IP Addresses:

Classful Addressing

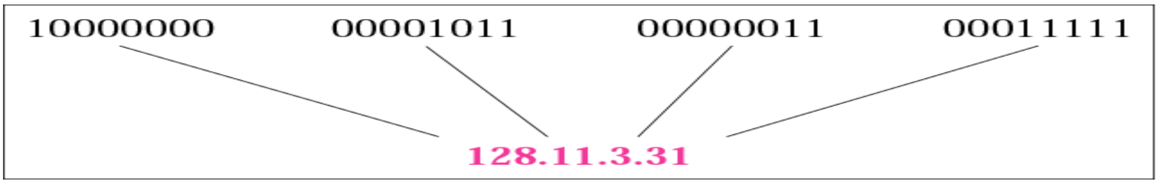
The identifier used in the IP layer of the TCP/IP protocol suite to identify each device connected to the Internet is called the Internet address or IP address. An IP address is a 32-bit address that uniquely and universally defines the connection of a host or a router to the Internet. IP addresses are 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

An IP address is a 32-bit address.

The IP addresses are unique

The address space of IPv4 is 232 or 4,294,967,296.

- Dotted-decimal notation



Example: 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 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: 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

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

Example: 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: 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 $C1831BFF_{16}$

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.

Occupation of the address space

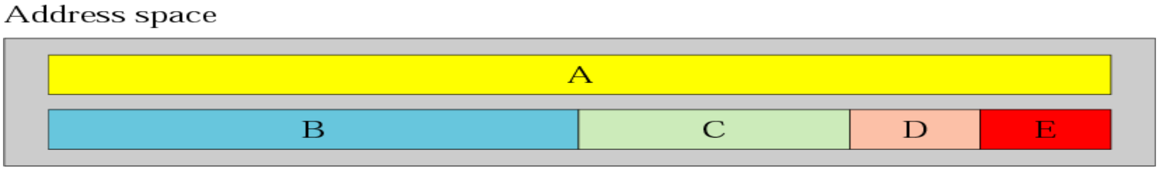
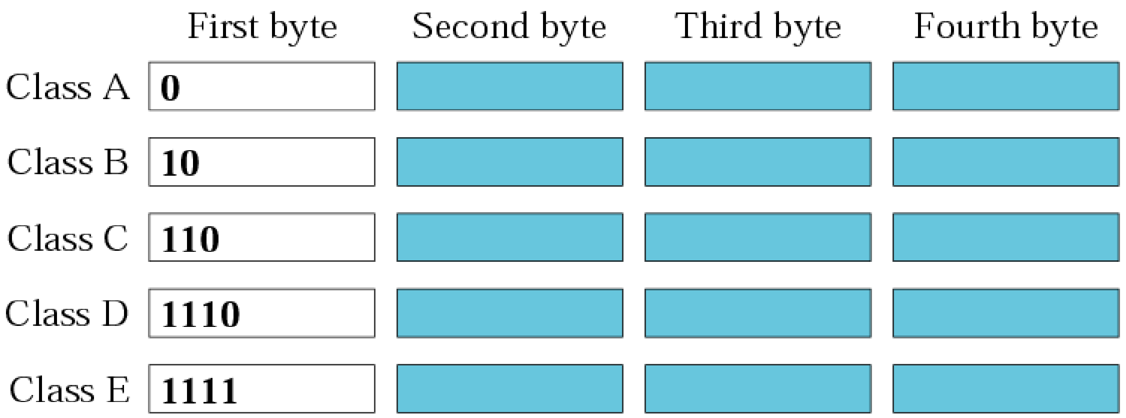


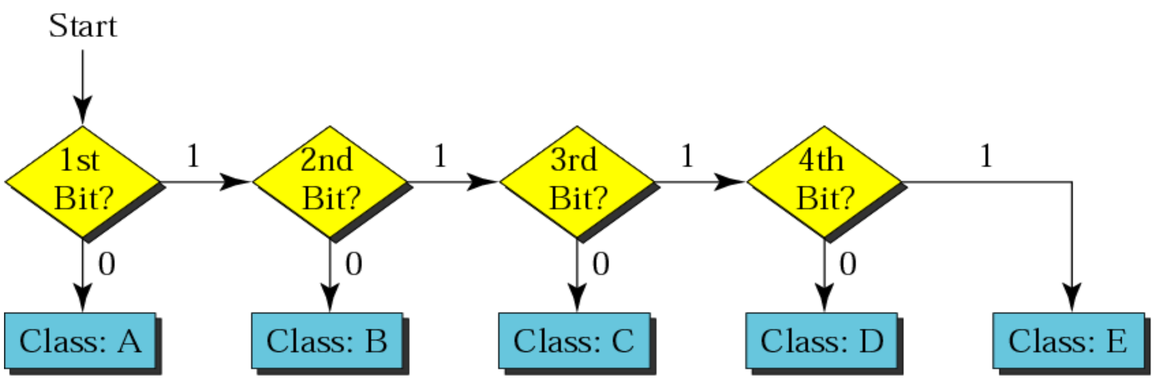
Table: Addresses per class

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%

Finding the class in binary notation:



Finding the address class:



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

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

Example: 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 :
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.

