Network Layer IP Addresses

172.16.0.0 /24

What are the first and last assignable IPs?

	10101100. 00010000. 00000000. 00000000	
First	10101100. 00010000. 00000000. 00000001	172.16.0.1
Last	10101100. 00010000. 00000000. 11111110	172.16.0.254

152.2.136.0 /26

	10011000. 00000010. 10001000. 00000000	
First	10011000. 00000010. 10001000. 00000001	152.2.136.1
Last	10011000. 00000010. 10001000. 00111110	152.2.136.62

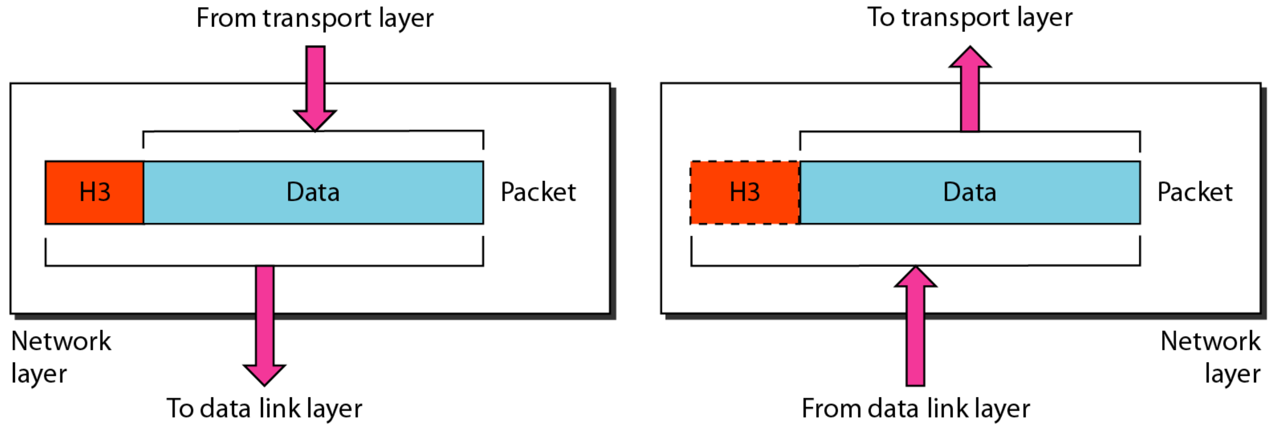
| Network Bits || Host Bits |

174.16.0.0

10101110. 00010000. 00000000. 00000000

Network Layer

- The network layer is responsible for the source-to-destination delivery of a packet, possibly across multiple networks (links).
- Whereas the data link layer oversees the delivery of the packet between two systems on the same network (links), the network layer ensures that each packet gets from its point of origin to its final destination.
- The network layer adds a header that includes the logical addresses of the sender and receiver to the packet corning from the upper layer.
- Network layer is to provide a routing mechanism.



IPv4 Addresses

- 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 on the Internet can never have the same address at the same time.
- if a device operating at the network layer has ***m*** connections to the Internet, it needs to have ***m*** addresses.

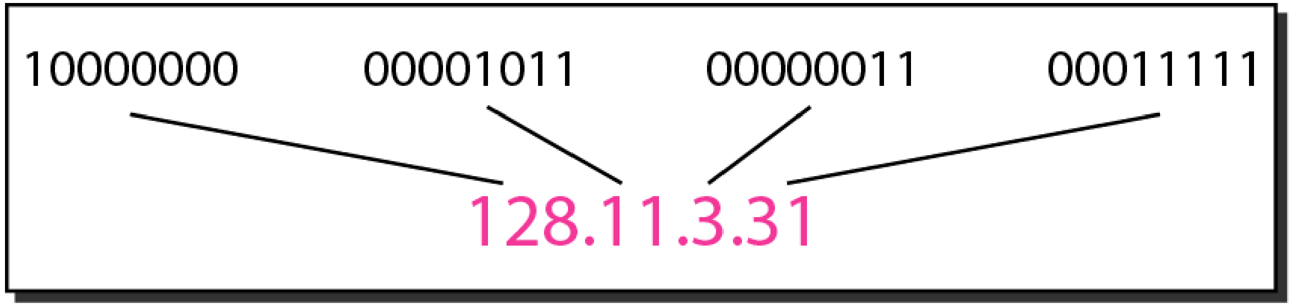
IPv4 Addresses Space

- An 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 because each bit can have two different values (0 or 1) and N bits can have 2^N values.

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

Notations for IPv4 Addresses

- There are two prevalent notations to show an IPv4 address:
  - ✓ Binary notation
    - 01110101 10010101 00011101 00000010
  - ✓ Dotted-Decimal notation
    - 117.149.29.2



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

We 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

We 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

Example 3

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.***

Classful Addressing

- In classful addressing, the address space is divided into five classes: **A, B, C, D, and E**.
- Binary and dotted-decimal notation

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

a. Binary notation

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

b. Dotted-decimal notation

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

Example 4

Find the class of each address.

a. **0**0000001 00001011 00001011 11101111

b. **110**00001 10000011 00011011 11111111

c. **14**.23.120.8

d. **252**.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.

Number of block and block size in Classful IPv4

Class	*Number of Blocks*	*Block Size*	*Application*
A	128	16,777,216	Unicast
B	16,384	65,536	Unicast
C	2,097,152	256	Unicast
D	1	268,435,456	Multicast
E	1	268,435,456	Reserved

Net ID and Host ID

- In classful addressing, an IP address in class A, B, or C is divided into netid and hostid.
- These parts are of varying lengths, depending on the class of the address.

Class	*Binary*
A	**11111111** 00000000 00000000 00000000
B	**11111111 11111111** 00000000 00000000
C	**11111111 11111111 11111111** 00000000

Mask

- The mask can help us to find the netid and the hostid.
- For example, the mask for a class A address has eight 1s, which means the first 8 bits of any address in class A define the netid; the next 24 bits define the hosted
- mask in the form In where n can be 8, 16, or 24 in classful addressing. This notation is also called slash notation or Classless Interdomain Routing (CIDR) notation.

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

Example

- 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.

  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.

- 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.

