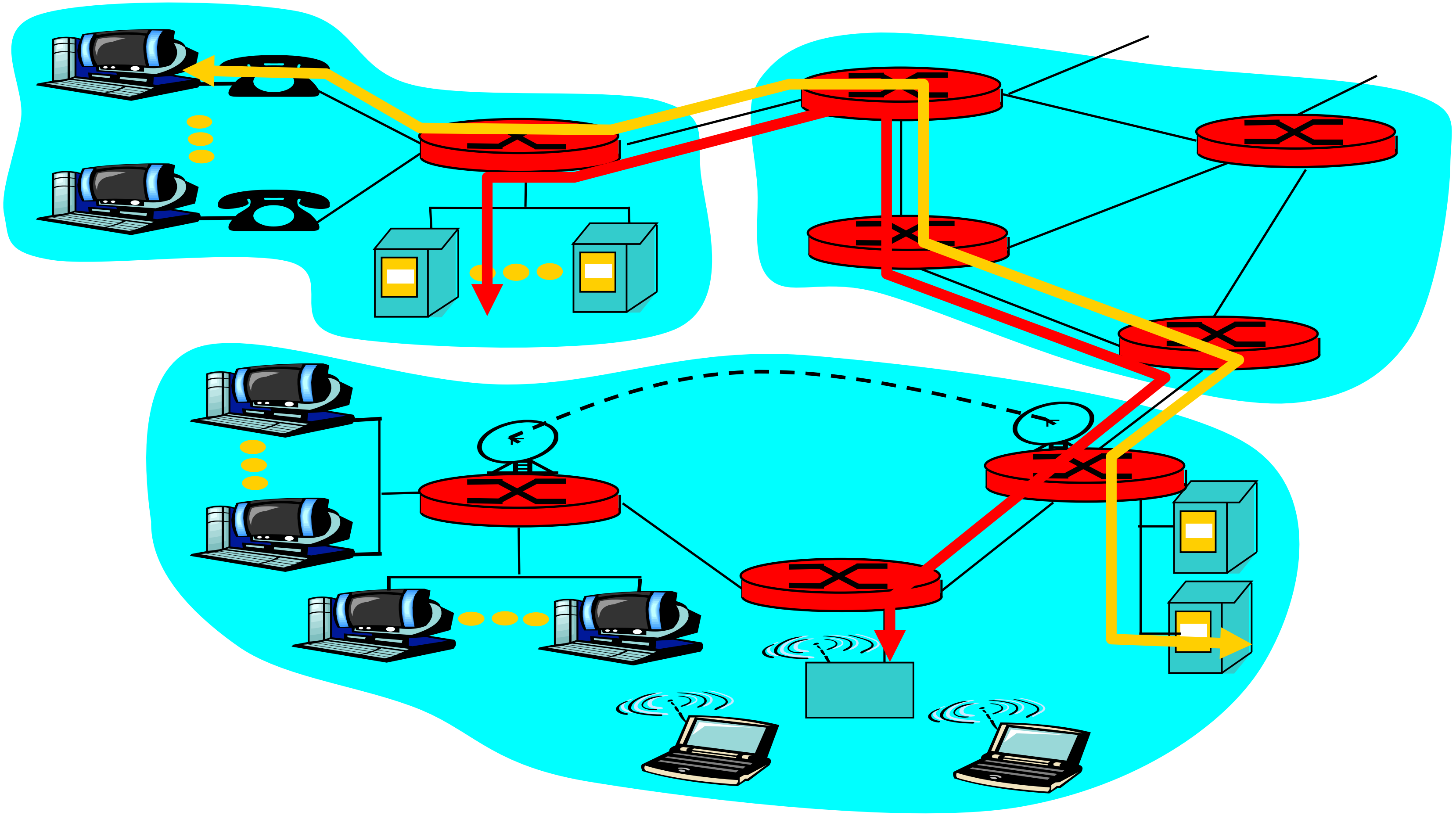
IP Addresses: Classful Addressing

Internet



IPv4

- Every computer on network has an IP address that represent its location on network.
- Two version of IP addresses are available IPv4 and IPv6.

- An IPv4 address is a 32-bit address that uniquely and universally defines the connection of a device (for example, a computer or a router) to the Internet.

- Two devices in the Internet can never have the same address at the same time.

- An address may be assigned to a device for a time period and then taken away and assigned to another device.

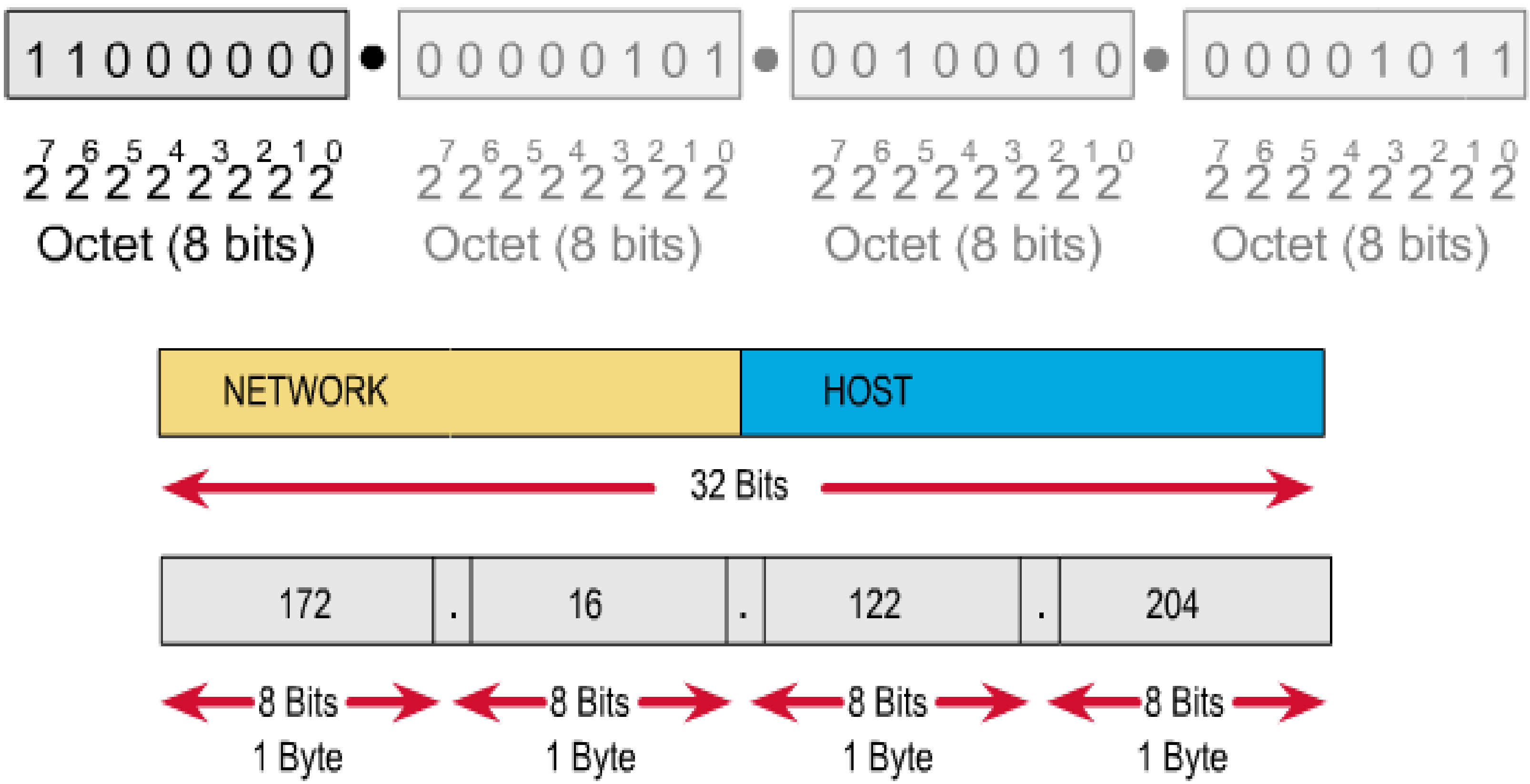
- If a device operating at the network layer has m connections to the Internet, it needs to have m address.(e.g. router)

IPv4

- IP addresses are displayed in dotted decimal notation, and appear as four numbers separated by dots.
- Each number of an IP address is made from eight individual bits known as octet. Each octet can create number value from 0 to 255.
- An IP address would be 32 bits long in binary divided into the two components, network component and host component.
- Network component is used to identify the network that the packet is intend for, and host component is used to identify the individual host on network.
- IP addresses are broken into the two components:
  - **Network component :-** Defines network segment of device.
  - **Host component :-** Defines the specific device on a particular network segment

Internet Addresses

IP Address as a 32-Bit Binary Number



IPv4 Address Space

- IPV4 address space is the total number of addresses used by the protocol.
- If a protocol uses N bits to define an address, the address space is 2^N .
- IPv4 uses 32-bit address.
- The address space=2^{32}=4,294,967,296 (more than 4 billion)
- This means, if there were no restrictions, more than 4 billion devices could be connected to the Internet.