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: 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 : In previous Example 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:

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

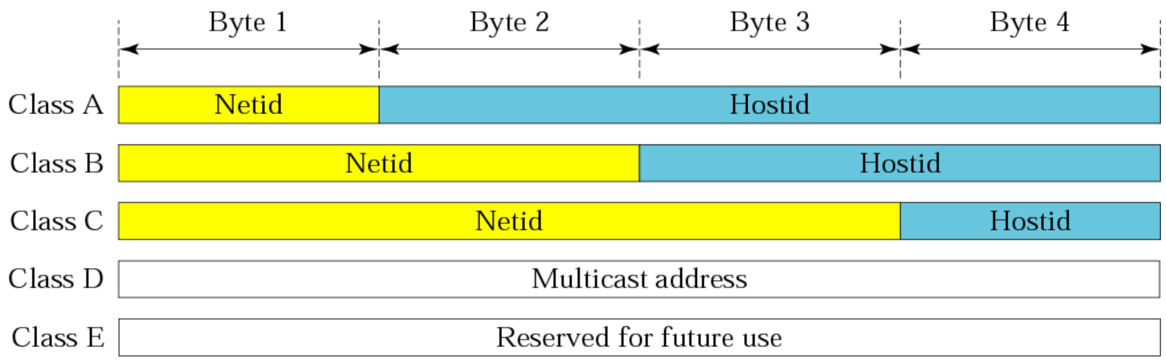
Now to find the integer value of each number, we multiply each byte by its weight:

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

First address: = 0

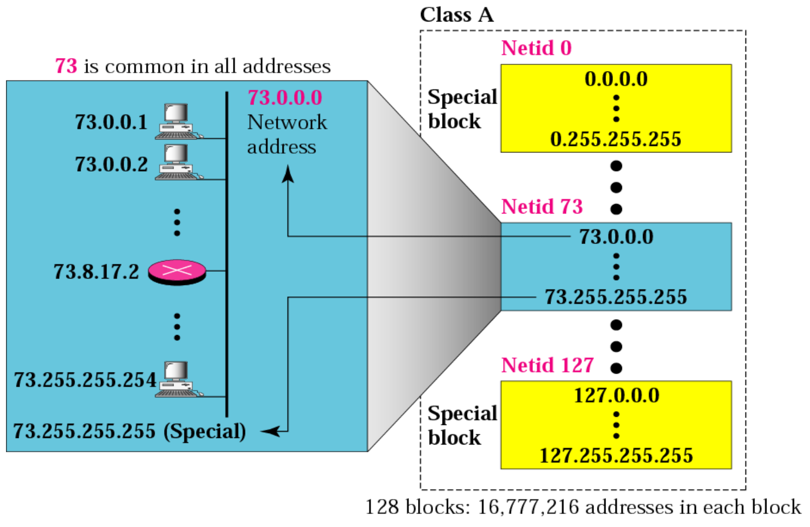
If we subtract the first from the last and add 1 to the result (remember we always add 1 to get the range), we get 2,147,483,648 or 2^{31}.

Netid and hosted:

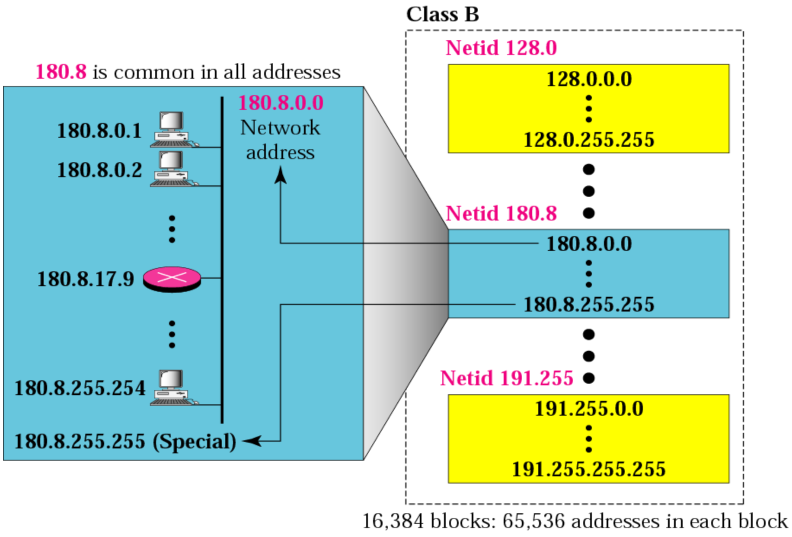


Note: Millions of class A addresses are wasted.

Blocks in class A:

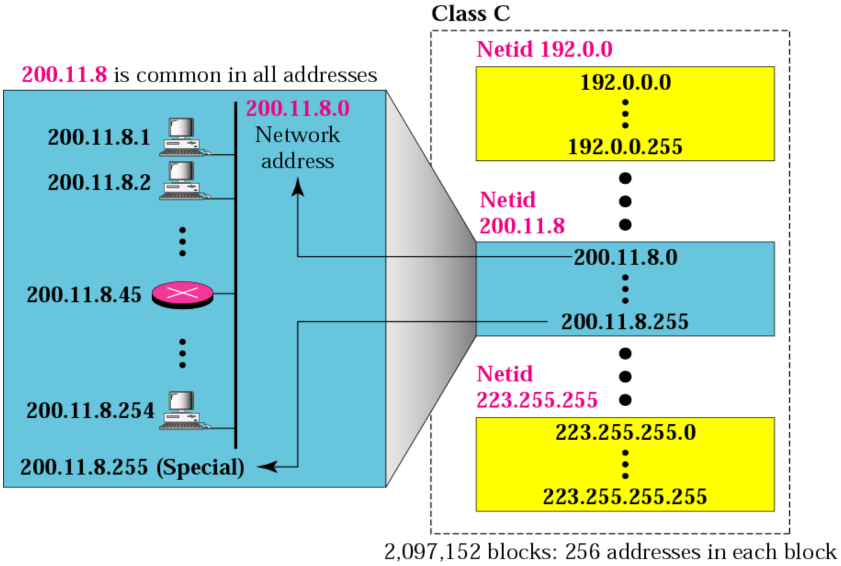


Blocks in class B:



Note: Many class B addresses are wasted.

Blocks in class C:



- The number of addresses in class C is smaller than the needs of most organizations.
- Class D addresses are used for multicasting; there is only one block in this class.
- Class E addresses are reserved for future purposes; most of the block is wasted.
- Class E addresses are reserved for future purposes; most of the block is wasted.

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.

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.