Subnetting and Supersubnetting

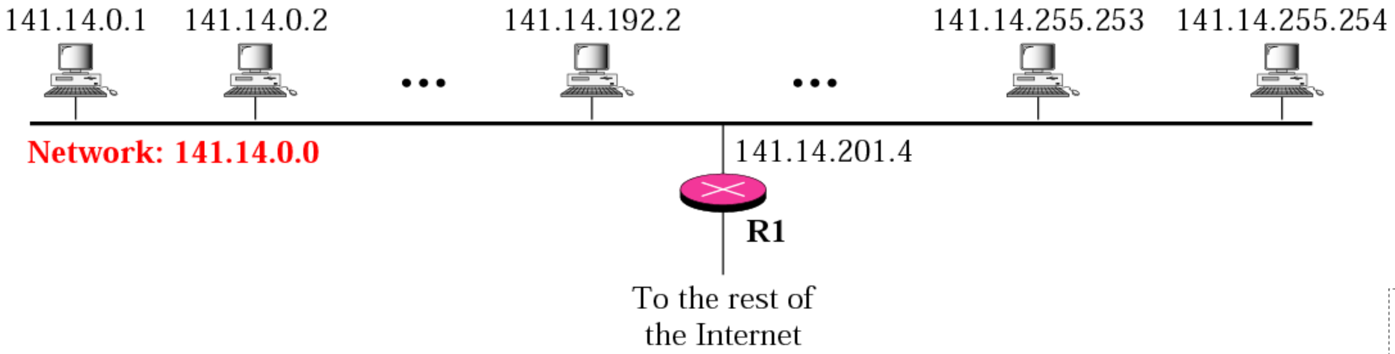
Subnetting

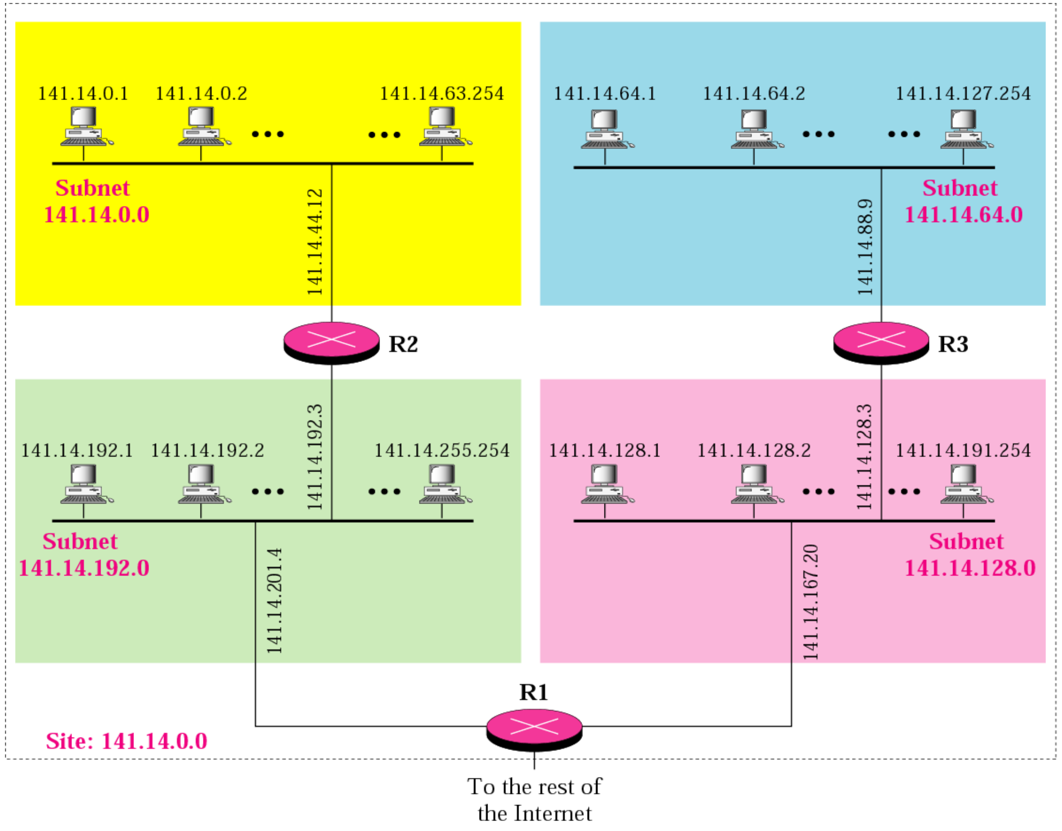
- If an organization was granted a large block in class A or B, it could divide the addresses into several contiguous groups and assign each group to smaller networks (called subnets) or, in rare cases, share part of the addresses with neighbors.
- Subnetting increases the number of 1’s in the mask.

Supersubnetting

- The size of a class C block with a maximum number of 256 addresses did not satisfy the needs of most organizations.
- Even a midsize organization needed more addresses. One solution was supernetting.
- In supernetting, an organization can combine several class C blocks to create a larger range of addresses.
- In other words, several networks are combined to create a supernetwork or a supernet. An organization can apply for a set of class C blocks instead of just one.

Subnetting and Supersubnetting

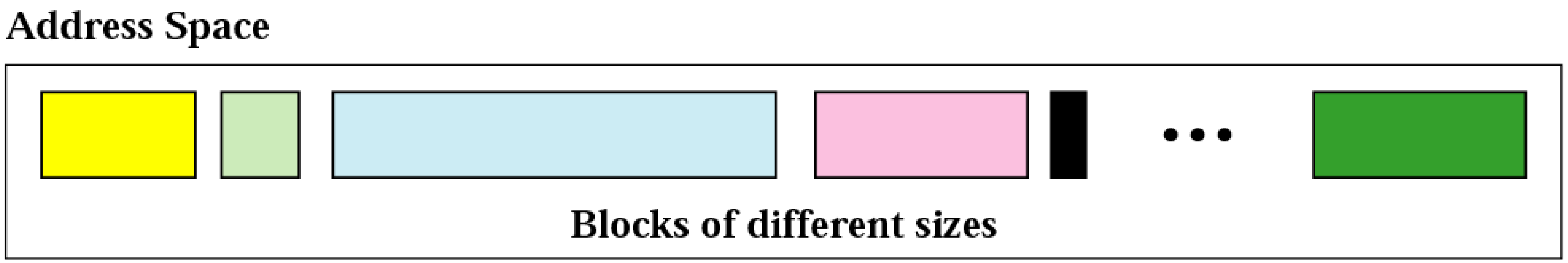




Classless Addressing

- To overcome address depletion and give more organizations access to the Internet, classless addressing was designed and implemented.
- There are no classes, but the addresses are still granted in blocks.
- Restriction To simplify the handling of addresses, the Internet authorities impose three restrictions on classless address blocks:

1. The addresses in a block must be contiguous, one after another.
2. The number of addresses in a block must be a power of 2 (1, 2, 4, 8,...)
3. The first address must be evenly divisible by the number of addresses.



Example 5

- Figure 19.3 shows a block of addresses, in both binary and dotted-decimal notation, granted to a small business that needs 16 addresses.
- We can see that the restrictions are applied to this block. The addresses are contiguous. The number of addresses is a power of 2 ($16 = 2^4$), and the first address is divisible by 16. The first address, when converted to a decimal number, is 3,440,387,360, which when divided by 16 results in 215,024,210.

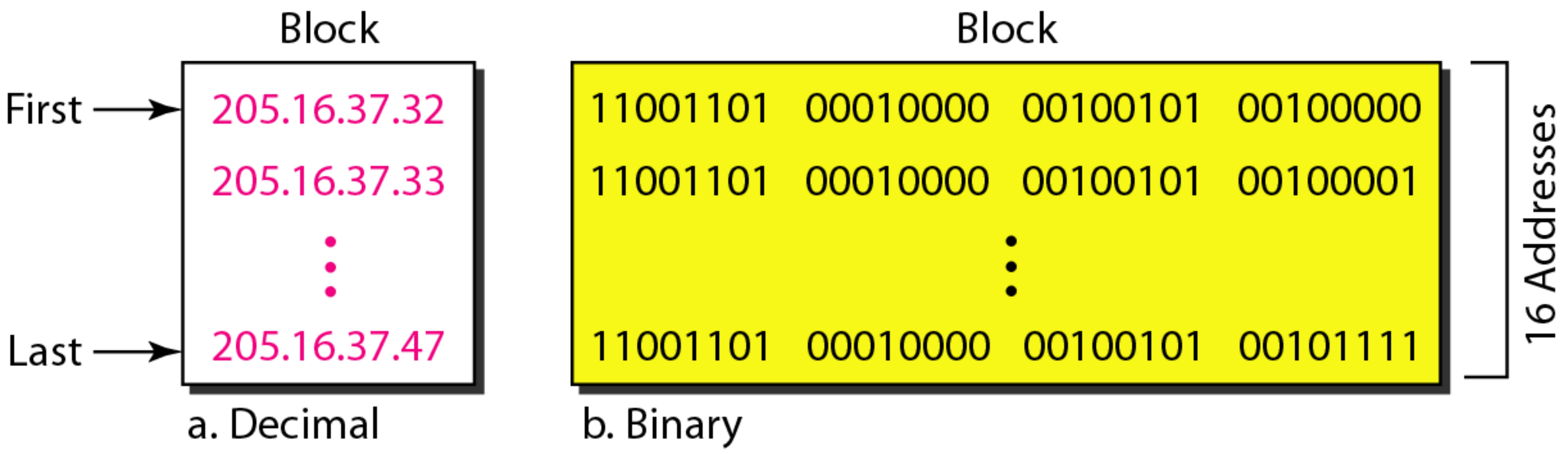


Figure 19.3

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 5.1

- What is the first address in the block 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 it is and change the remaining bits (5) to 0s. The following shows the process:

Address in binary:	10100111	11000111	10101010	01010010
Keep the left 27 bits:	10100111	11000111	10101010	01000000
Result in CIDR notation: 167.199.170.64/27				

What is the first address in the block if one of the addresses is 140.120.84.24/20?