IPv4 Notations

- There are two prevalent notations to show an IPv4 address:

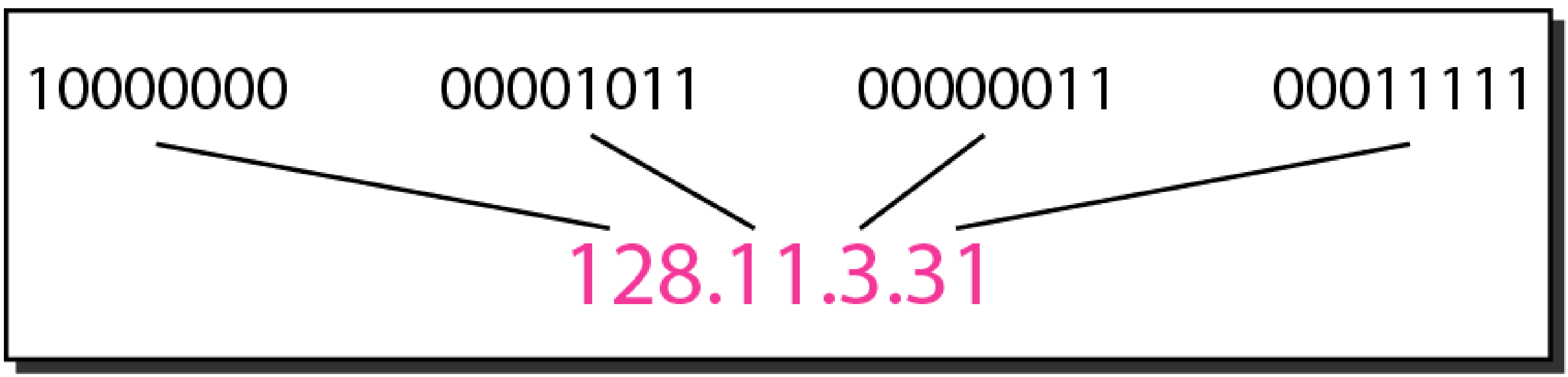
Binary notation:

- Address is displayed as 32 bits.
- IPv4 address referred to as **32-bit address** or **4-byte address**
- Example: **01110101 10010101 00011101 00000010**

Dotted-decimal notation:

- More compact and easier to read
- Written in decimal form with a decimal point(dot) separating the bytes.
- Example: **117.149.29.2**
- Each decimal value range from **0 to 255**

Dotted-decimal notation and binary notation for an IPv4 address



Decimal Equivalents of 8-Bit Patterns

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

Binary and Decimal Conversion

$2^{(7)}$	$2^{(6)}$	$2^{(5)}$	$2^{(4)}$	$2^{(3)}$	$2^{(2)}$	$2^{(1)}$	$2^{(0)}$
128	64	32	16	8	4	2	1

192.57.30.224
11000000.00111001.00011110.11100000

Example-1

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

a. 10000001 00001011 00001011 11101111

b. 11000001 10000011 00011011 11111111

Solution

Replace each group of 8 bits with its equivalent decimal number and add dots for separation.

a. 129.11.11.239

b. 193.131.27.255

Example -2

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

a. 111.56.45.78

b. 221.34.7.82

Solution

Replace each decimal number with its binary equivalent.

a. 01101111 00111000 00101101 01001110

b. 11011101 00100010 00000111 01010010

Example -3

Find the error, if any, in the following IPv4 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 must be no leading zero (045).

b. There can be no more than four numbers.

c. Each number needs to be less than or equal to 255.

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

Example -4

Find the class of each address.

a. <u>**0**</u>0000001 00001011 00001011 11101111

b. <u>**110**</u>00001 10000011 00011011 11111111

c. <u>**14**</u>.23.120.8

d. <u>**252**</u>.5.15.111

Solution

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 byte is 14; the class is A.***

d. ***The first byte is 252; the class is E.***

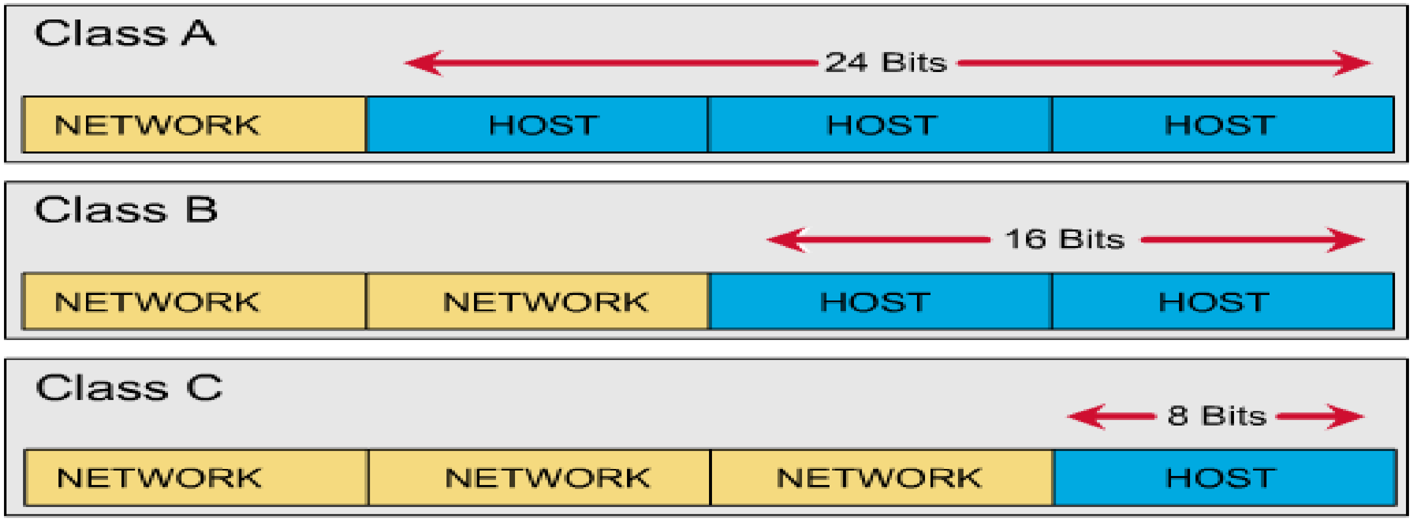
IP Address Classes

	1 Byte 8 Bits	1 Byte 8 Bits	1 Byte 8 Bits	1 Byte 8 Bits
Class A:	N	H	H	H
Class B:	N	N	H	H
Class C:	N	N	N	H

- N = Network number assigned by ARIN
- H = Host number assigned by administrator

Hosts for Classes of IP Addresses

- The 32-bit address is divided into **netid** and **hostid**.
- These part are of varying lengths, depending on the class.
- Dose not apply to classes D and E.



Class A (24 bits for hosts) $2^{24} - 2^{*}$ = 16,777,214 maximum hosts

Class B (16 bits for hosts) $2^{16} - 2^{*}$ = 65,534 maximum hosts

Class C (8 bits for hosts) $2^{8} - 2^{*}$ = 254 maximum hosts

* *Subtracting the network and broadcast reserved address*

Classes and Blocks

- **Class A address:** designed for **large organizations** with a large number of attached hosts or routers. (wasted and not used)

- **Class B address:** designed for **midsize organizations** with ten of thousands of attached hosts or routers(too large for many organizations)
- **Class C address:** designed for **small organizations** with a small number of attached hosts or routers.(too small for many organizations)
- **Class D address:** designed for **multicasting**. (waste of addresses)

- **Class E address:** reserved for future use (waste of addresses)

IPv4 Address Classes

Address Class	First Octet Range	Number of Possible Networks	Number of Hosts per Network
Class A	0 to 127	128 (2 are reserved)	16,777,214
Class B	128 to 191	16,348	65,534
Class C	192 to 223	2,097,152	254

Class D Addresses

- A Class D address begins with binary 1110 in the first octet.
- First octet range 224 to 239.
- Class D address can be used to represent a group of hosts called a host group, or multicast group.

Class E Addresses

- First octet of an IP address begins with 1111
- First octet range 240 to 255.
- Class E addresses are reserved for experimental purposes and should not be used for addressing hosts or multicast groups.

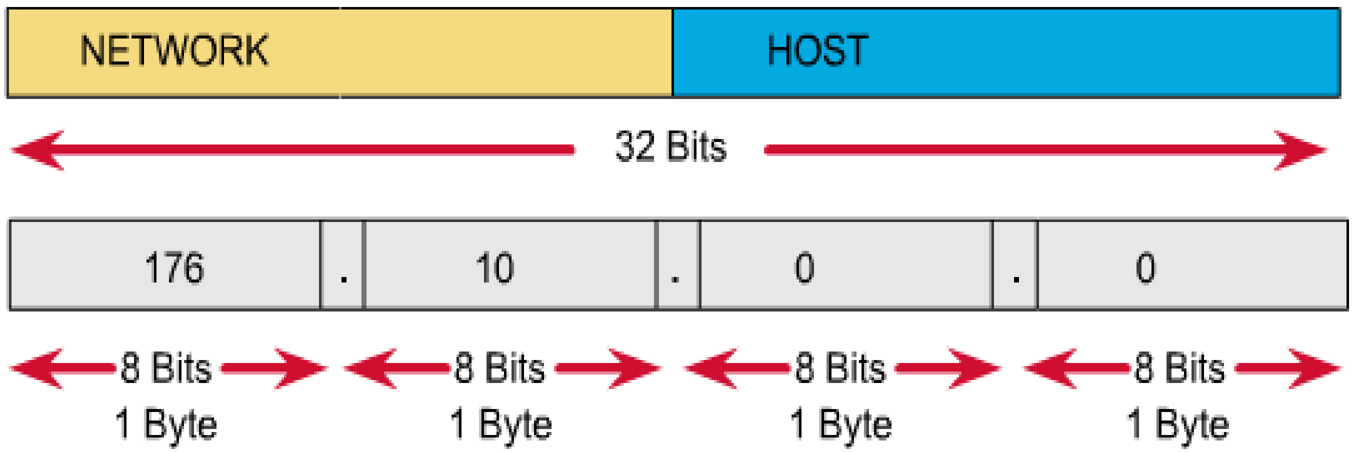
IP Addresses as Decimal Numbers

Class	Starts with	Binary range	Decimal Value range	Maximum subnets	Maximum hosts	Routing mask
A	0	00000000-01111111	0-127*	127	16,777,214	255.0.0.0
B	10	10000000-10111111	128-191	16,384	65,534	255.255.0.0
C	110	11000000-11011111	192-223	2,097,152	254	255.255.255.0
D	1110	11100000-11101111	224-239			
E	1111	11110000-11111111	240-255			

* The 0 octet is forbidden in the RFC, and 127 is reserved for loopback testing.

