depletion. This is coupled with the ever-increasing demand for addresses from organizations that want connection to the Internet. In this section we briefly discuss two solutions: subnetting and supernetting.

The topics discussed in this section include:

Subnetting
Supernetting
Supernet Mask
Obsolescence

Note:

IP addresses are designed with two levels of hierarchy.

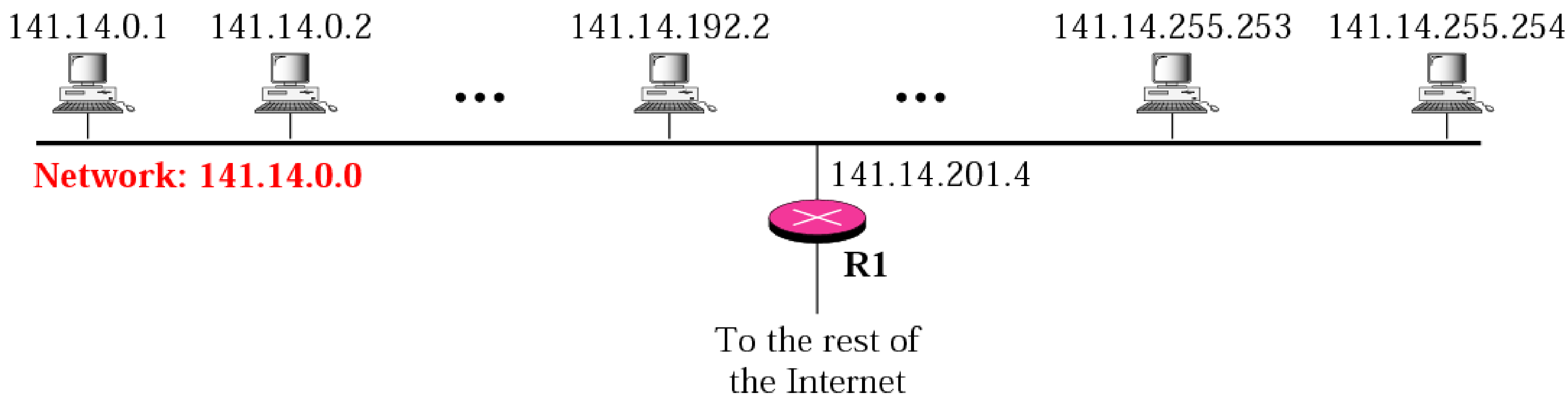
Subnetting

- Network is divided into several smaller subnetworks with each subnet having its own subnet address.
- Two levels is not enough.
- Ex. Fig.
- Hosts not organized into groups.
- All hosts at same level.
- One solution is subnetting.
- Division of network into smaller networks is subnets.

Two levels of hierarchy

- Network is divided into several smaller subnetworks with each subnet having its own subnet address.

A network with two levels of hierarchy (not subnetted)



Three levels of hierarchy

- Intermediate level of hierarchy in IP addr.
- Three levels: site, subnet and host

A network with three levels of hierarchy (subnetted)