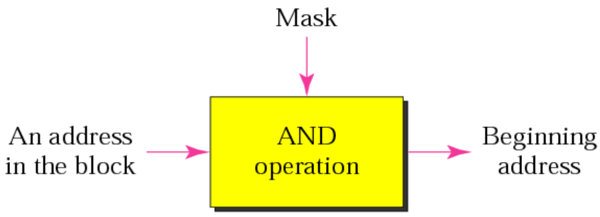
Example: Given the network address 132.21.0.0, find the class, the block, and the range of the addresses.

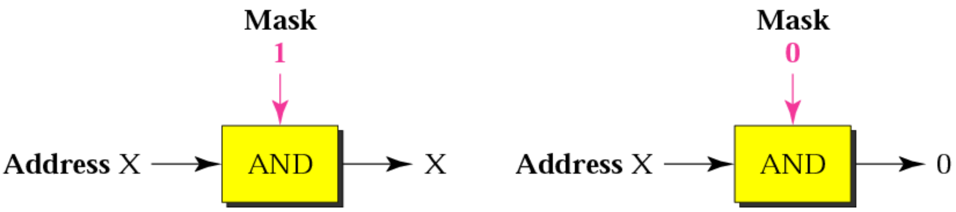
Solution: The class is B, because the first byte is between 128 and 191. The block has a netid of 132.21. The addresses range from 132.21.0.0 to 132.21.255.255.

Example: 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.

Masking concept:





Default masks

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 111111111 11111111** 00000000	**255.255.255.**0

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: 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: 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: 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.

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

Multihomed Devices

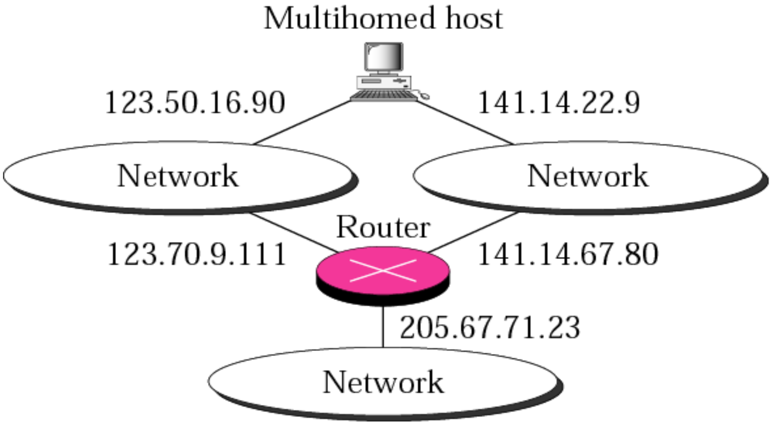
Location, Not Names

Special Addresses

Private Addresses

Unicast, Multicast, and Broadcast Addresses

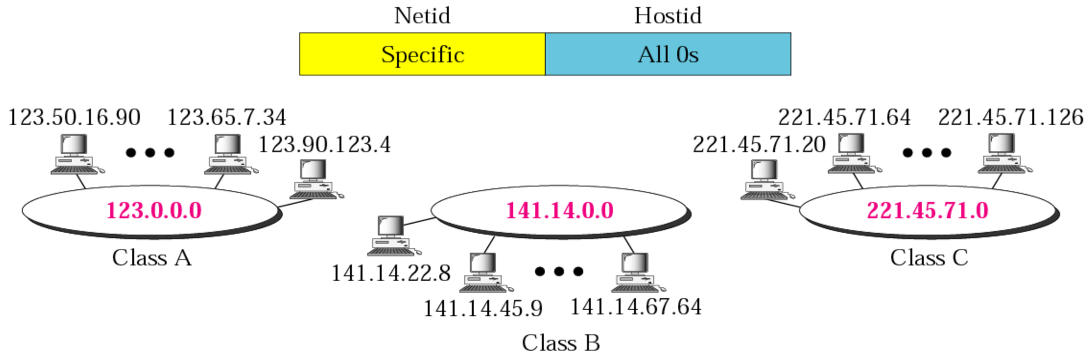
Multihomed devices:



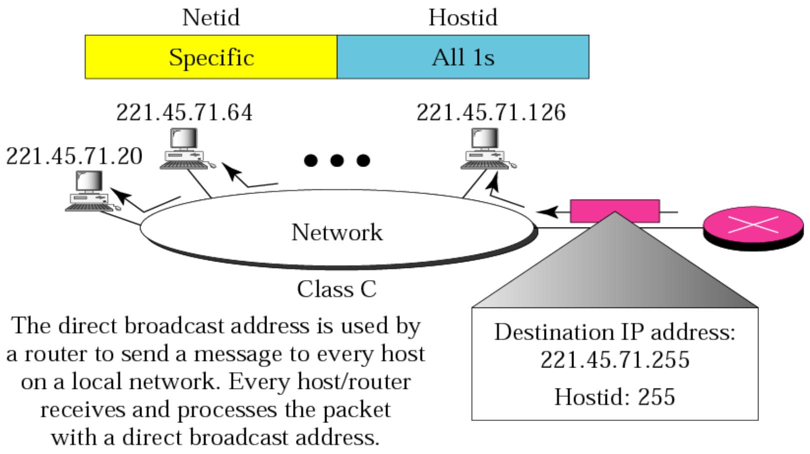
Special addresses

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

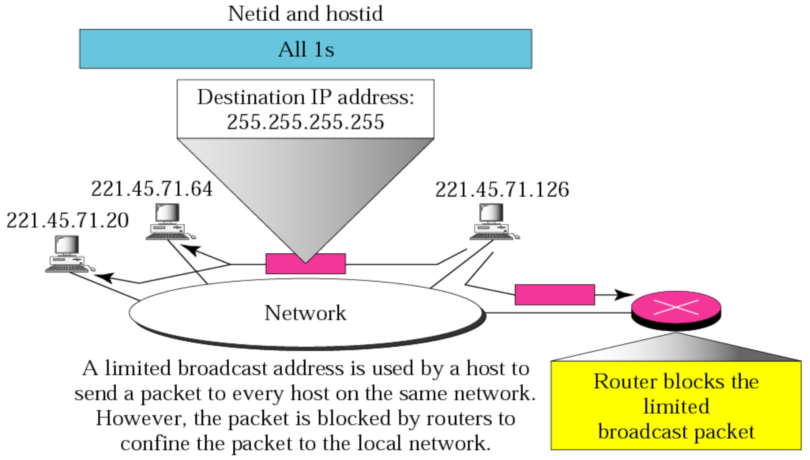
Network address



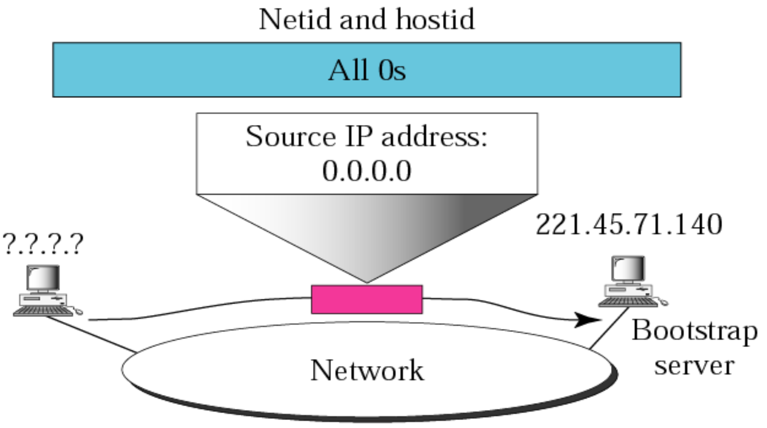
Example of direct broadcast address



Example of limited broadcast address

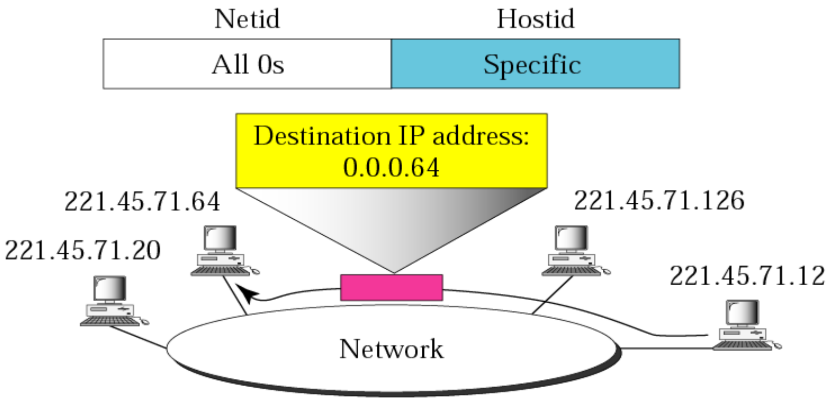


Examples of "this host on this network"



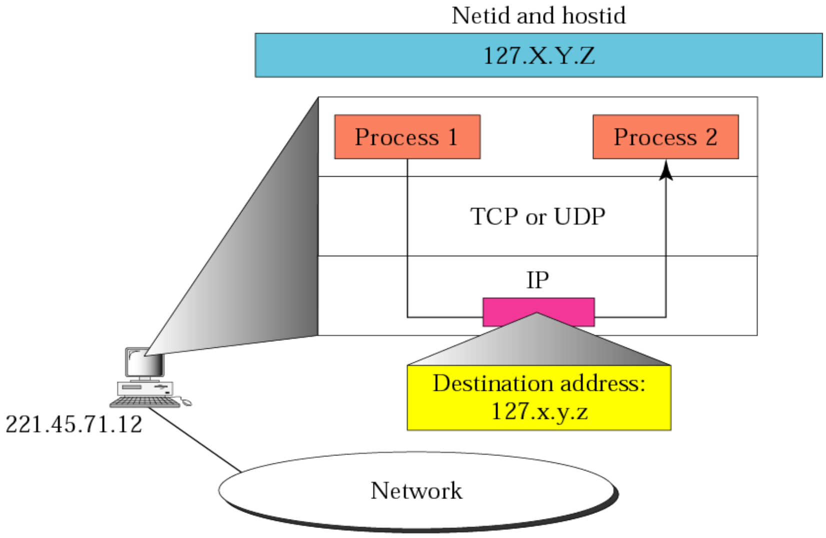
A host that does not know its IP address uses the IP address 0.0.0.0 as the source address and 255.255.255.255 as the destination address to send a message to a bootstrap server.

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.

Example of loopback address

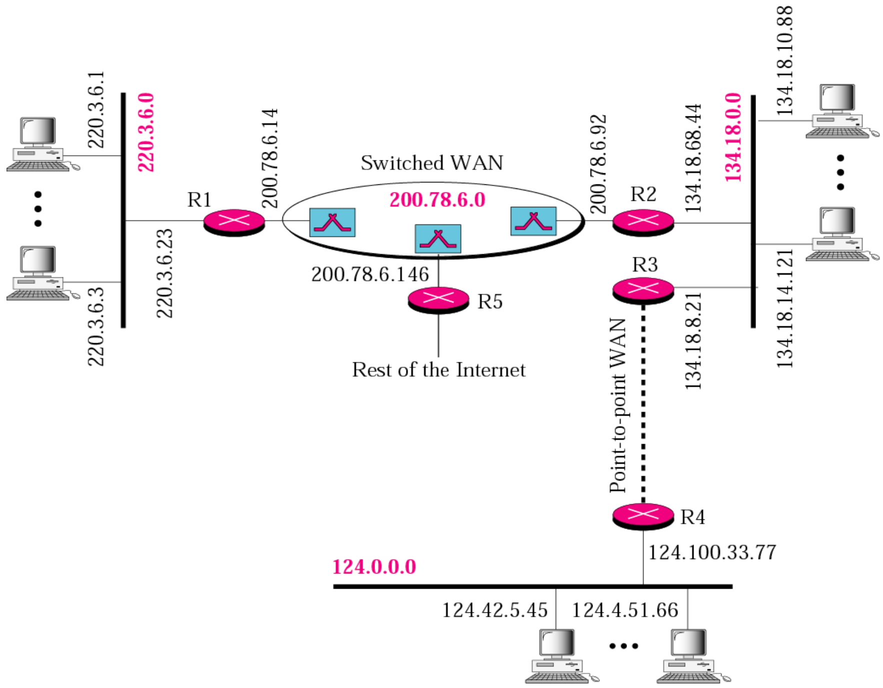


A packet with a loopback address will not reach the network.