Example 5.2

- **Find the number of addresses in the block if one of the addresses is** 140.120.84.24/20.

Solution
The prefix length is 20. The number of addresses in the block is 2^{32-20} or 2^{12} or 4096.

Note that this is a large block with 4096 addresses.

- **Find the last address in the block if one of the addresses is** 140.120.84.24/20.

Solution
The mask has twenty 1s and twelve 0s. The complement of the mask has twenty 0s and twelve 1s. In other words, the mask complement is **00000000 00000000 00001111 11111111**

We add the mask complement to the beginning address to find the last address.

```
140 . 120 . 80 .   0
  0 .   0  . 15 . 255
----------------------------
140 . 120 . 95 . 255
```

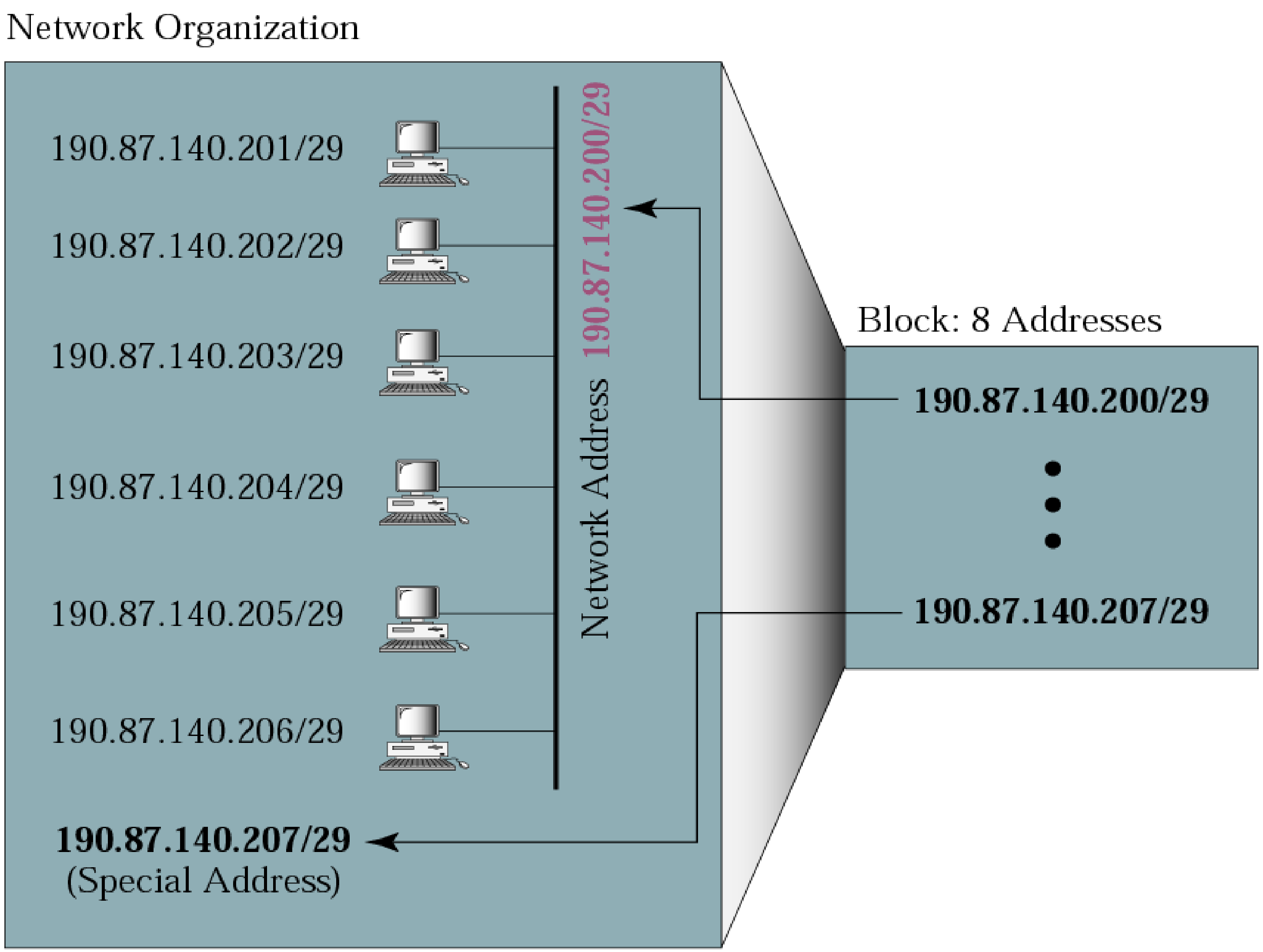
The last address is 140.120.95.255/20.

Example 5.3

- **Find the block if one of the addresses is** 190.87.140.202/29.

- The number of addresses is 2^{32-29} or 8.
- To find the last address, we use the complement of the mask.
- The mask has twenty-nine 1s; the complement has three 1s.
- The complement is 0.0.0.7.
- If we add this to the first address, we get 190.87.140.207/29. In other words, the first address is 190.87.140.200/29, the last address is 190.87.140.207/29.
- There are only 8 addresses in this block.

Example 5.3



Network Organization
190.87.140.201/29
190.87.140.202/29
190.87.140.203/29
190.87.140.204/29
190.87.140.205/29
190.87.140.206/29
Network Address 190.87.140.200/29
190.87.140.207/29
(Special Address)
Block: 8 Addresses
190.87.140.200/29
190.87.140.207/29

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.

  a) Find first address in the block?

  b) Find last address in the block?

  c) Find numbers of addresses in the block?

Example 6

a) Find first address in the block?

Solution

205.16.37.39/28

The binary representation of 205.16.37.39 is

11001101 00010000 00100101 00100111

If we set 32−28 rightmost bits to 0 (the value of n = 28 means 32 - 28 = 5 bits)

we get

11001101 00010000 00100101 0010000

First address of block is : 205.16.37.32.

Example 6

b) Find Last address in 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

Last address of block is : 205.16.37.47

c) Find numbers of addresses in the block?

The value of n is 28, which means that number of addresses is

2^{32-28} or 16.

No of addresses in block are : 16

Another Way to Solve Example 6

- 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.