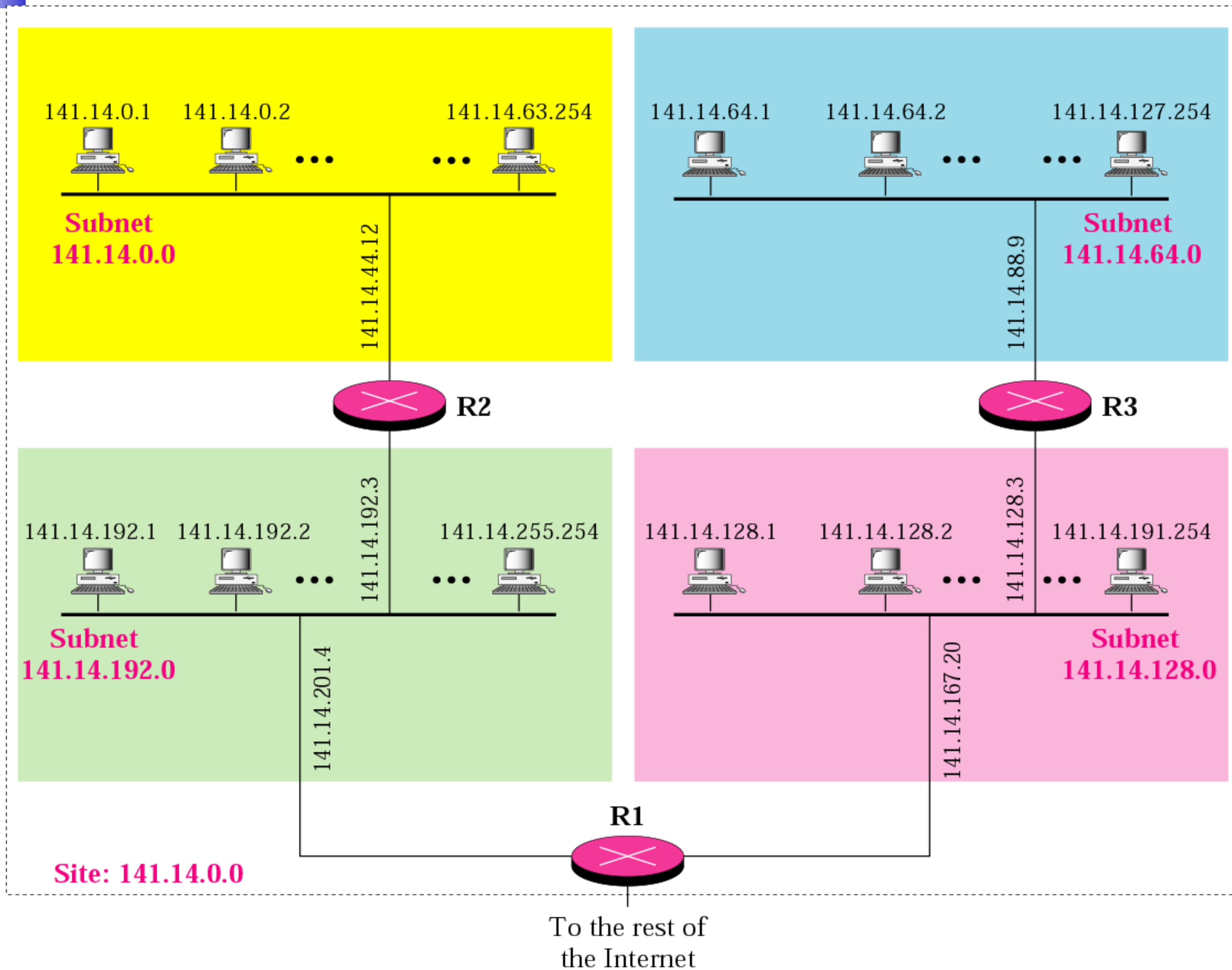
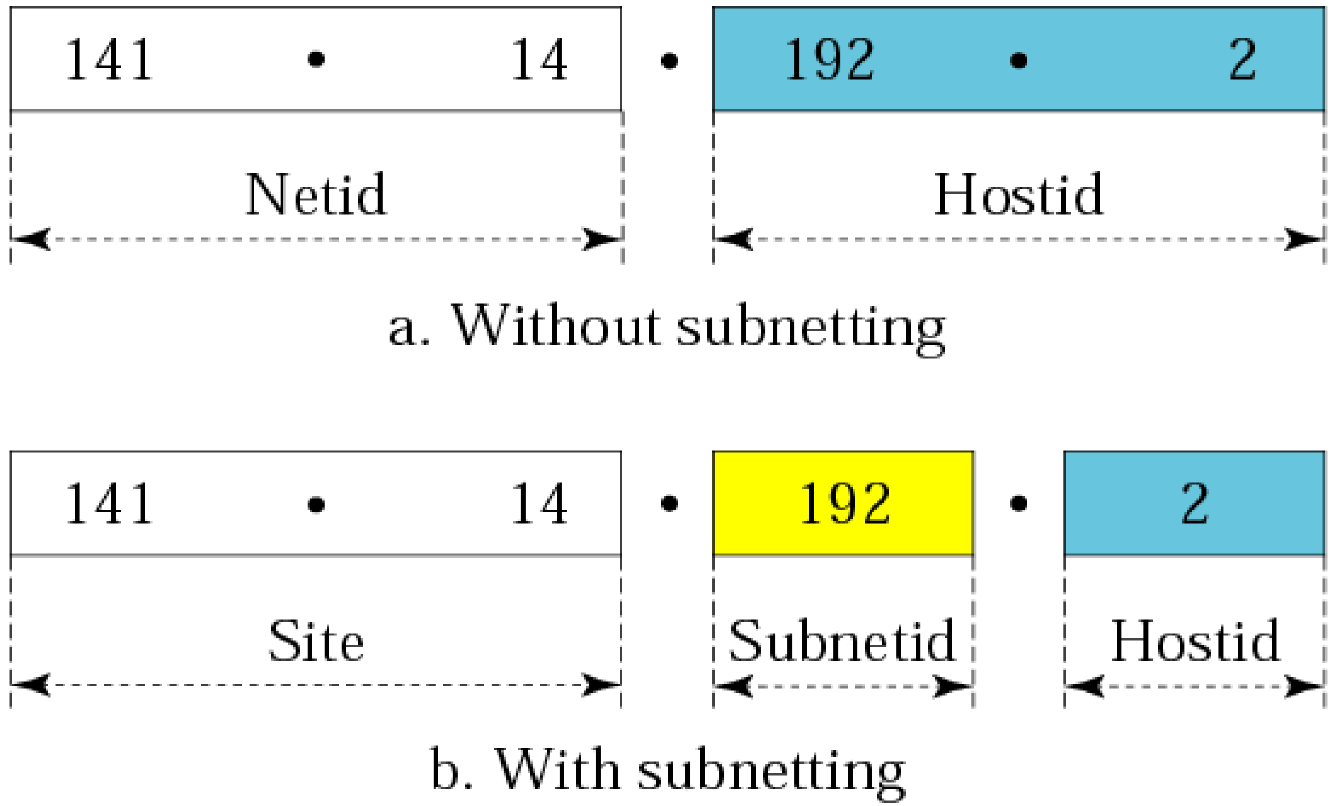