Network IDs and Broadcast Addresses

An IP address such as 176.10.0.0 that has all binary 0s in the host bit positions is reserved for the network address.



An IP address such as 176.10.255.255 that has all binary 1s in the host bit positions is reserved for the broadcast address.

Special Addresses

0 [Zero] i.e 0.0.0.0.is reserved and represents all IP addresses.
127.0.0.1 is a reserved address and is used for testing, like a loop back on an interface.
255.255.255.255 is a reserved address and is used for broadcasting purposes.

Private Addresses

The following ranges are available for private addressing

10.0.0.0 - 10.255.255.255

172.16.0.0 - 172.31.255.255

192.168.0.0 - 192.168.255.255

Class A – **16,777,216 hosts**

Class B – **1,048,576 hosts**

Class C– **65,535 hosts**

Mask

- Subnet mask is a 32 bits long address used to distinguish between network address and host address in IP address. Subnet mask is always used with IP address. Subnet mask has only one purpose, to identify which part of an IP address is network address and which part is host address.
- For example how will we figure out network partition and host partition from IP address 192.168.1.10 ?
  - Here we need subnet mask to get details about network address and host address.
- In decimal notation subnet mask value 1 to 255 represent network address and value 0 [Zero] represent host address.
- In binary notation subnet mask **ON** bit [1] represent network address while **OFF** bit[0] represent host address.
- **In decimal notation**

  IP address 192.168.1.10 Subnet mask 255.255.255.0
- Network address is **192.168.1** and host address is **10**.
- **In binary notation**
- IP address 11000000.10101000.00000001.00001010 Subnet mask 11111111.11111111.11111111.00000000
- Network address is 11000000.10101000.00000001 and host address is 00001010

CIDR [Classless Inter Domain Routing]

- CIDR is a slash notation of subnet mask. CIDR tells us number of on bits in a network address.
- Class A has default subnet mask 255.0.0.0. that means first octet of the subnet mask has all on bits. In slash notation it would be written as /8, means address has 8 bits on.
- Class B has default subnet mask 255.255.0.0. that means first two octets of the subnet mask have all on bits. In slash notation it would be written as /16, means address has 16 bits on.
- Class C has default subnet mask 255.255.255.0. that means first three octets of the subnet mask have all on bits. In slash notation it would be written as /24, means address has 24 bits on.
- Help us to find the netid and hostid
- Dose not apply to classes D and E.
- CIDR(Classless Interdomain Routing) used to show the mask in the form /n (n=8,16,24)

Default Mask for Classful Addressing

Class	Binary	Dotted-Decimal	CIDR
A	**11111111** 00000000 00000000 00000000	**255**.0.0.0	/8
B	**11111111 11111111** 00000000 00000000	**255.255**.0.0	/16
C	**11111111 11111111 11111111** 00000000	**255.255.255**.0	/24

In decimal notation:

IP address 192.168.1.10
Default mask 255.255.255.0
Network address is 192.168.1 and host address is 10.

In binary notation:

IP address 11000000 10101000 00000001 00001010
Subnet mask 11111111 11111111 11111111 00000000
Network address is 11000000 10101000 00000001 and
host address is 00001010

Note

In IPv4 addressing, a block of addresses can be defined as

x.y.z.t /*n*

in which x.y.z.t defines one of the addresses and the /*n* defines the mask.

The first address in the block can be found by setting the rightmost $32 - n$ bits to 0s.

The last address in the block can be found by setting the rightmost $32 - n$ bits to 1s.

The number of addresses in the block can be found by using the formula 2^{32-n}.

Example -6

A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.39/28. What is the first address, last address in the block? Also find the number of addresses.

Solution

The binary representation of the given address is

11001101 00010000 00100101 00100111

If we set 32−28 rightmost bits to 0, we get

11001101 00010000 00100101 0010000

or

205.16.37.32.

Last address for the block:

Solution

The binary representation of the given address is

11001101 00010000 00100101 00100111

If we set 32 − 28 rightmost bits to 1, we get

11001101 00010000 00100101 00101111

or

205.16.37.47

Number of addresses:

The value of n is 28, which means that number of addresses is 2^{32-28} or 16.

Example -7

Another way to find the first address, the last address, and the number of addresses is to represent the mask as a 32-bit binary (or 8-digit hexadecimal) number. This is particularly useful when we are writing a program to find these pieces of information. In Example 19.5 the /28 can be represented as

11111111 11111111 11111111 11110000

(twenty-eight 1s and four 0s).

Find

a.** **The first address
b.** **The last address
c.** **The number of addresses.

Example -7 (continued)

Solution

a. ***The first address can be found by ANDing the given addresses with the mask. ANDing here is done bit by bit. The result of ANDing 2 bits is 1 if both bits are 1s; the result is 0 otherwise.***

Address:	11001101	00010000	00100101	00100111
Mask:	**11111111**	**11111111**	**11111111**	**11110000**
First address:	11001101	00010000	00100101	00100000

Example -7 (continued)

b. ***The last address can be found by ORing the given addresses with the complement of the mask. ORing here is done bit by bit. The result of ORing 2 bits is 0 if both bits are 0s; the result is 1 otherwise. The complement of a number is found by changing each 1 to 0 and each 0 to 1.***

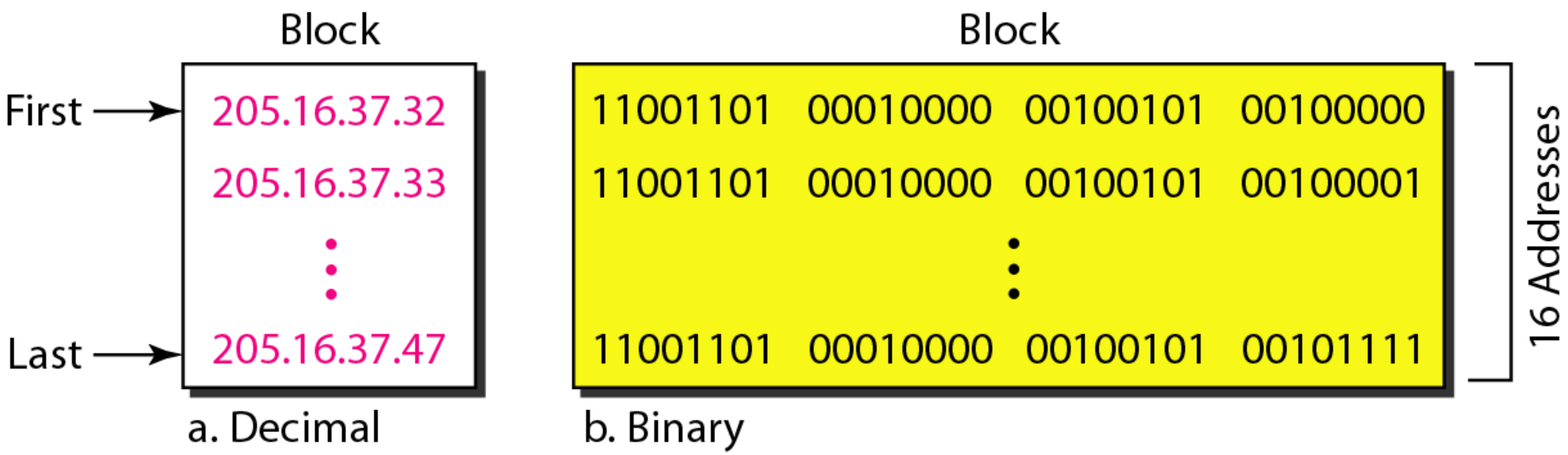
Address:	11001101	00010000	00100101	00100111
Mask complement:	**00000000**	**00000000**	**00000000**	**00001111**
Last address:	11001101	00010000	00100101	00101111

Example -7 (continued)

c. ***The number of addresses can be found by complementing the mask, interpreting it as a decimal number, and adding 1 to it.***

Mask complement:	**000000000 00000000 00000000 00001111**
Number of addresses:	15 + 1 = 16

A network configuration for the block 205.16.37.32/28



Network Address

- First address in the block.
- All hostid bytes are 0s.
- The **first address** in a block is normally **not assigned to any device**.
- It is used as the **network address** that represents the organization to the rest of the world.

- **Network ID -** First address of network/subnet is called network ID.
- **Block Size** – Total number of addresses including network address, hosts addresses and broadcast address.
- **Broadcast ID** -There are **two types of broadcast**, direct broadcast and full broadcast.
- **Direct broadcast or local broadcast-** Is the last address of subnet and can be hear **by all hosts in subnet**.
- **Full broadcast** - Is the last address of IP classes and can be **hear by all** IP hosts in network. Full broadcast address is 255.255.255.255
- **Host Addresses** -All address between the network address and the directed broadcast address is called host address. Host addresses can be assigned to any IP devices such as PCs, servers, routers, and switches.

Example-8

- Given the address 132.6.17.85 and 23.56.7.91, find the network address?

Solution

- The class is B. The first 2 bytes defines the netid. We can find the network address by replacing the hostid bytes (17.85) with 0s. 132.6.0.0.

- The class is A. Only the first byte defines the netid. We can find the network address by replacing the hostid bytes (56.7.91) with 0s. Therefore, the network address is 23.0.0.0.