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

Sample internet

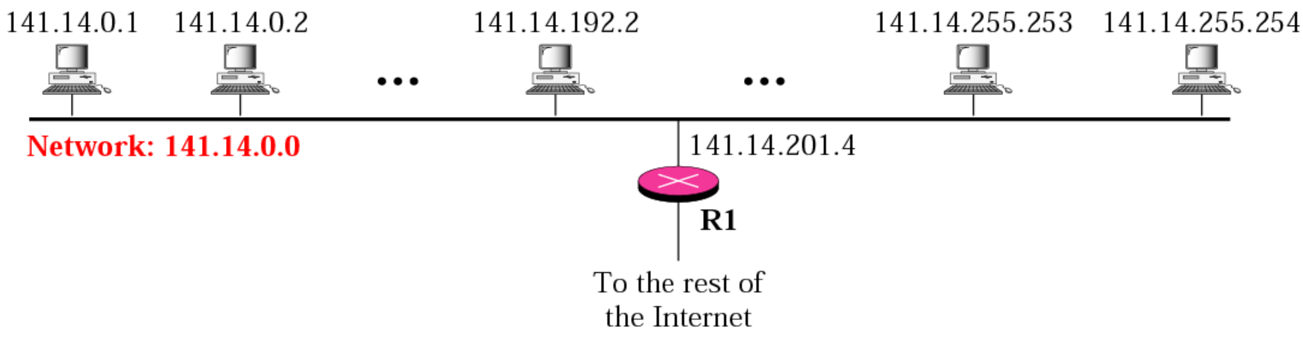


SUBNETTING AND SUPERNETTING:

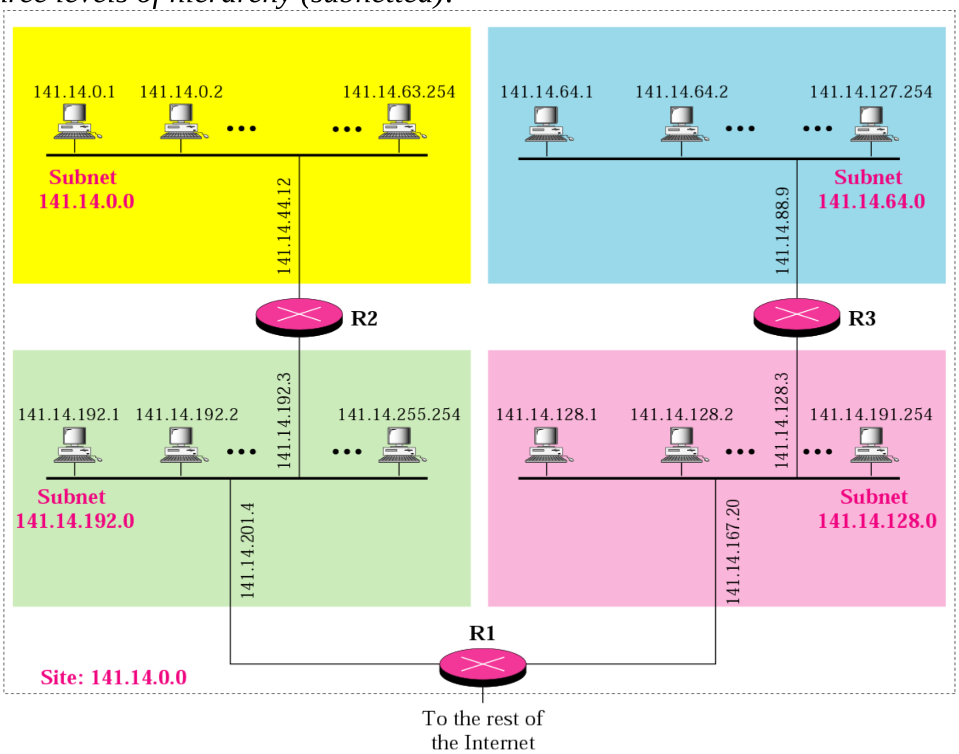
In the previous sections we discussed the problems associated with classful addressing. Specifically, the network addresses available for assignment to organizations are close to depletion. This is coupled with the ever-increasing demand for addresses from organizations that want connection to the Internet.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

IP addresses are designed with two levels of hierarchy.

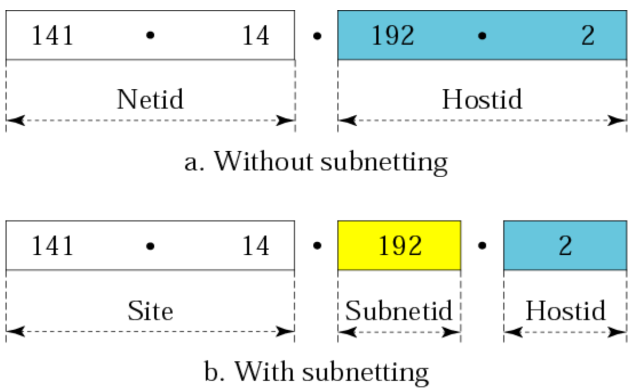
A network with two levels of hierarchy (not subnetted):



A network with three levels of hierarchy (subnetted):