Figure 4.22 *Addresses in a network with and without subnetting*



Three levels of hierarchy

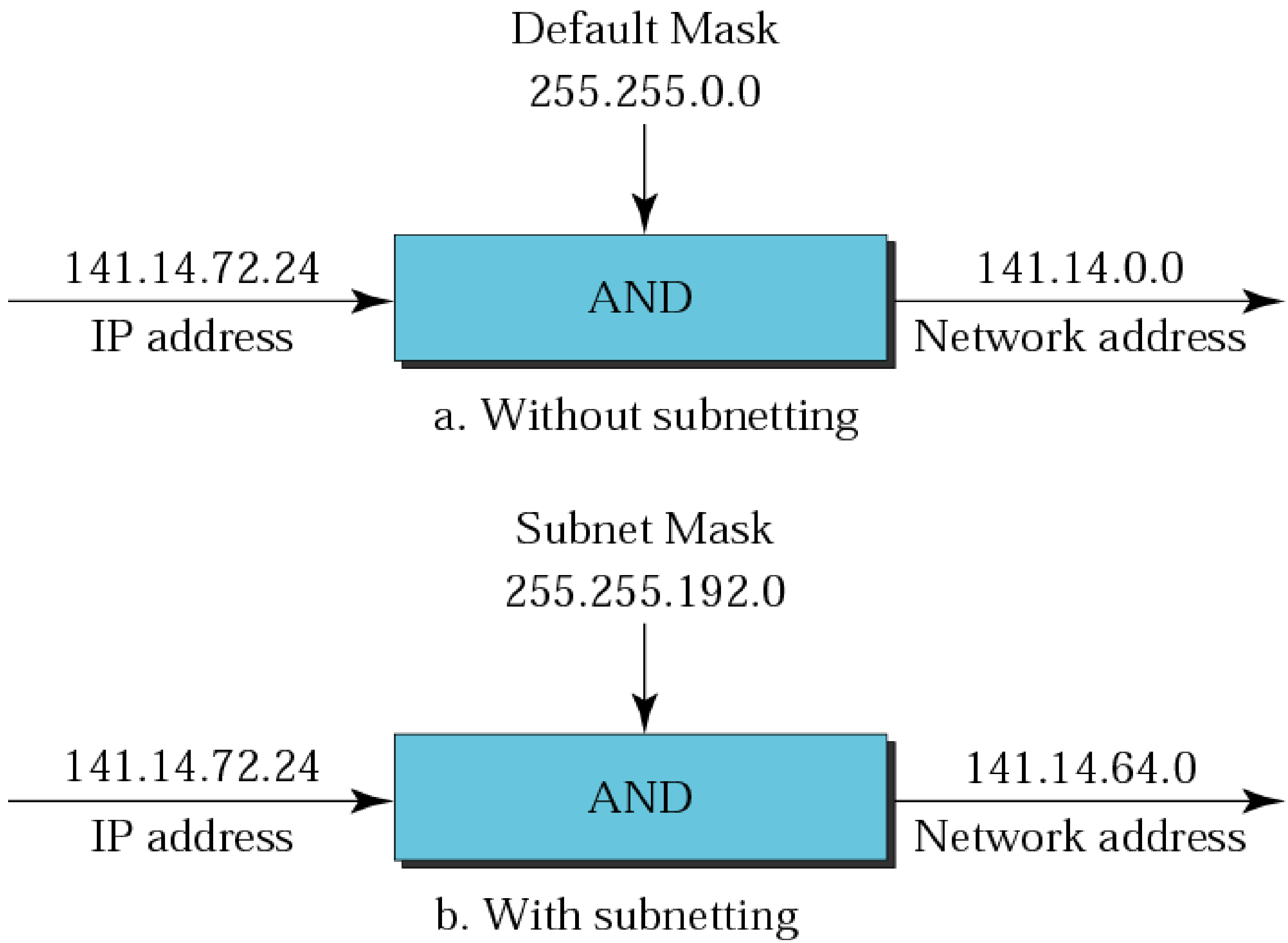
- Routing now involves three steps:
  - Delivery to the site
  - Delivery to subnetwork
  - Delivery to host
- Analogous to telephone no.