IP Address	Class	NID	DBA	FBA
1.2.3.4	A	1.0.0.0	1.255.255.255	255.255.255.255
10.15.20.60	A	10.0.0.0	10.255.255.255	255.255.255.255
130.1.2.3	B	130.1.0.0	130.1.255.255	255.255.255.255
150.0.150.150	B	150.0.0.0	150.0.255.255	255.255.255.255
200.1.10.100	C	200.1.0.0	200.1.10.255	255.255.255.255
220.15.1.10	C	220.15.1.0	220.15.1.255	255.255.255.255
250.0.1.2	D	X	X	X
300.1.2.3	X	X	X	X

Note

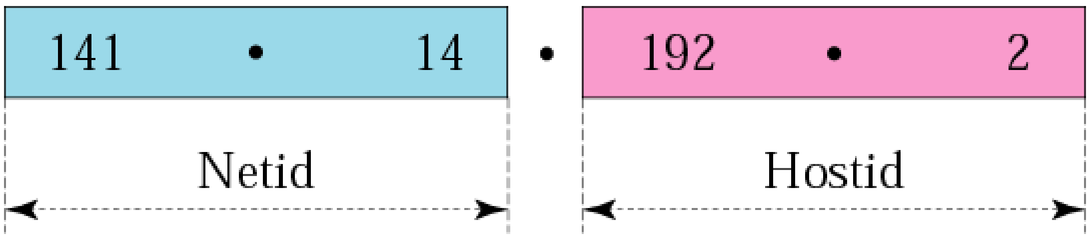
IP addresses are designed with two levels of hierarchy.

Figure 5-4

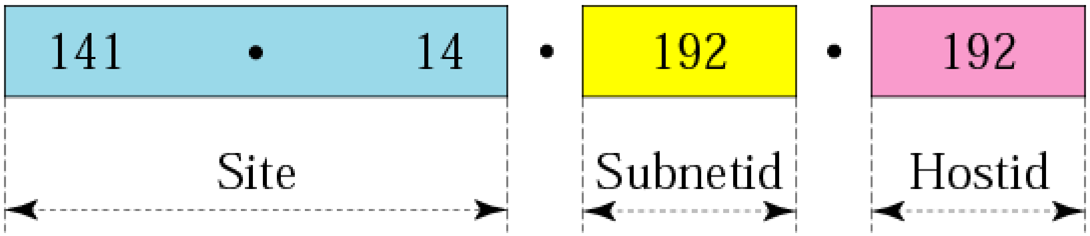
Hierarchy concept in a telephone number

Figure 5-3

Addresses in a network with and without subnetting



a. Without subnetting



b. With subnetting

Two-level Hierarchy: No subnetting

- IP address can define only **two levels** of hierarchy when not subnetted.
- **Prefix:** the leftmost *n* bits define the network
- **Suffix:** the rightmost 32 – n bits define the host(computer or router).
- Prefix is common to all network address. Suffix change from one device to another.

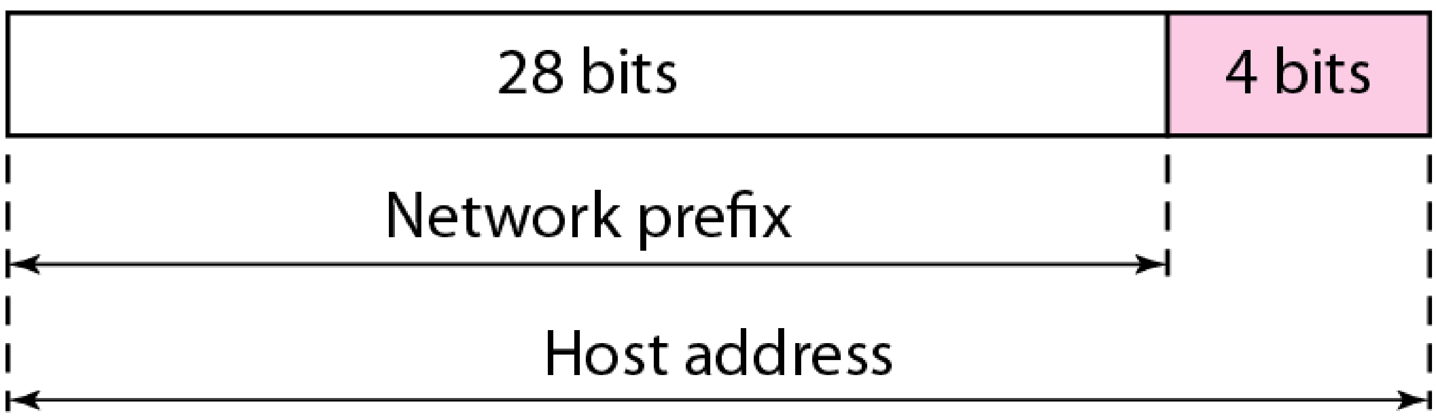
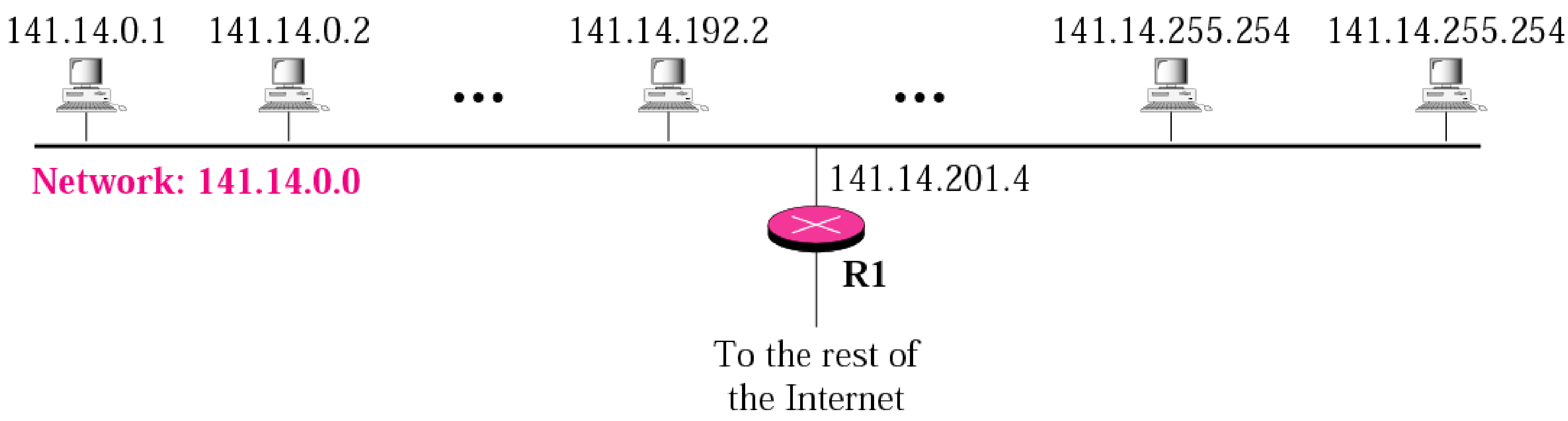
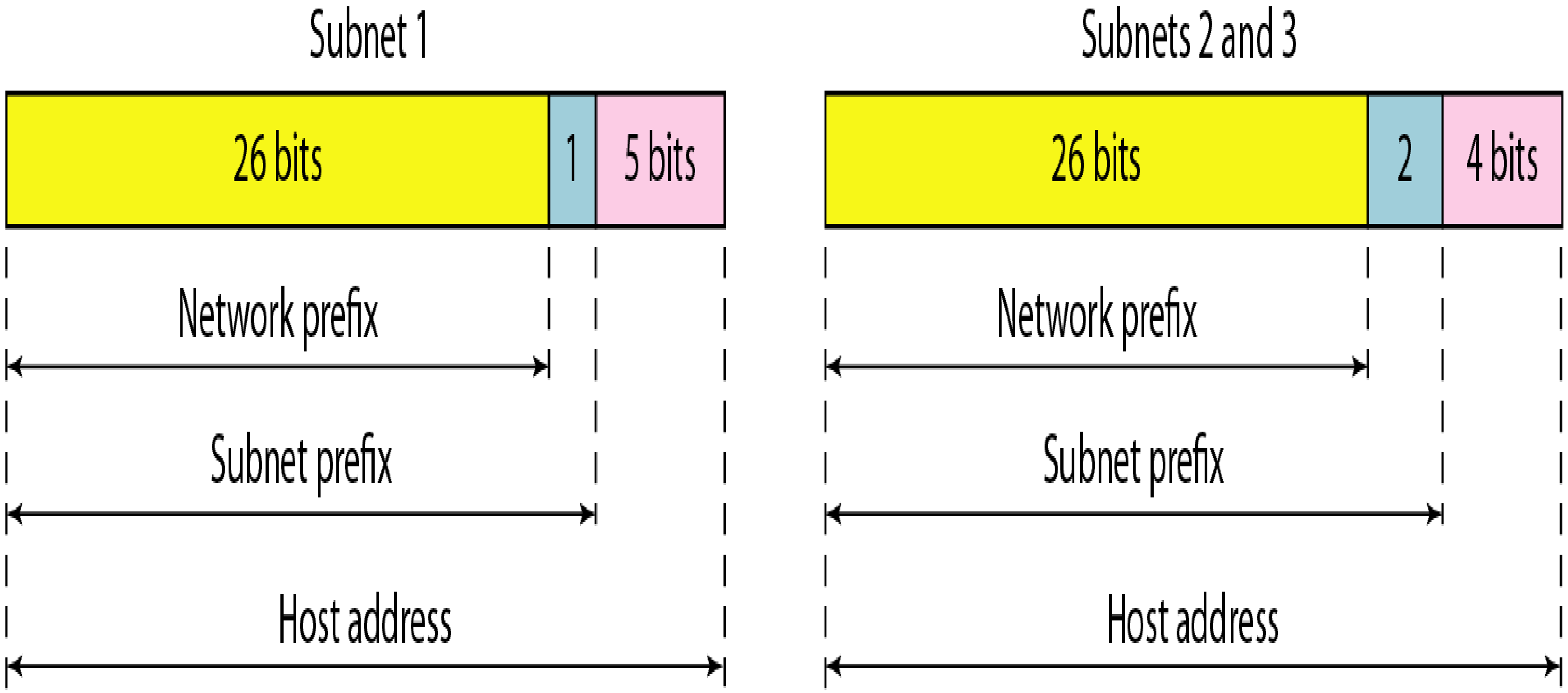