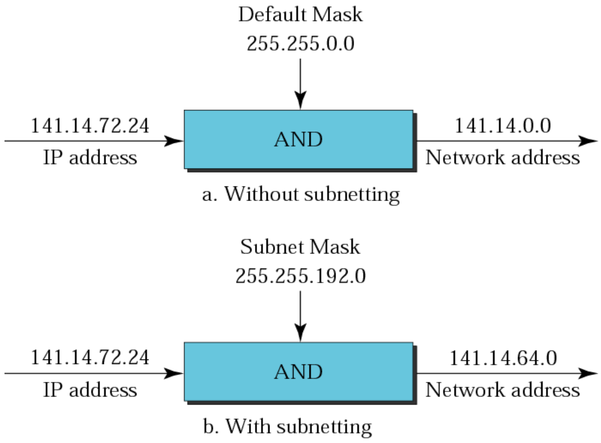


Addresses in a network with and without subnetting:



Hierarchy concept in a telephone number:

Default mask and subnet mask:



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

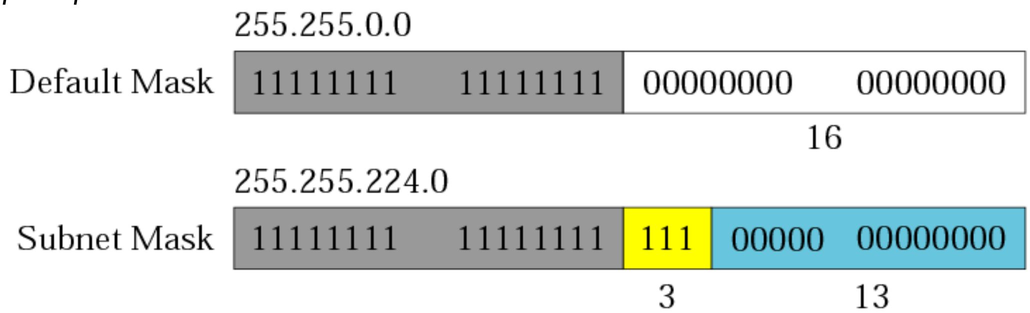
Solution: We apply the AND operation on the address and the subnet mask.

Address ➡ 11001000 00101101 00100010 00111000

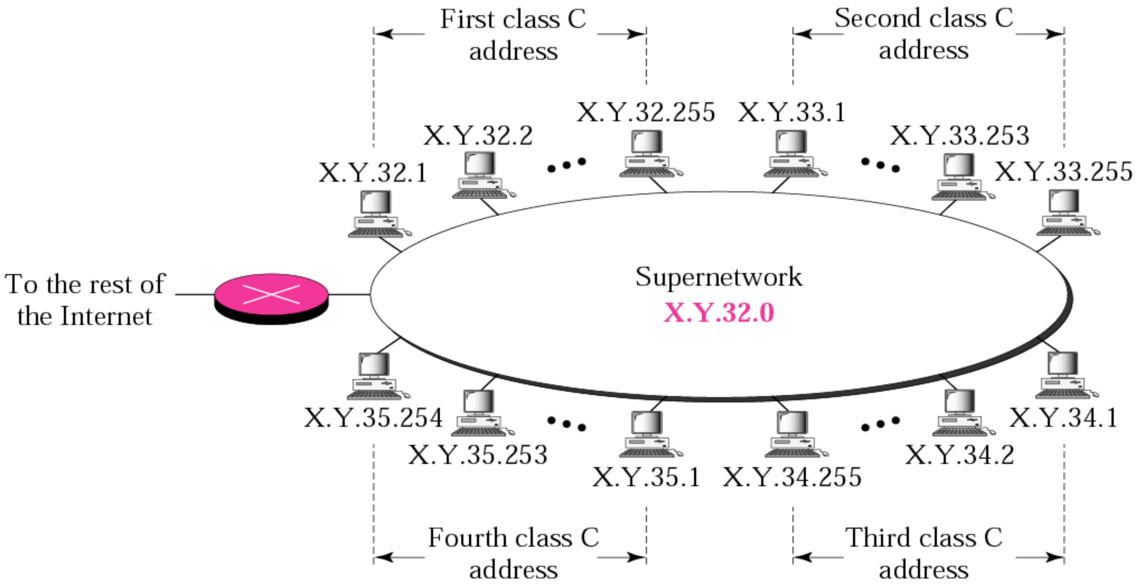
Subnet Mask ➡ 11111111 11111111 11110000 00000000

Subnetwork Address ➡ 11001000 00101101 00100000 00000000.

Comparison of a default mask and a subnet mask:



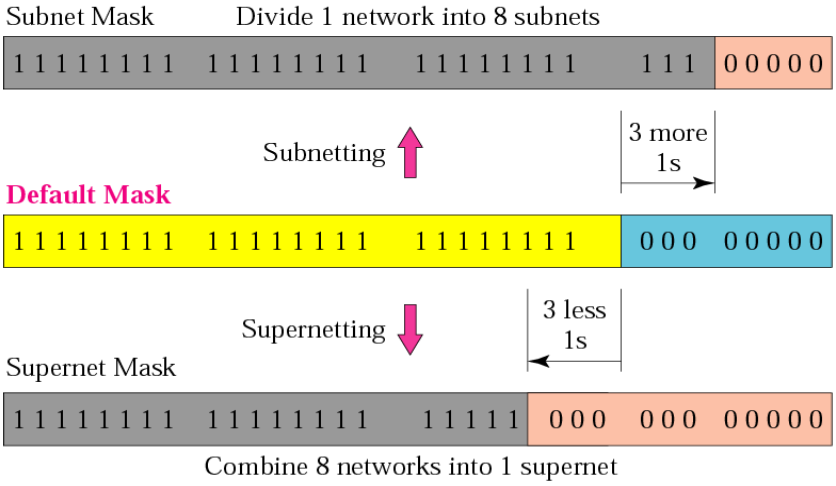
A supernetwork:



- 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.