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

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

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

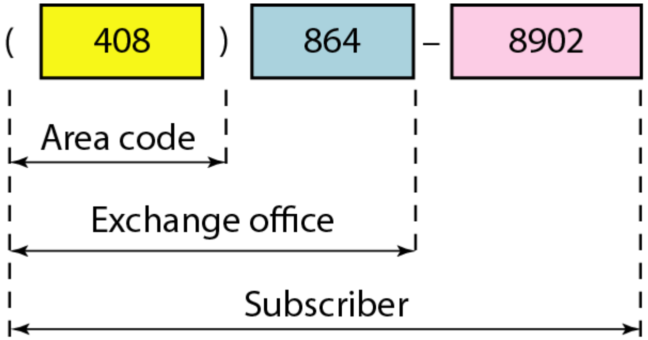
Mask complement:	**000000000**	**00000000**	**00000000**	**00001111**
Number of addresses:	15 + 1 = 16			

Subnetting

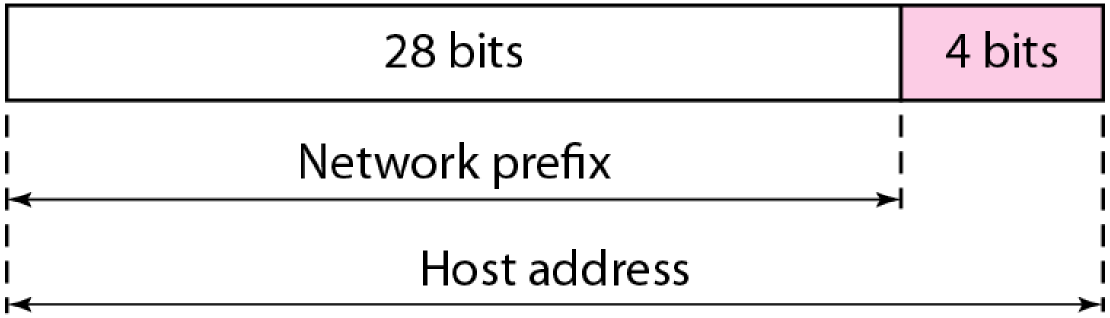
Note

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.

Subnetting



Two levels of hierarchy in an IPv4 address

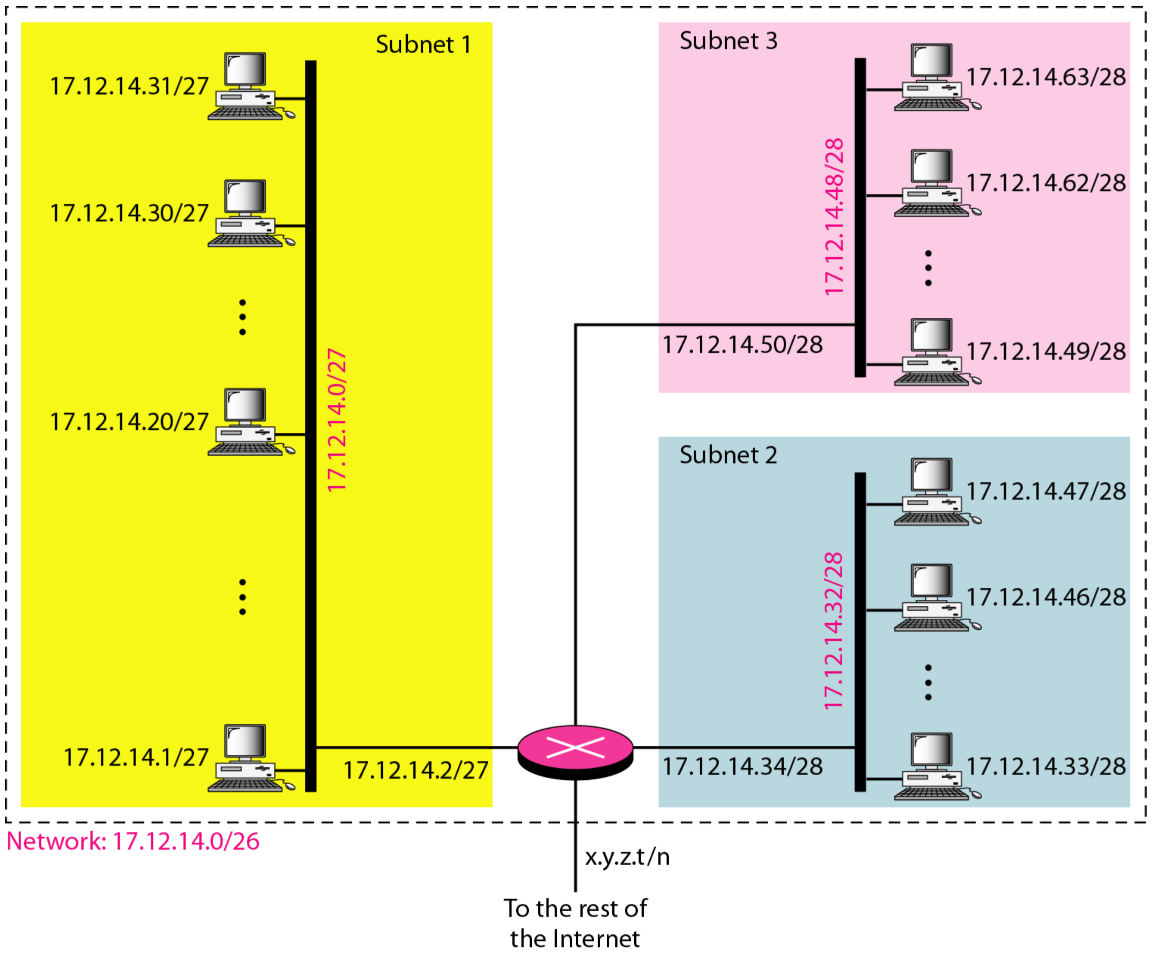


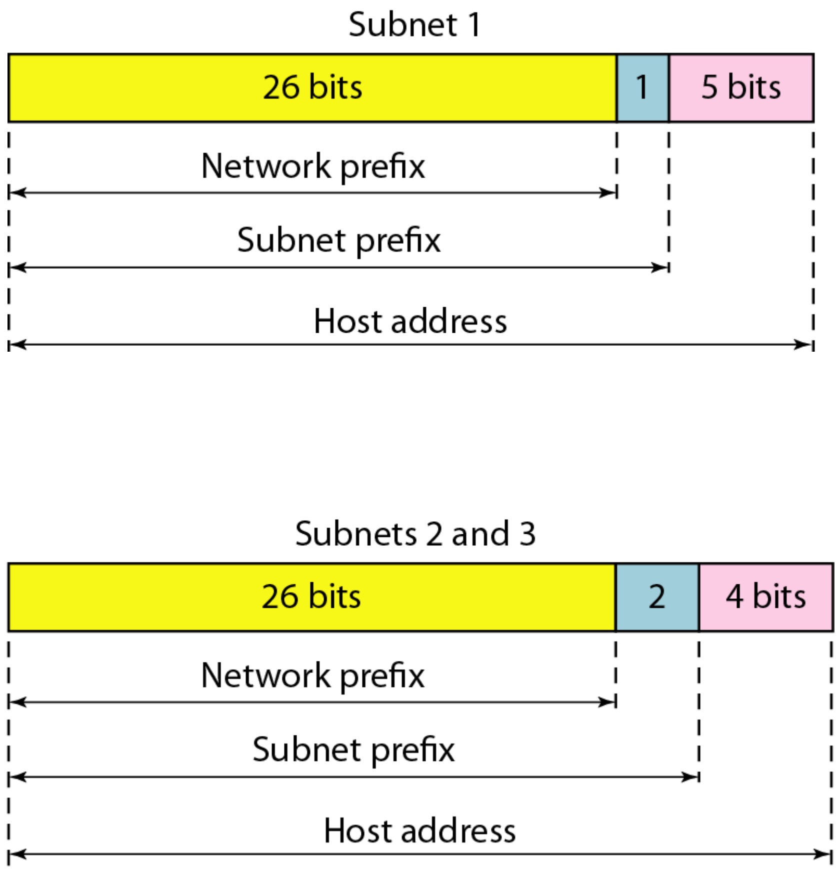
A frame in a character-oriented protocol

Note

Each address in the block can be considered as a two-level hierarchical structure:
the leftmost n bits (prefix) define the network;
the rightmost 32 − n bits define the host.