Figure 4.23 *Hierarchy concept in a telephone number*

Subnet Mask

- Default mask is used to find the first address in the block or network address.
- Every subnet should have subnet maks.
- Default mask creates network address, subnet mask creates subnetwork address.

Figure 4.24 *Default mask and subnet mask*



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?

Apply the AND operation on the address and subnet mask.

Example 15

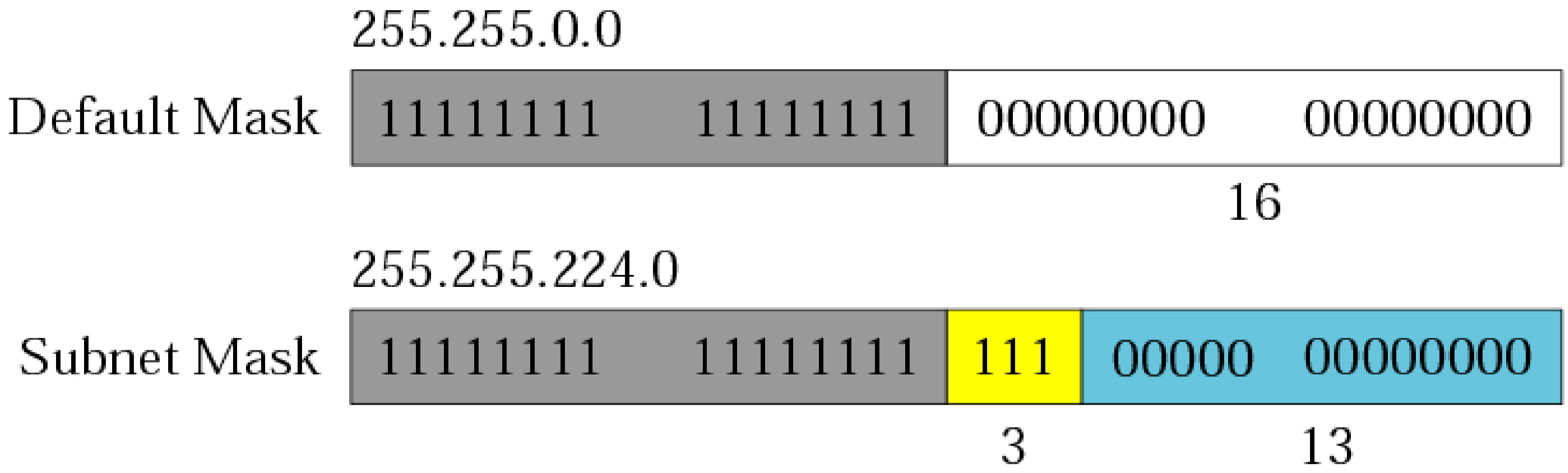
What is the subnetwork address if the destination address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Solution

We apply the AND operation on the address and the subnet mask.