Comparison of subnet, default, and supernet masks:



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

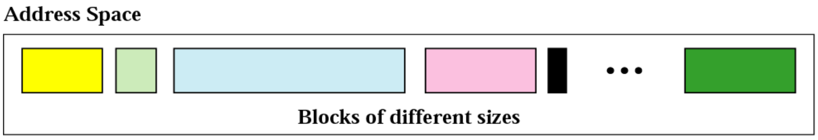
IP Addresses:

Classless Addressing

VARIABLE-LENGTH BLOCKS:

In classless addressing variable-length blocks are assigned that belong to no class. In this architecture, the entire address space (2^{32} addresses) is divided into blocks of different sizes.

Variable-length blocks:



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

a. 205.16.37.32 b.190.16.42.44 c. 17.17.33.80 d.123.45.24.52

Solution: Only two are eligible (a and c). 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.

Example: Which of the following can be the beginning address of a block that contains 256 addresses?

a.205.16.37.32 b.190.16.42.0 c.17.17.32.0 d.123.45.24.52

Solution: In this case, the right-most byte must be 0; the IP addresses use base 256 arithmetic. When the right-most byte is 0, the total address is divisible by 256. Only two addresses are eligible (b and c).

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

a. 205.16.37.32 b.190.16.42.0 c. 17.17.32.0 d.123.45.24.52

Solution: In this case, we need to check two bytes because 1024 = 4 × 256. The right-most byte must be divisible by 256. The second byte (from the right) must be divisible by 4. Only one address is eligible (c).

Format of classless addressing address: Classless inter-domain routing (**CIDR**)

x.y.z.t/n

Prefix lengths:

/n	Mask	/n	Mask	/n	Mask	/n	Mask
/1	128.0.0.0	/9	255.128.0.0	/17	255.255.128.0	/25	255.255.255.128
/2	192.0.0.0	/10	255.192.0.0	/18	255.255.192.0	/26	255.255.255.192
/3	224.0.0.0	/11	255.224.0.0	/19	255.255.224.0	/27	255.255.255.224
/4	240.0.0.0	/12	255.240.0.0	/20	255.255.240.0	/28	255.255.255.240
/5	248.0.0.0	/13	255.248.0.0	/21	255.255.248.0	/29	255.255.255.248
/6	252.0.0.0	/14	255.252.0.0	/22	255.255.252.0	/30	255.255.255.252
/7	254.0.0.0	/15	255.254.0.0	/23	255.255.254.0	/31	255.255.255.254
/8	255.0.0.0	/16	255.255.0.0	/24	255.255.255.0	/32	255.255.255.255

Note: Classful addressing is a special case of classless addressing.

Example: 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 is and change the remaining bits (5) to 0s. The following shows the process:

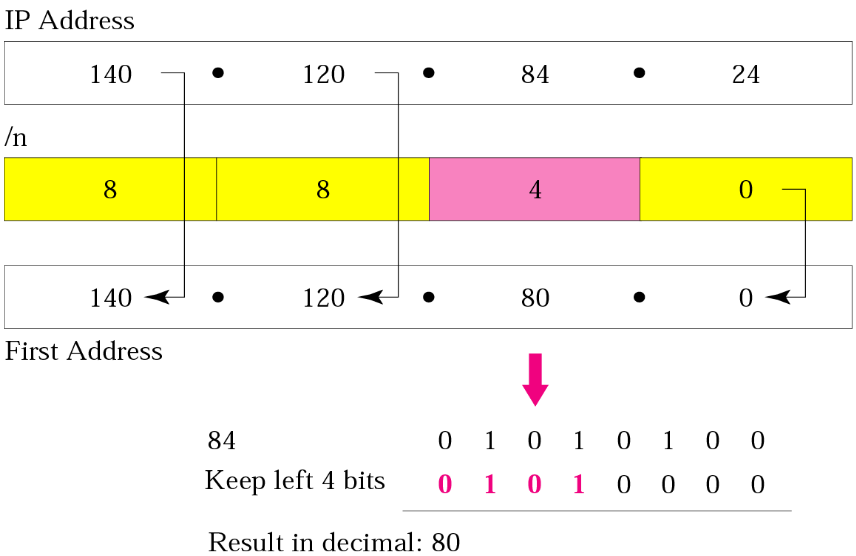
Address in binary: 10100111 11000111 10101010 01010010

Keep the left 27 bits: 10100111 11000111 10101010 010**00000**

Result in CIDR notation: 167.199.170.64/27.

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

Solution: The first, second, and fourth bytes are easy; for the third byte we keep the bits corresponding to the number of 1s in that group. The first address is 140.120.80.0/20. As fellow:



Example: Find the first address in the block if one of the addresses is 140.120.84.24/20.

Solution: The first, second, and fourth bytes are as defined in the previous example. To find the third byte, we write 84 as the sum of powers of 2 and select only the leftmost 4 (m is 4) as shown in Figure. The first address is 140.120.80.0/20.

	128	64	32	16	8	4	2	1
Write 84 as sum of:	0	64	0	16	0	4	0	0
Select only leftmost 4:	0	64	0	16				
Add to find the result:	80							

Example: 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.

Example: Using the first method, find the last address in the block if one of the addresses is 140.120.84.24/20.

Solution: We found in the previous examples that the first address is 140.120.80.0/20 and the number of addresses is 4096. To find the last address, we need to add 4095 (4096 − 1) to the first address. To keep the format in dotted-decimal notation, we need to represent 4095 in base 256 and do the calculation in base 256. We write 4095 as 15.255. We then add the first address to this number (in base 255) to obtain the last address as shown below:

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

The last address is 140.120.95.255/20.

Example: Using the second method, 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

Or 0.0.15.255. We add the mask complement to the beginning address to find the last address.