Figure 5-1

A network with two levels of hierarchy (not subnetted)



Three-level of Hierarchy: Subnetting



Subnetting

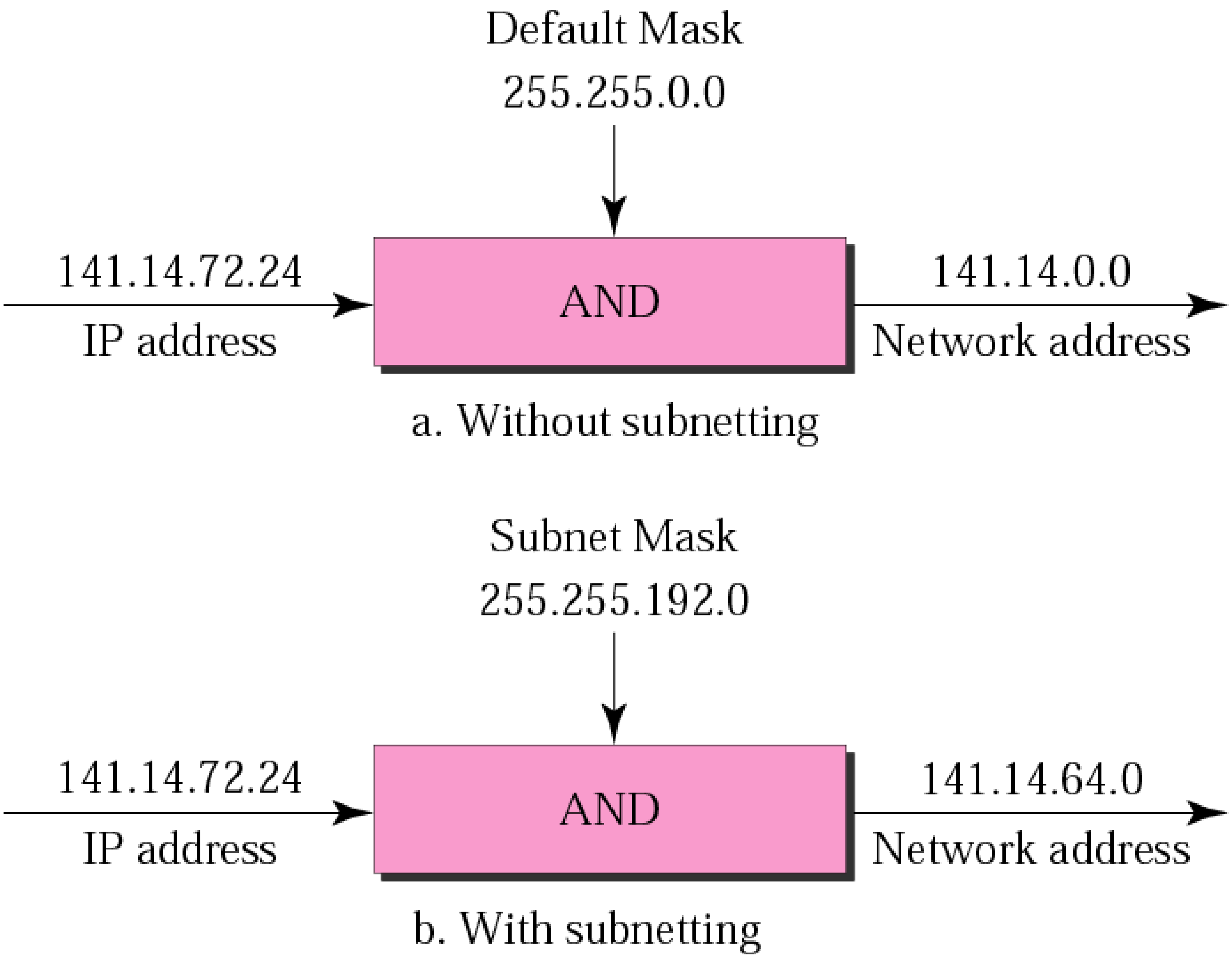
- Subnetting is a process of breaking large network in small networks known as subnets.
- Subnetting happens when we extend default boundary of subnet mask.
- Basically we borrow host bits to create networks.

Advantage of Subnetting

- Easy to manage.
- Reduces network traffic by removing collision and broadcast traffic, that overall improve performance.
- Aapply network security polices at the interconnection between subnets.
- Save money by reducing requirement for IP range.

Figure 5-5

Default mask and subnet mask



Finding the Subnet Address

- Given an IP address, we can find the subnet address the same way we found the network address.
- We apply the mask to the address.
- We can do this in two ways: straight or short-cut.

Subnet mask

- Number of 1s in a subnet mask is more than the number of 1s in the corresponding default mask.

- In a subnet mask, we change some of the leftmost 0s in the default mask to make a subnet mask.

Straight Method

In the straight method, we use binary notation for both the address and the mask and then apply the AND operation to find the subnet address.

Example 1

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

11001000 00101101 00100010 00111000

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

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

The subnetwork address is **200.45.32.0**.

Short-Cut Method

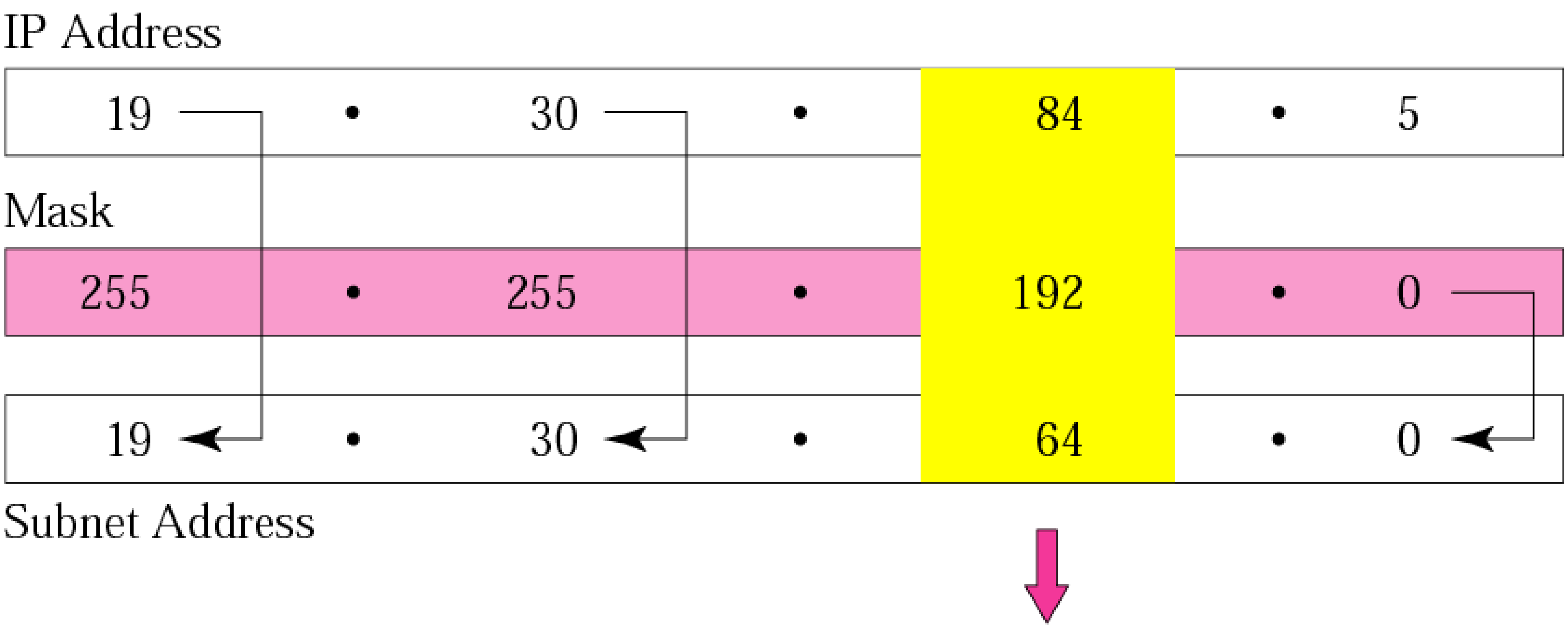
** If the byte in the mask is 255, copy the byte in the address.

** If the byte in the mask is 0, replace the byte in the address with 0.

** If the byte in the mask is neither 255 nor 0, we write the mask and the address in binary and apply the AND operation.

Example 2

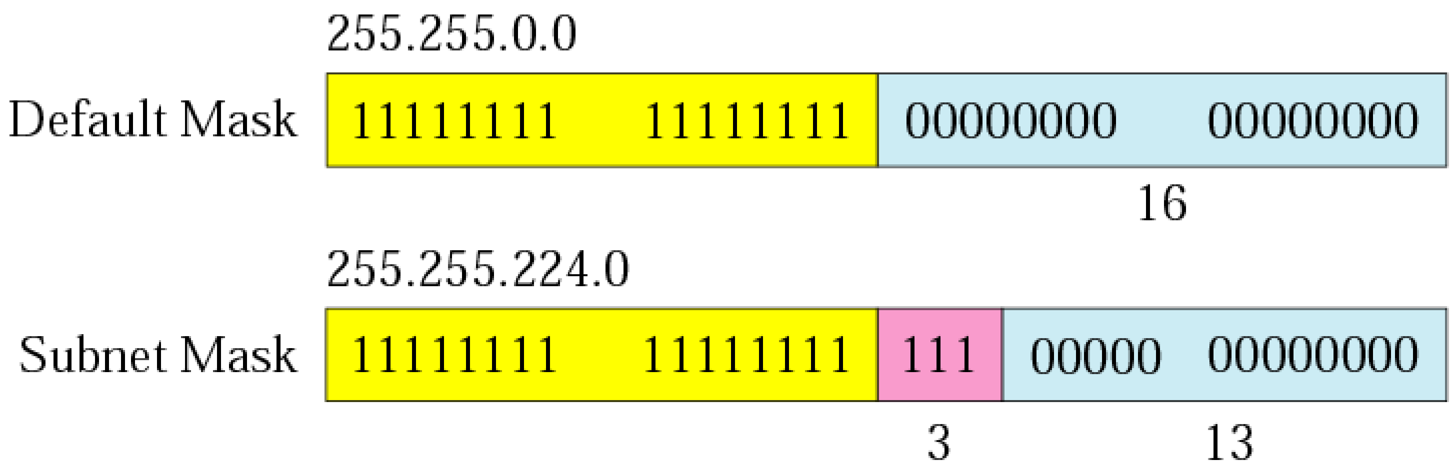
What is the subnetwork address if the destination address is 19.30.80.5 and the mask is 255.255.192.0?