Address	➡ *11001000 00101101 00100010 00111000*
Subnet Mask	➡ *11111111 11111111 11110000 00000000*
Subnetwork Address	➡ *11001000 00101101 00100000 00000000.*

Comparison of a default mask and a subnet mask



Number of subnetworks

- Found by counting the extra 1s that are added to the default mask to make the subnet mask.
- In fig. Extra 1s are 3, so number of subnets possible is 2*2*2=8

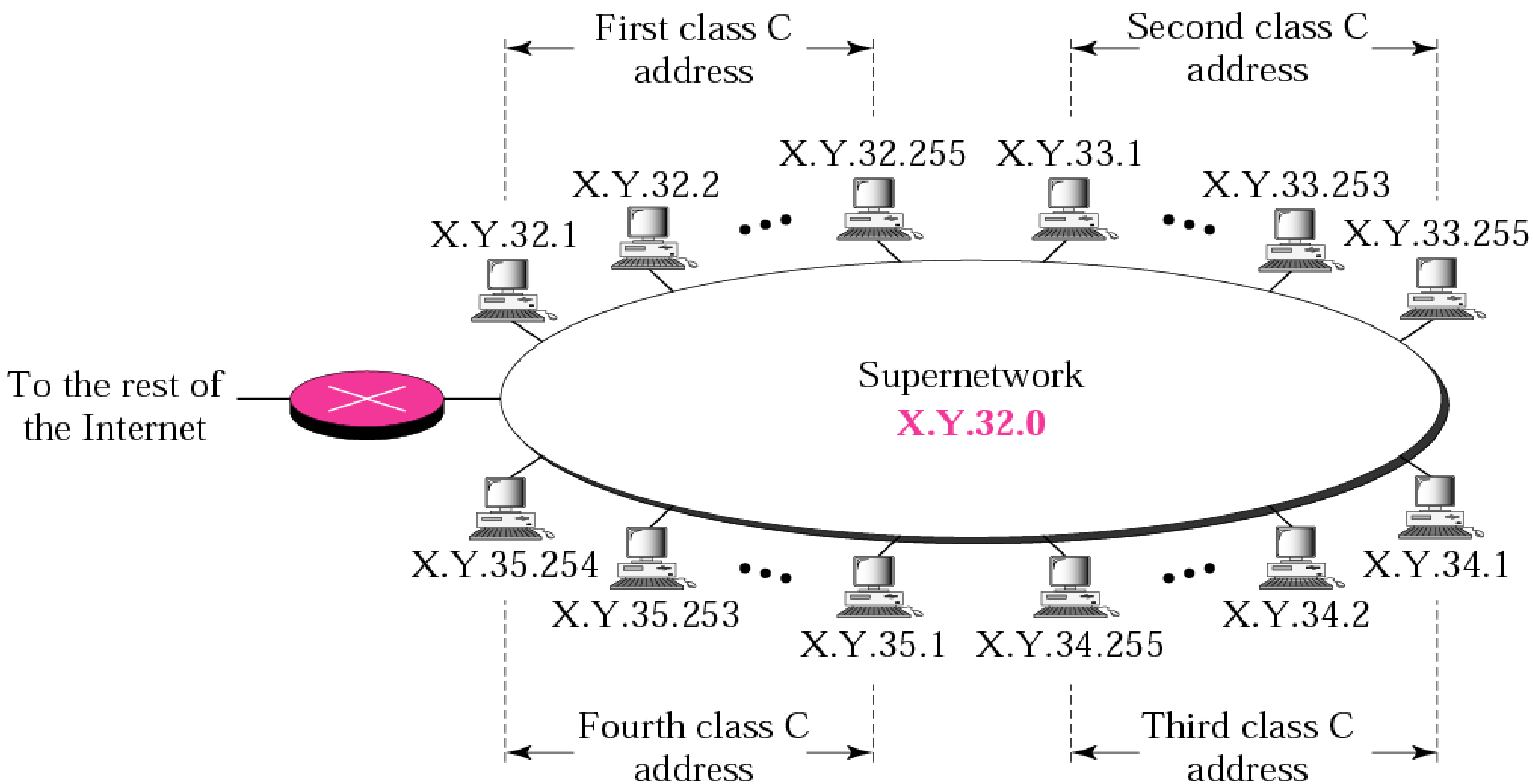
Number of addresses per subnet

- By counting number of 0s in subnet mask.
- In fig. Number of 0s is 13 so number of addresses is 2^13=8192

Supernetting

- An organization can combine several class C addr to create larger range of addresses.
- Several networks are combined to create supernetwork.
- Ex. Fig.