Configuration and addresses in a subnetted network





Example 7

- 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.

Number of Host (Theoretically), practically $2^n - 2$

Number of bits (Suffix)	Number of Host
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024
11	2048
12	4096

Given block is: 190.100.0.0/16

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

Mask is 32-8=24

Customer-1: 190.100.0.0/24 to 190.100.0.255/24

Customer-2: 190.100.1.0/24 to 190.100.1.255/24

Customer-64: 190.100.63.0/24 to 190.100.63.255/24

Number of bits (Suffix)	Number of Host
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	**256**
9	512
10	1024
11	2048
12	4096

Given block is: 190.100.0.0/16

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

Mask is 32-7=25

Available after Group-1 last customer:

Customer-1: 190.100.64.0/25 to 190.100.64.127/25

Customer-2: 190.100.64.128/25 to 190.100.64.255/25

Customer-3: 190.100.65.0/25 to 190.100.65.127/25

Customer-128: 190.100.127.128/25 to 190.100.127.255/25

Number of bits (Suffix)	Number of Host
1	2
2	4
3	8
4	16
5	32
6	64
7	**128**
8	256
9	512
10	1024
11	2048
12	4096

Solution - Example 7

a) For first group, there are 64 customer and 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		

Solution - Example 7

b) For second group ,there are 128 customers and 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 $= 128 \times 128 = 16{,}384$		

Solution - Example 7

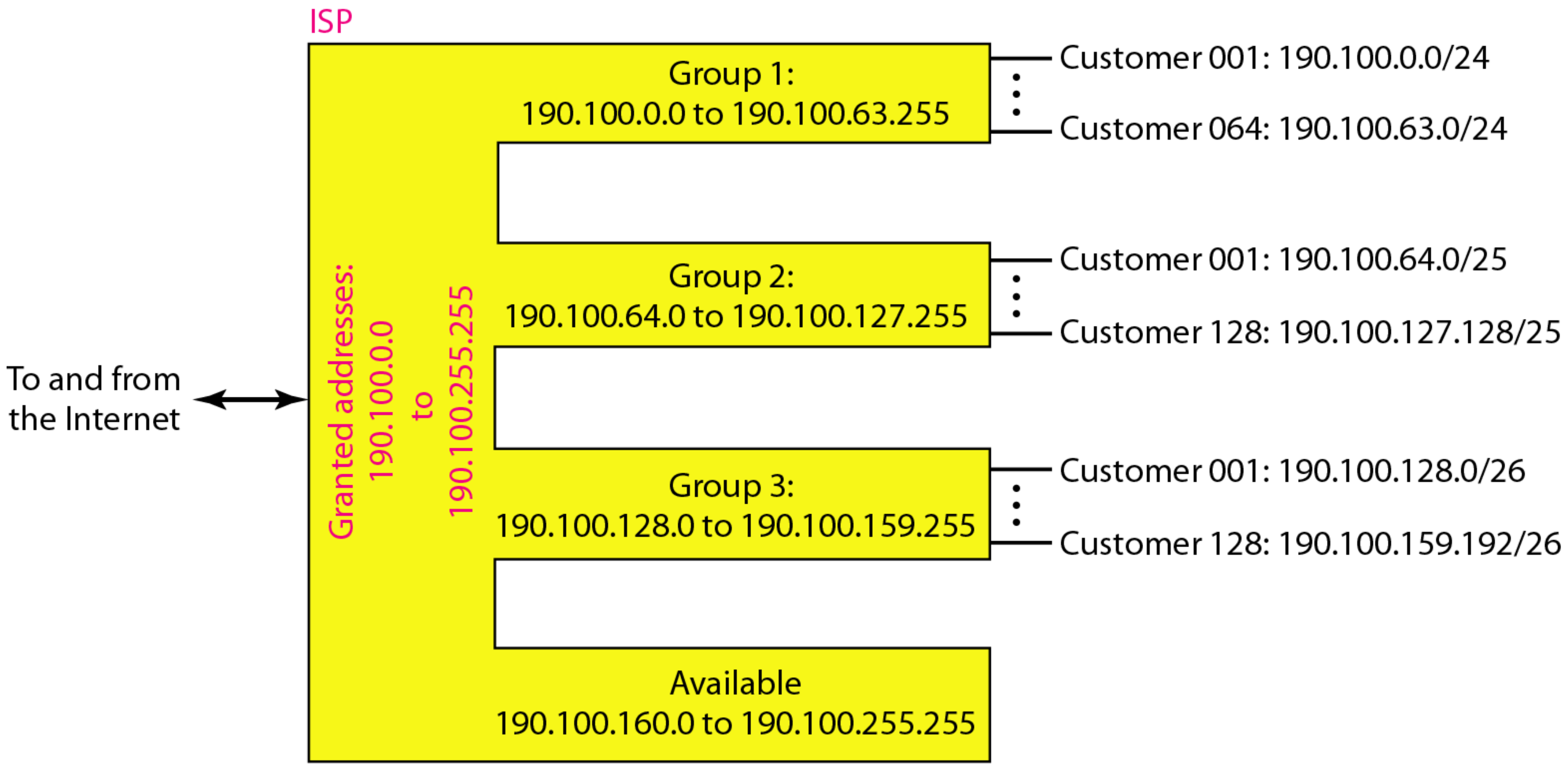
c) For this group, each customer needs 64 addresses. This means that 6 (log264) bits are needed to each host. The prefix length is then 32 − 6 = 26. The addresses are

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 $= 128 \times 64 = 8192$		

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

Solution - Example 7

Address allocation and distribution by an ISP



Example 8

- An organization is granted a block of addresses with the beginning address 14.24.74.0/24. There are 2^{32-24}= 256 addresses in this block. The organization needs to have 11 subnets as shown below:

    a. two subnets, each with 64 addresses.