84	0	1	0	1	0	1	0	0
192	1	1	0	0	0	0	0	0
64	0	1	0	0	0	0	0	0

Figure 5-7

Comparison of a default mask and a subnet mask



Note

The number of subnets must be a power of 2.

A company is granted the site address 201.70.64.0 (class C). The company needs six subnets. Design the subnets.

The number of 1s in the default mask is 24 (class C).

The company needs six subnets. This number 6 is not a power of 2. The next number that is a power of 2 is 8 (2^3). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3).

The total number of 0s is 5 (32 – 27).

The mask is

$$\underline{\mathbf{11111111\ 11111111\ 11111111}}\ \underline{\mathbf{111}}00000$$

or

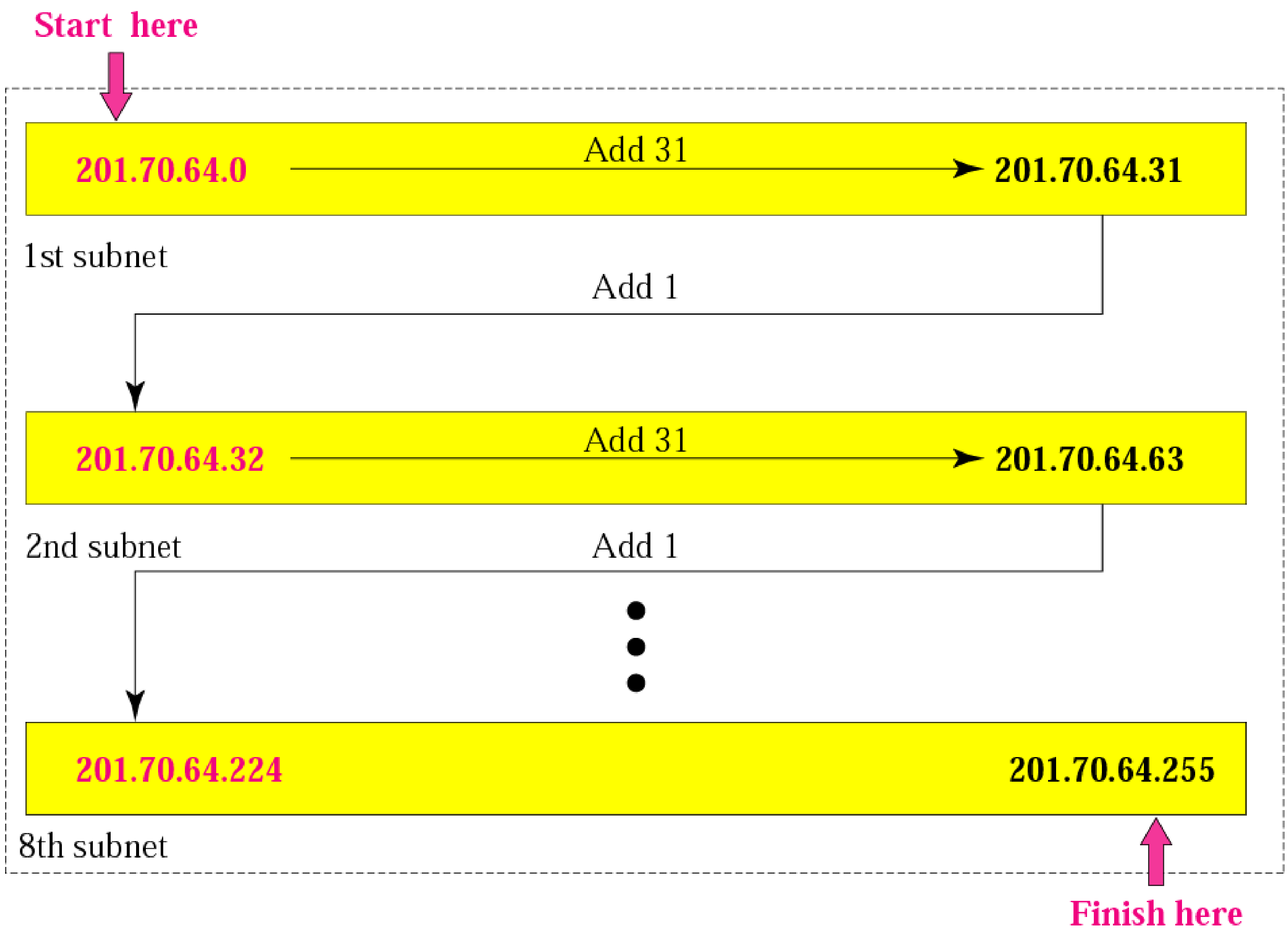
255.255.255.224

The number of subnets is 8.

The number of addresses in each subnet is 2^5 (5 is the number of 0s) or 32.

Figure 5-8

Example 3



A company is granted the site address 181.56.0.0 (class B). The company needs 1000 subnets. Design the subnets.

The number of 1s in the default mask is 16 (class B).

The company needs 1000 subnets. This number is not a power of 2. The next number that is a power of 2 is 1024 (2^{10}). We need 10 more 1s in the subnet mask.

The total number of 1s in the subnet mask is 26 (16 + 10).

The total number of 0s is 6 (32 – 26).

The mask is

$\underline{11111111\ 11111111\ 11111111}\ \underline{11}000000$

or

255.255.255.192.

The number of subnets is 1024.

The number of addresses in each subnet is 2^6 (6 is the number of 0s) or 64.