Figure 4.26 *A supernetwork*



Note:

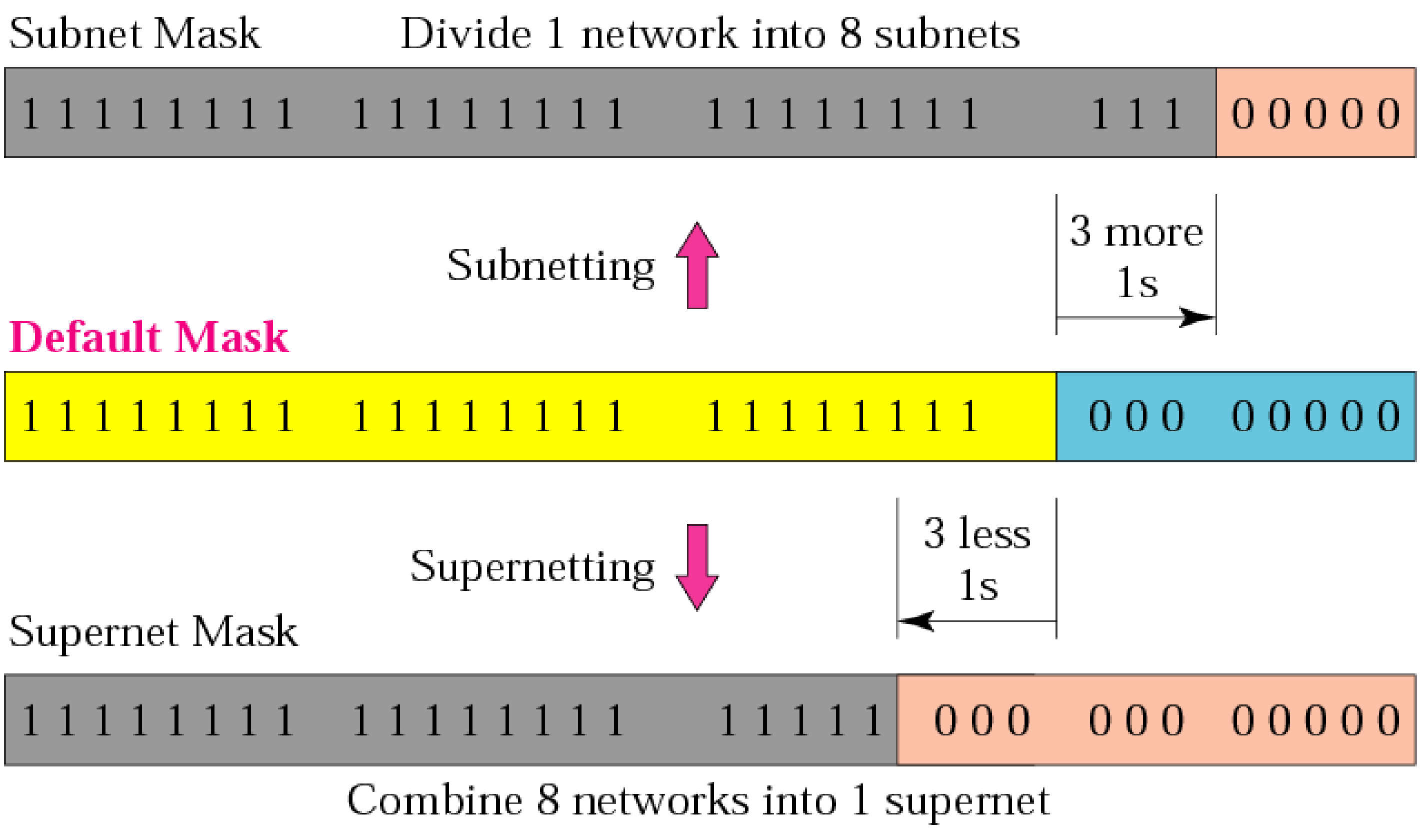
In subnetting, we need the first address of the subnet and the subnet mask to define the range of addresses.

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

Supernet mask

- It is reverse of subnet mask.
- Ex. fig.
- A supernet mask that combines eight blocks into one superblock has three less 1s than the default mask.

Figure 4.27 *Comparison of subnet, default, and upernet masks*



Note:

The idea of subnetting and supernetting of classful addresses is almost obsolete.