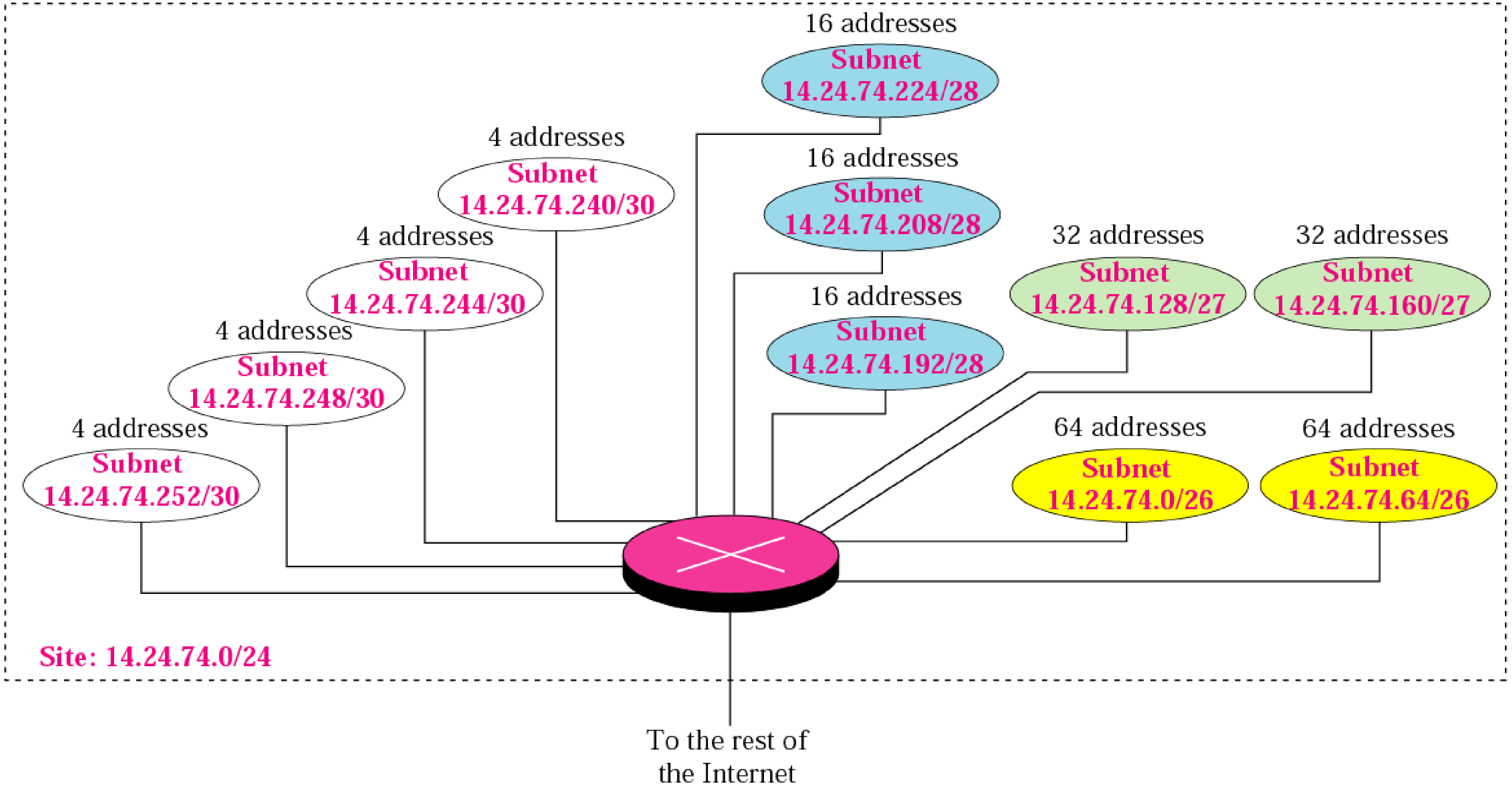
    b. two subnets, each with 32 addresses.

    c. three subnets, each with 16 addresses.

    d. four subnets, each with 4 addresses.

Design the subnets.

Example 8



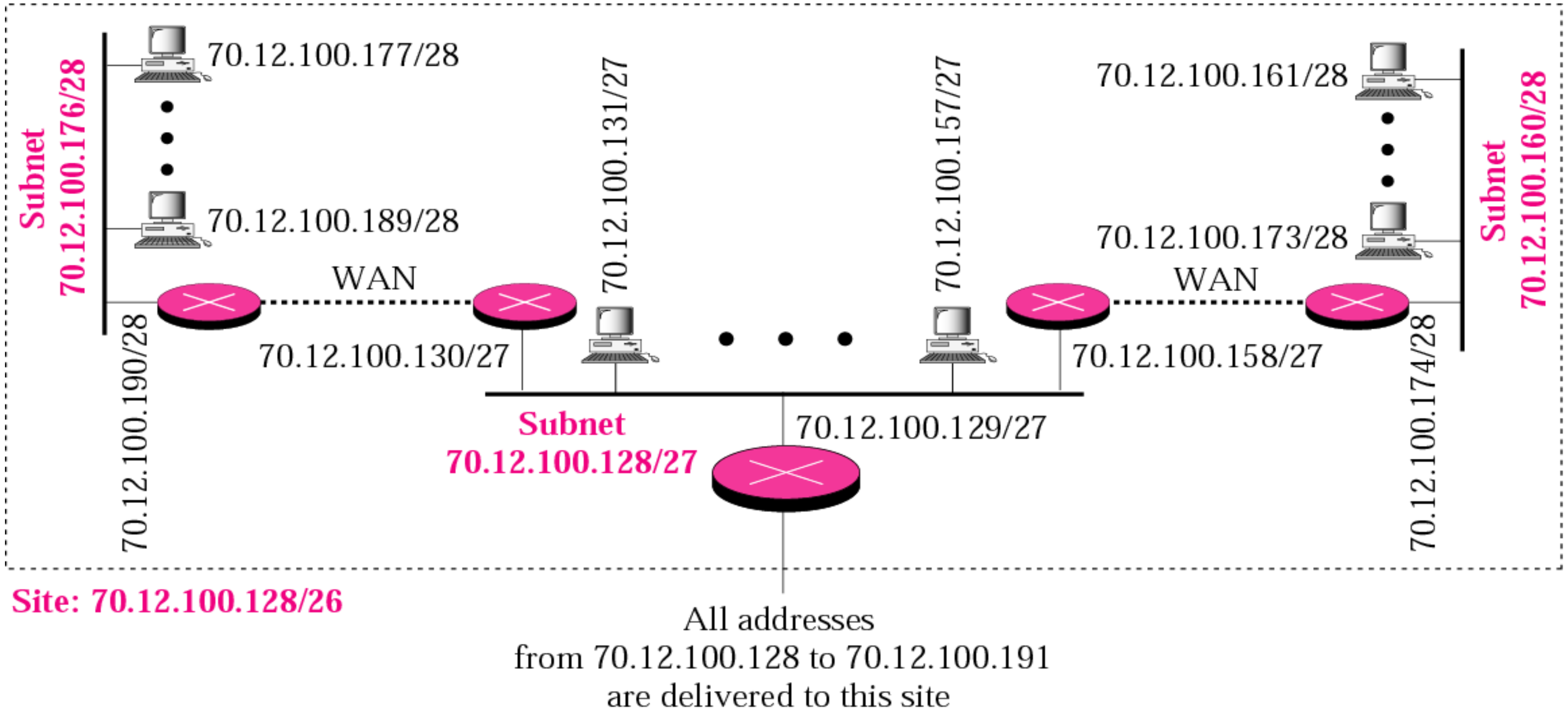
16 addresses
Subnet
14.24.74.224/28
4 addresses
Subnet
14.24.74.240/30
16 addresses
Subnet
14.24.74.208/28
4 addresses
Subnet
14.24.74.244/30
32 addresses
Subnet
14.24.74.128/27
32 addresses
Subnet
14.24.74.160/27
16 addresses
Subnet
14.24.74.192/28
4 addresses
Subnet
14.24.74.248/30
4 addresses
Subnet
14.24.74.252/30
64 addresses
Subnet
14.24.74.0/26
64 addresses
Subnet
14.24.74.64/26
Site: 14.24.74.0/24
To the rest of
the Internet

Example 8

- We use the first 128 addresses for the first two subnets, each with 64 addresses. Note that the mask for each network is /26. The subnet address for each subnet is given in the figure.
- We use the next 64 addresses for the next two subnets, each with 32 addresses. Note that the mask for each network is /27. The subnet address for each subnet is given in the figure.
- We use the next 48 addresses for the next three subnets, each with 16 addresses. Note that the mask for each network is /28. The subnet address for each subnet is given in the figure.
- We use the last 16 addresses for the last four subnets, each with 4 addresses. Note that the mask for each network is /30. The subnet address for each subnet is given in the figure.

Example 9

- Assume a company has three offices: Central, East, and West. The Central office is connected to the East and West offices via private, point-to-point WAN lines. The company is granted a block of 64 addresses with the beginning address 70.12.100.128/26. The management has decided to allocate 32 addresses for the Central office and divides the rest of addresses between the two offices.