Figure 5-9

Example 4

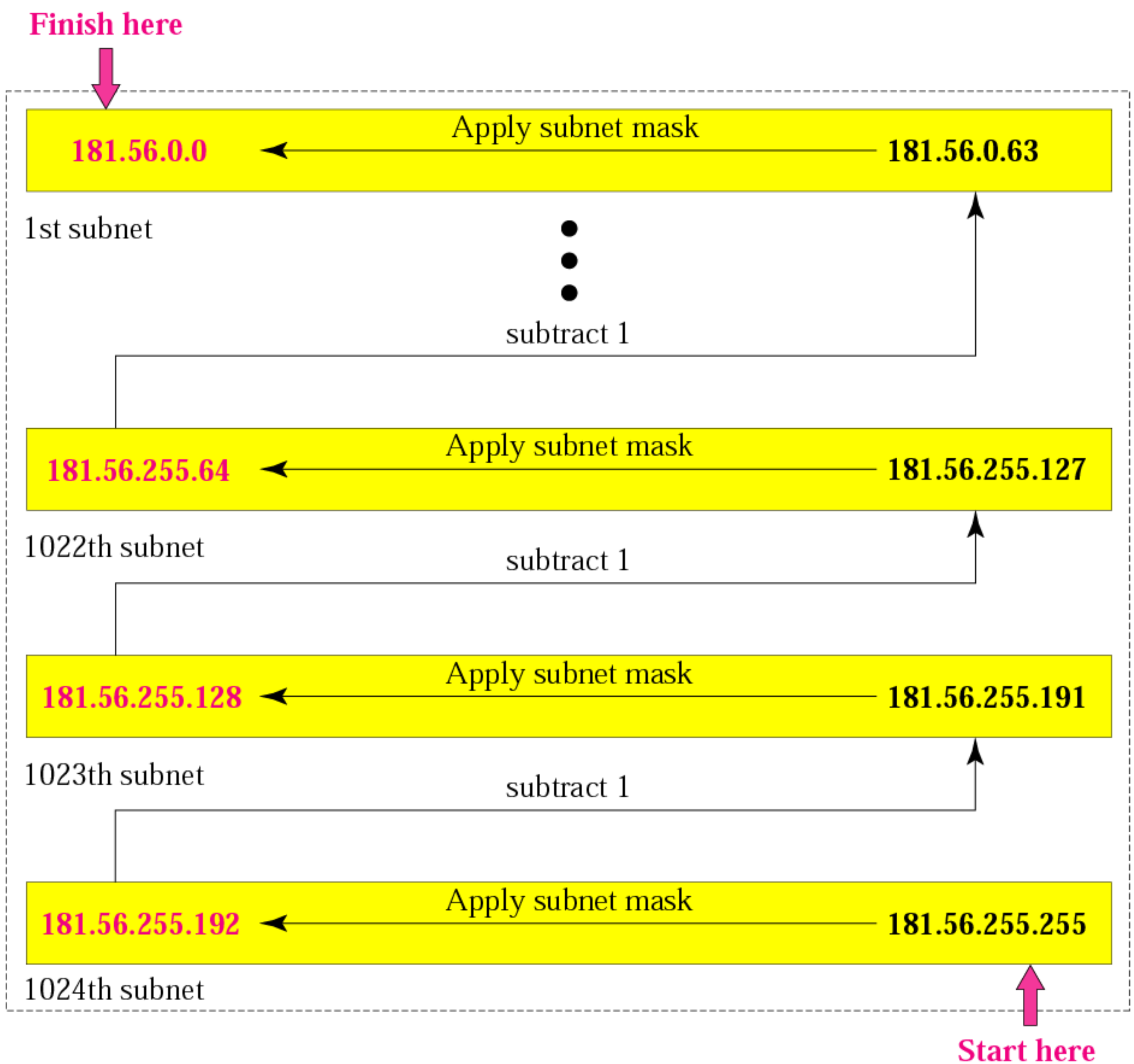
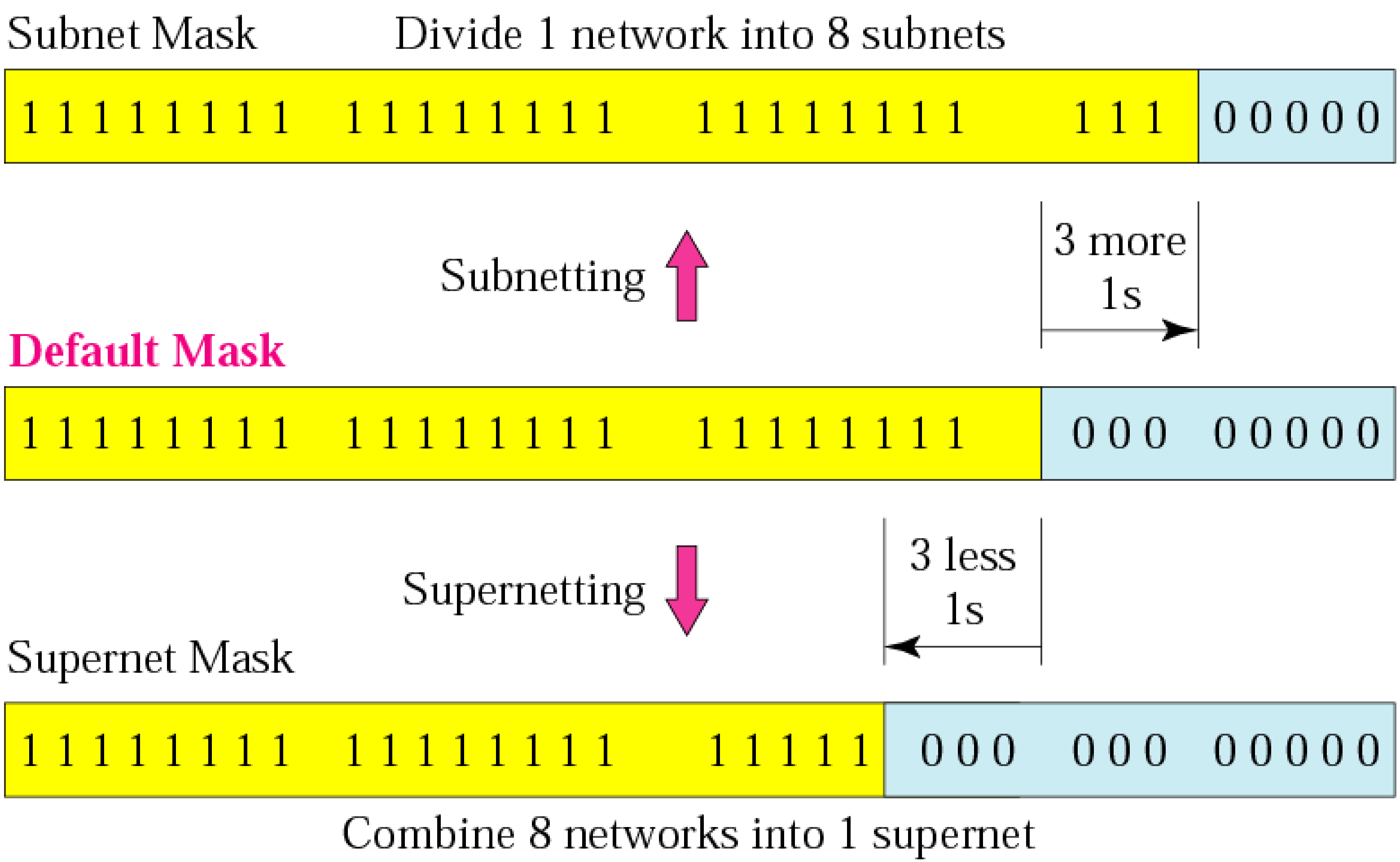
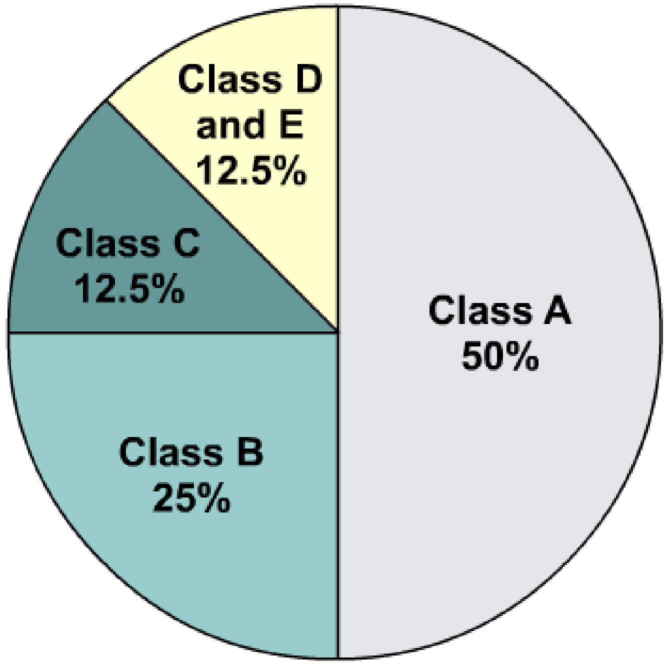


Figure 5-12

Comparison of subnet, default, and supernet masks



IP addressing crisis



With Class A and B addresses virtually exhausted, Class C addresses (12.5 percent of the total space) are left to assign to new networks.

In classful addressing, a large part of the available addresses were wasted.

Short Term Solutions: IPv4 Enhancements

- CIDR (Classless Inter-Domain Routing)
- VLSM (Variable Length Subnet Mask)
- Private Addressing
- NAT/PAT (Network Address Translation / Port Address Translation)

Long Term Solution: IPv6 (coming)

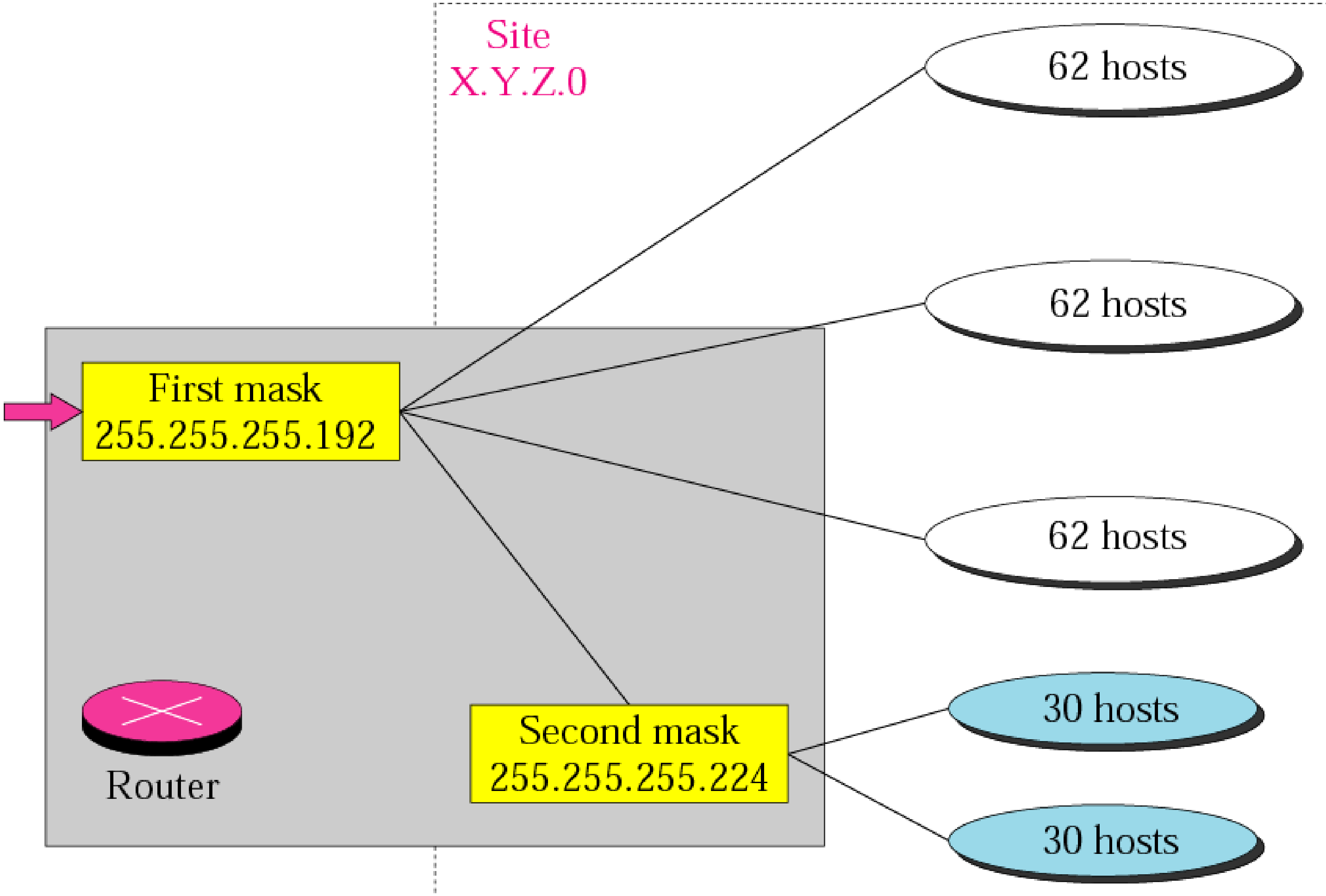
- IPv6, or IPng (IP – the Next Generation) uses a 128-bit address space, yielding

  340,282,366,920,938,463,463,374,607,431,768,211,456

  possible addresses.
- IPv6 has been slow to arrive.
- IPv4 revitalized by new features, making IPv6 a luxury, and not a desperately needed fix.
- IPv6 requires new software; IT staffs must be retrained.
- IPv6 will most likely coexist with IPv4 for years to come.
- Some experts believe IPv4 will remain for more than 10 years.