Example 9

- The Central office uses the network address 70.12.100.128/27.
- This is the first address, and the mask /27 shows that there are 32 addresses in this network.
- Note that three of these addresses are used for the routers and the company has reserved the last address in the sub-block. The addresses in this subnet are 70.12.100.128/27 to 70.12.100.159/27.
- Note that the interface of the router that connects the Central subnet to the WAN needs no address because it is a point-to-point connection.

Example 9

- The West office uses the network address 70.12.100.160/28. The mask /28 shows that there are only 16 addresses in this network. Note that one of these addresses is used for the router and the company has reserved the last address in the sub-block. The addresses in this subnet are 70.12.100.160/28 to 70.12.100.175/28. Note also that the interface of the router that connects the West subnet to the WAN needs no address because it is a point-to- point connection.

- The East office uses the network address 70.12.100.176/28. The mask /28 shows that there are only 16 addresses in this network. Note that one of these addresses is used for the router and the company has reserved the last address in the sub-block. The addresses in. this subnet are 70.12.100.176/28 to 70.12.100.191/28. Note also that the interface of the router that connects the East subnet to the WAN needs no address because it is a point-to-point connection.

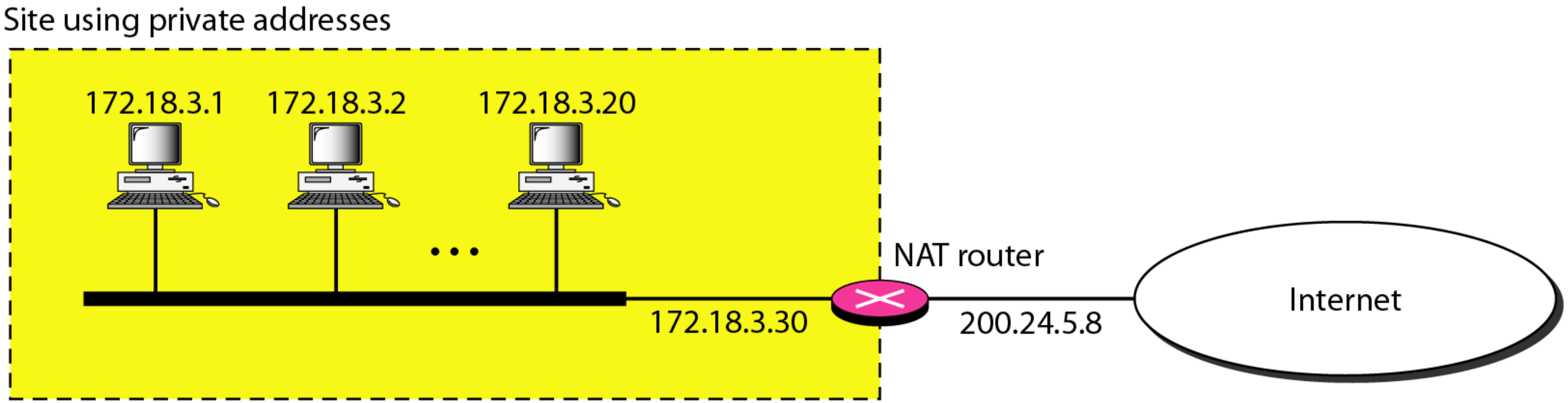
Network Address Translation(NAT)

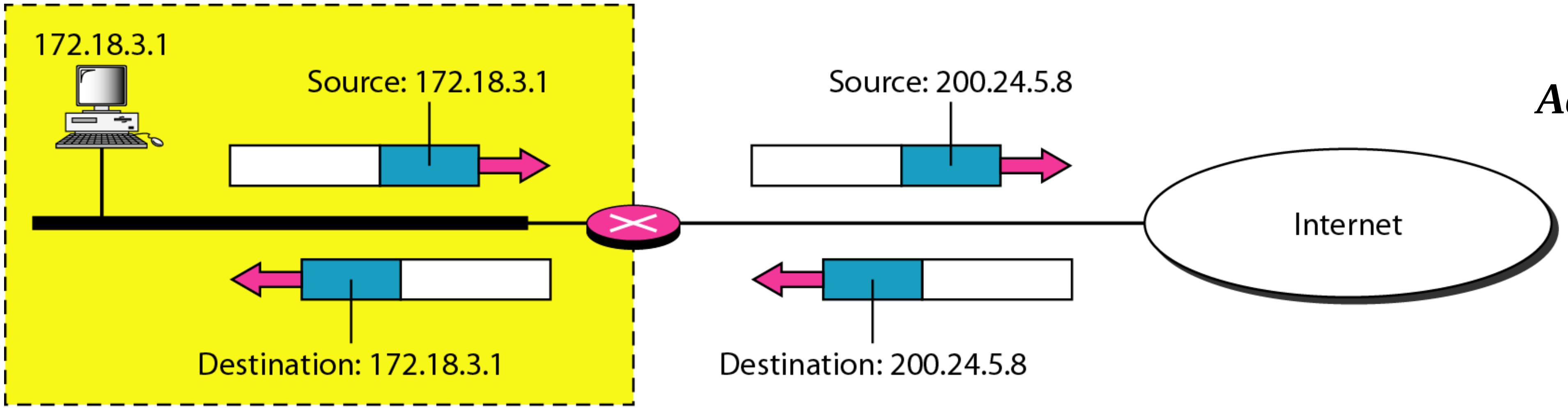
- NAT enables a user to have a large set of addresses internally and one address, or a small set of addresses, externally.
- The traffic inside can use the large set; the traffic outside, the small set.
- To separate the addresses used inside the home or business and the ones used for the Internet, the Internet authorities have reserved three sets of addresses as private addresses

Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

Addresses for private networks

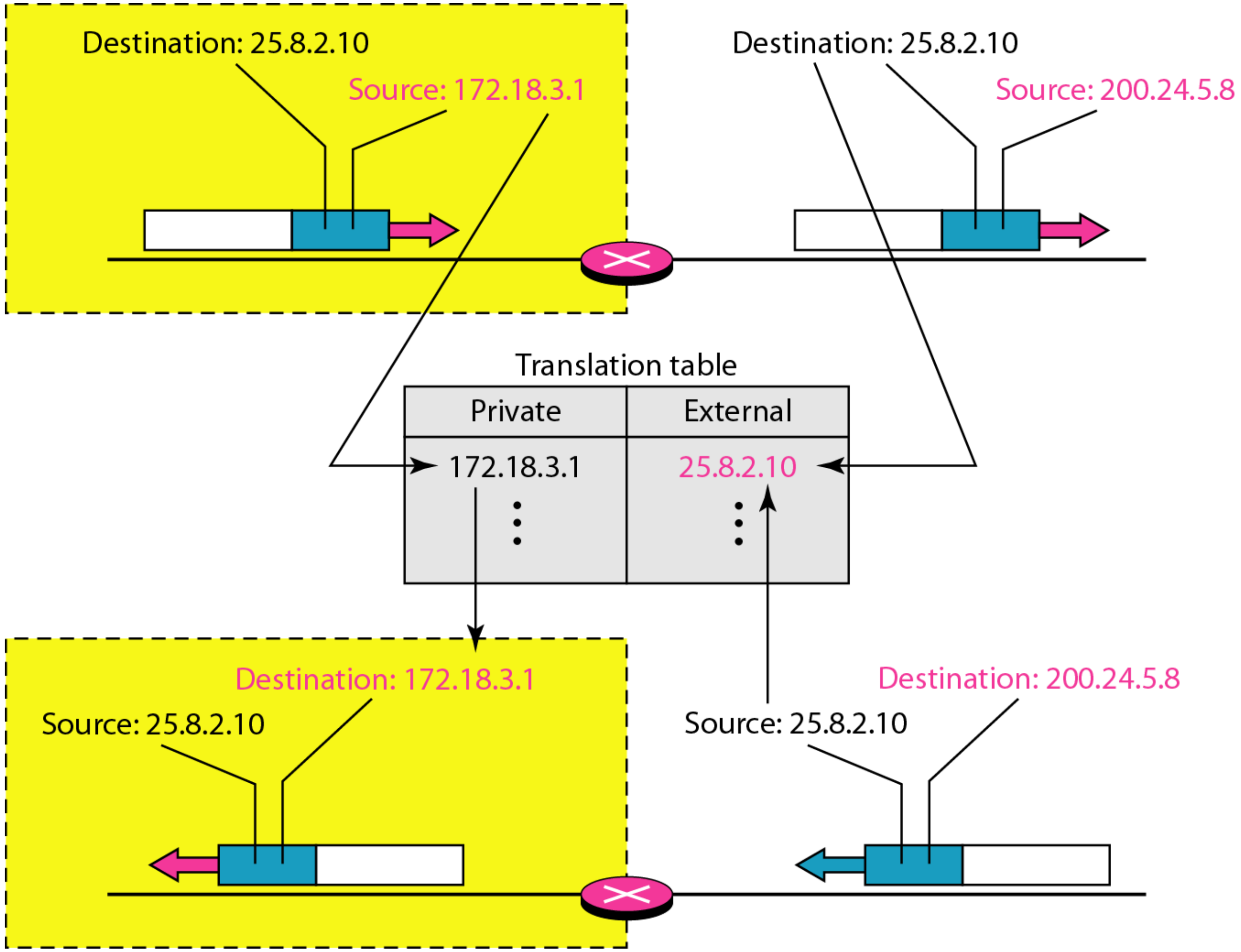
A NAT Implementation





Addresses in a NAT

NAT Address translation table



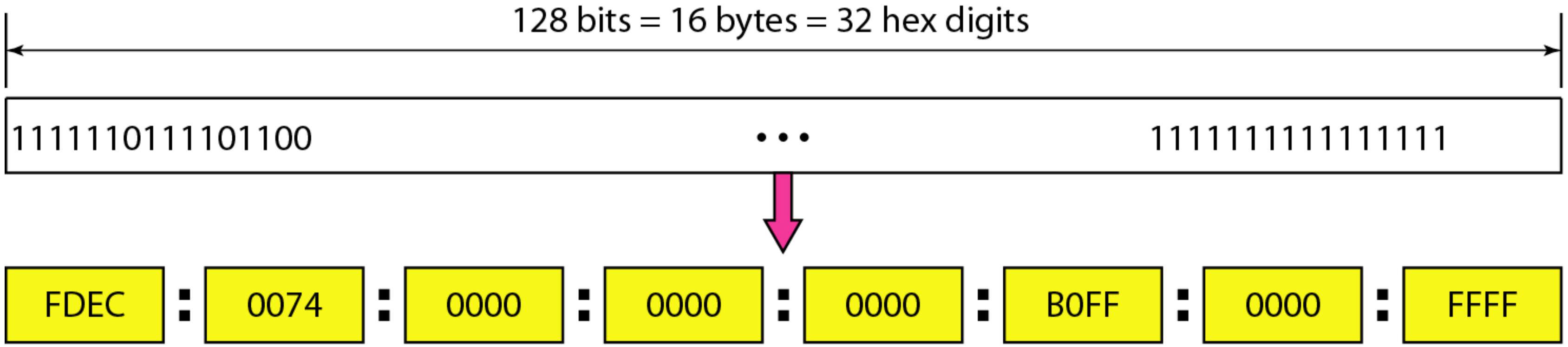
Five-column translation table

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
. . .	. . .	. . .	. . .	. . .

IPv6 Addresses

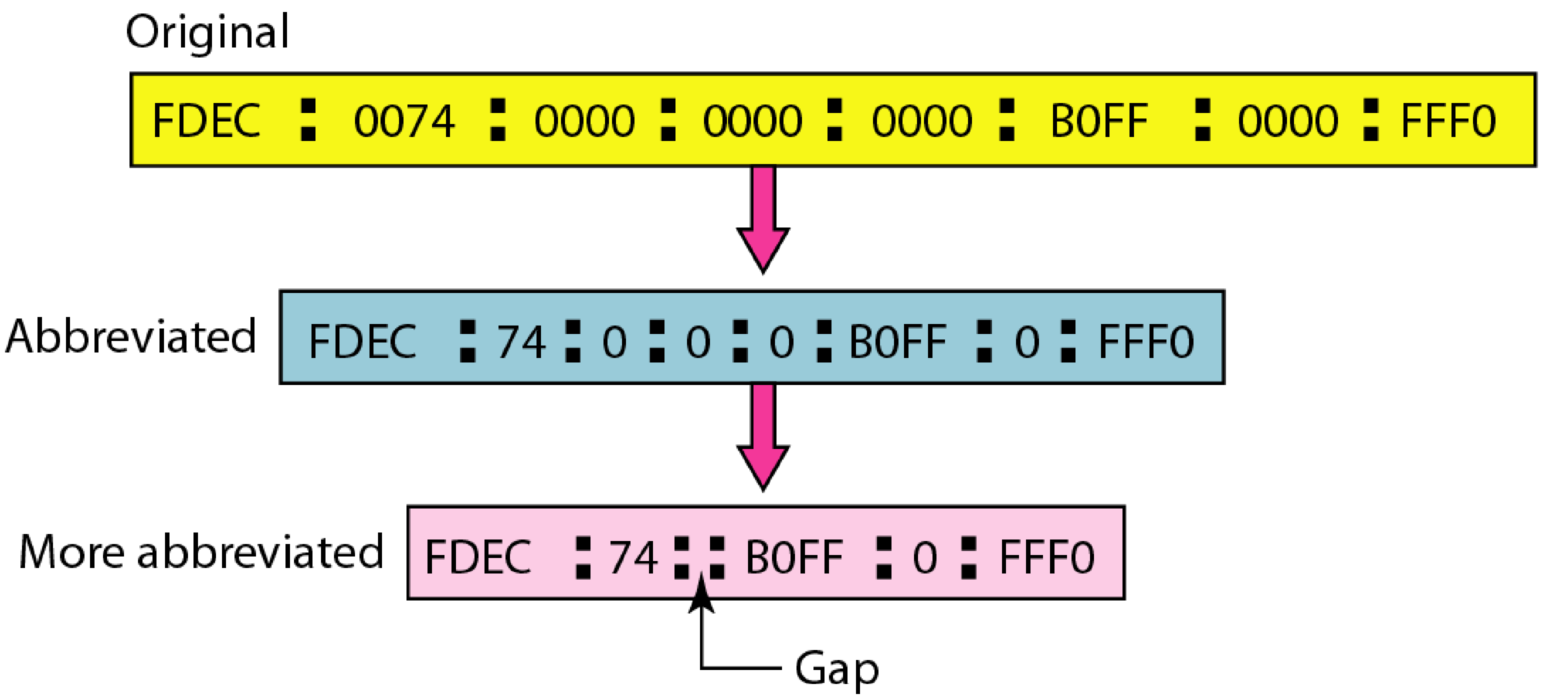
- Despite all short-term solutions, address depletion is still a long-term problem for the Internet. This and other problems in the IP protocol itself have been the motivation for IPv6.

An IPv6 address is 128 bits long.



IPv6 address in binary and hexadecimal colon notation

IPv6 Addresses



Abbreviated IPv6 addresses