CLASSLESS ADDRESSING

Variable-length subnetting



Rules:

** The number of blocks must be a power of 2 (1, 2, 4, 8, 16, . . .).

** The blocks must be contiguous in the address space (no gaps between the blocks).

** The third byte of the first address in the superblock must be evenly divisible by the number of blocks. In other words, if the number of blocks is *N*, the third byte must be divisible by *N*.

Rules : Beginning Address

The beginning address must be evenly divisible by the number of addresses.

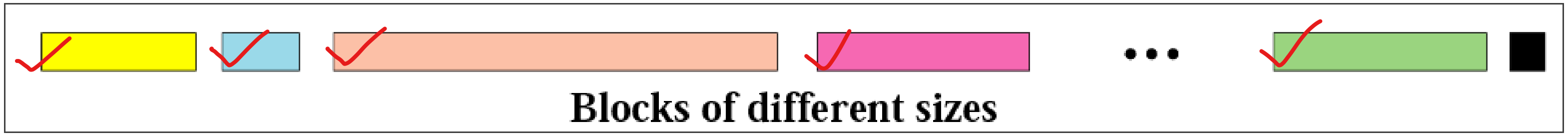
For example, if a block contains 4 addresses, the beginning address must be divisible by 4.

If the block has less than 256 addresses, we need to check only the rightmost byte.

If it has less than 65,536 addresses, we need to check only the two rightmost bytes, and so on.

Variable-length blocks

Address Space



Number of Addresses in a Block

There is only one condition on the number of addresses in a block; it must be a power of 2 (2, 4, 8, . . .).

A household may be given a block of 2 addresses.

A small business may be given 16 addresses.

A large organization may be given 1024

Which of the following can be the beginning address of a block that contains 16 addresses?

205.16.37.32
190.16.42.44
17.17.33.80

123.45.24.52

The address 205.16.37.32 is eligible because 32 is divisible by 16. The address 17.17.33.80 is eligible because 80 is divisible by 16.

Which of the following can be the beginning address of a block that contains 1024 addresses?

205.16.37.32
190.16.42.0
17.17.32.0
123.45.24.52

Solution:

To be divisible by 1024, the rightmost byte of an address should be 0 and the second rightmost byte must be divisible by 4. Only the address 17.17.32.0 meets this condition.

A small organization is given a block with the beginning address and the prefix length 205.16.37.24/29 (in slash notation). What is the range of the block?

- The beginning address is 205.16.37.24. To find the last address we keep the first 29 bits and change the last 3 bits to 1s.

Beginning: <u>**11001111 00010000 00100101 00011**</u>000
Ending : <u>**11001111 00010000 00100101 00011**</u>111

- Length of the suffix is 32 – 29 or 3.
- So, there are $2^3 = 8$ addresses in this block.
- If the first address is 205.16.37.24, the last address is 205.16.37.31 (24 + 7 = 31).

What is the network address if one of the addresses is 167.199.170.82/27?

Solution:

- The prefix length is 27, which means that we must keep the first 27 bits as is and change the remaining bits (5) to 0s.
- The 5 bits affect only the last byte.
- The last byte is 01010010. Changing the last 5 bits to 0s, we get 01000000 or 64.
- The network address is 167.199.170.64/27.

An organization is granted the block 130.34.12.64/26. The organization needs to have four subnets. What are the subnet addresses and the range of addresses for each subnet?

Solution:

The suffix length is 6. This means the total number of addresses in the block is 64 (2^6). If we create four subnets, each subnet will have 16 addresses.
Let us first find the subnet prefix (subnet mask). We need four subnets, which means we need to add two more 1s to the site prefix. The subnet prefix is then /28.

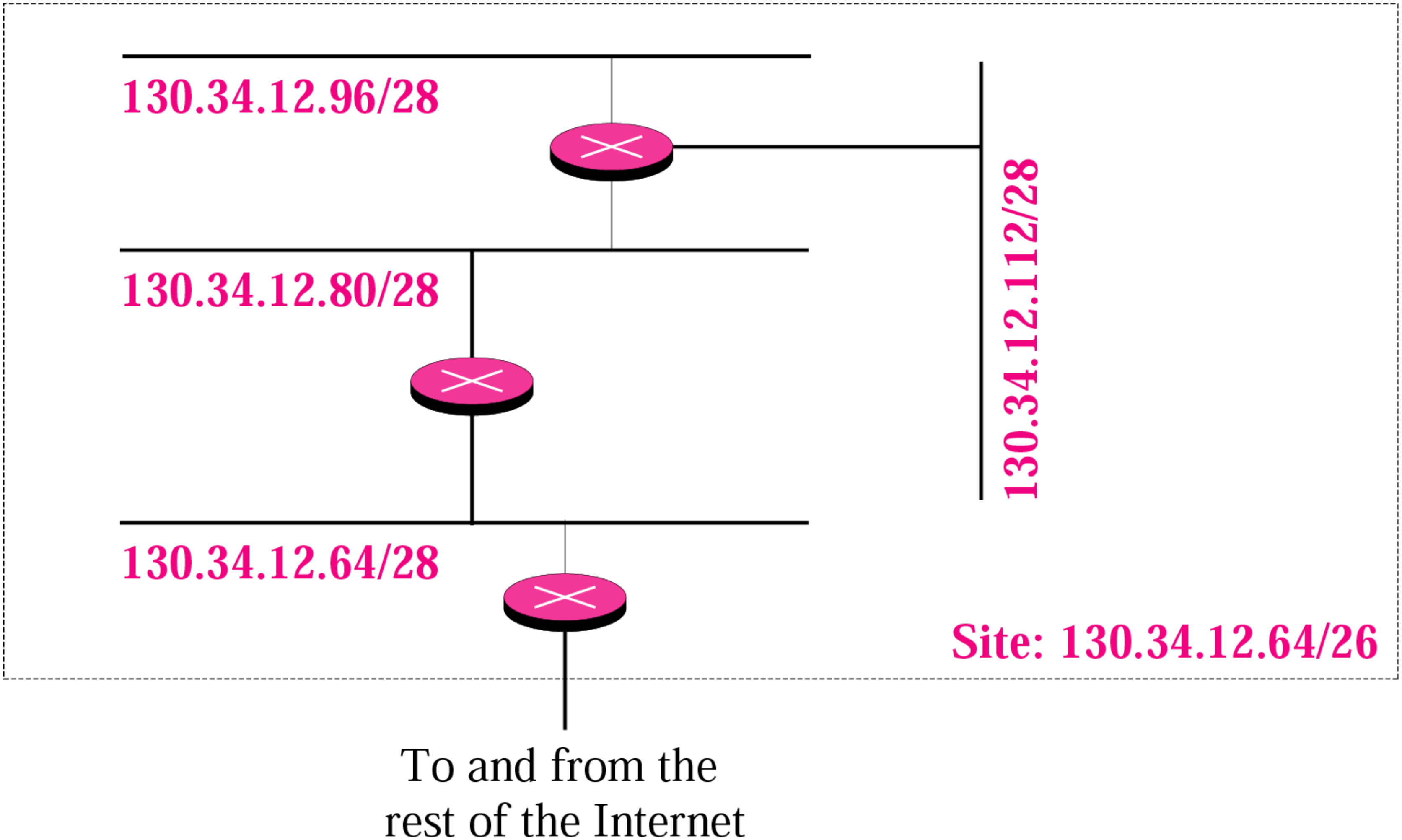
Subnet 1: 130.34.12.64/28 to 130.34.12.79/28.

Subnet 2 : 130.34.12.80/28 to 130.34.12.95/28.

Subnet 3: 130.34.12.96/28 to 130.34.12.111/28.

Figure 5-15

Example 14



An ISP is granted a block of addresses starting with 190.100.0.0/16 (65,536 addresses). The ISP needs to distribute these addresses to three groups of customers as follows:

a. The first group has 64 customers; each needs 256 addresses.

b. The second group has 128 customers; each needs 128 addresses.

c. The third group has 128 customers; each needs 64 addresses.

Design the subblocks and find out how many addresses are still available after these allocations.

Group 1

For this group, each customer needs 256 addresses. This means that 8 (log2 256) bits are needed to define each host. The prefix length is then 32 − 8 = 24. The addresses are

1st Customer:	190.100.0.0/24	190.100.0.255/24
2nd Customer:	190.100.1.0/24	190.100.1.255/24
. . .		
64th Customer:	190.100.63.0/24	190.100.63.255/24

Total = 64 × 256 = 16,384

Group 2

For this group, each customer needs 128 addresses. This means that 7 (log2 128) bits are needed to define each host. The prefix length is then 32 − 7 = 25. The addresses are

1st Customer:	190.100.64.0/25	190.100.64.127/25
2nd Customer:	190.100.64.128/25	190.100.64.255/25
. . .		
128th Customer:	190.100.127.128/25	190.100.127.255/25

Total = 128 × 128 = 16,384

Group 3

For this group, each customer needs 64 addresses. This means that 6 ($\log_2 64$) bits are needed to each host. The prefix length is then 32 − 6 = 26. The addresses are

1st Customer:	190.100.128.0/26	190.100.128.63/26
2nd Customer:	190.100.128.64/26	190.100.128.127/26
. . .		
128th Customer:	190.100.159.192/26	190.100.159.255/26
Total = 128 × 64 = 8192		

Number of granted addresses to the ISP: 65,536
Number of allocated addresses by the ISP: 40,960
Number of available addresses: 24,576

Address allocation and distribution by an ISP