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

Solution: We follow the procedure in the previous examples to find the first address, the number of addresses, and the last address. To find the first address, we notice that the mask (/29) has five 1s in the last byte. So we write the last byte as powers of 2 and retain only the leftmost five as shown below:

202 ➡ 128 + 64 + 0 + 0 + 8 + 0 + 2 + 0

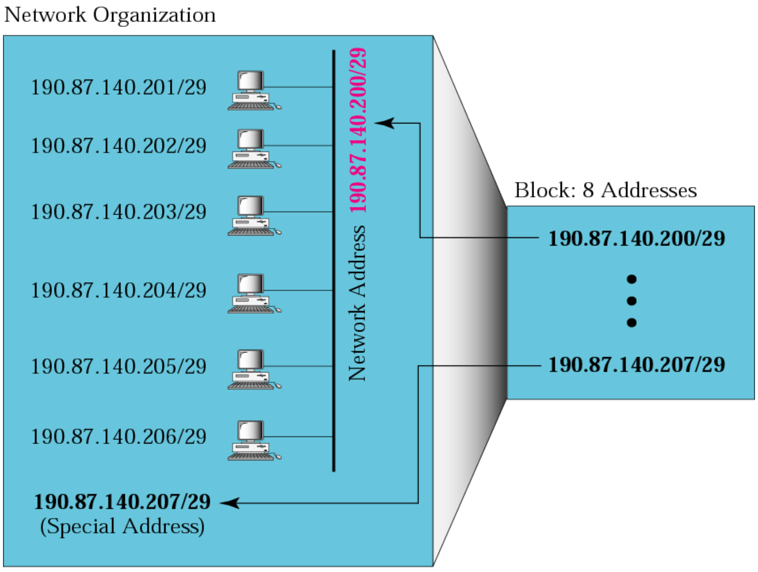
The leftmost 5 numbers are ➡ 128 + 64 + 0 + 0 + 8

The first address is 190.87.140.200/29

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 190.87.140.207/20. There are only 8 addresses in this block.

Example: Show a network configuration for the block in the previous example.

Solution: The organization that is granted the block in the previous example can assign the addresses in the block to the hosts in its network. However, the first address needs to be used as the network address and the last address is kept as a special address (limited broadcast address). Figure below shows how the block can be used by an organization. Note that the last address ends with 207, which is different from the 255 seen in classful addressing.



Note: In classless addressing, the last address in the block does not necessarily end in 255.

Note: In CIDR notation, the block granted is defined by the first address and the prefix length.

SUBNETTING

When an organization is granted a block of addresses, it can create subnets to meet its needs. The prefix length increases to define the subnet prefix length.

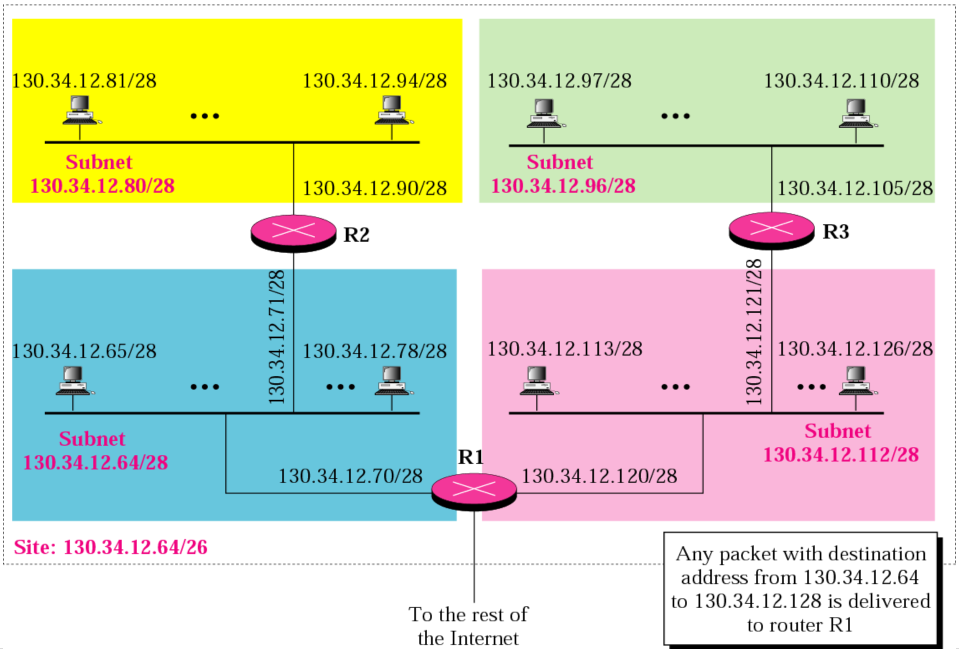
In fixed-length subnetting, the number of subnets is a power of 2.

Example: An organization is granted the block 130.34.12.64/26. The organization needs 4 subnets. What is the subnet prefix length?

Solution: We need 4 subnets, which means we need to add two more 1s ($\log_2 4 = 2$) to the site prefix. The subnet prefix is then /28.

Example: What are the subnet addresses and the range of addresses for each subnet in the previous example?

Solution: Figure below shows one configuration



The site has 2^{32-26} = 64 addresses. Each subnet has 2^{32-28} = 16 addresses. Now let us find the first and last address in each subnet.

1. The first address in the first subnet is 130.34.12.64/28, using the procedure we showed in the previous examples. Note that the first address of the first subnet is the first address of the block. The last address of the subnet can be found by adding 15 (16 −1) to the first address. The last address is 130.34.12.79/28.
2. The first address in the second subnet is 130.34.12.80/28; it is found by adding 1 to the last address of the previous subnet. Again adding 15 to the first address, we obtain the last address, 130.34.12.95/28.
3. Similarly, we find the first address of the third subnet to be 130.34.12.96/28 and the last to be 130.34.12.111/28.
4. Similarly, we find the first address of the fourth subnet to be 130.34.12.112/28 and the last to be 130.34.12.127/28.

Example: 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.

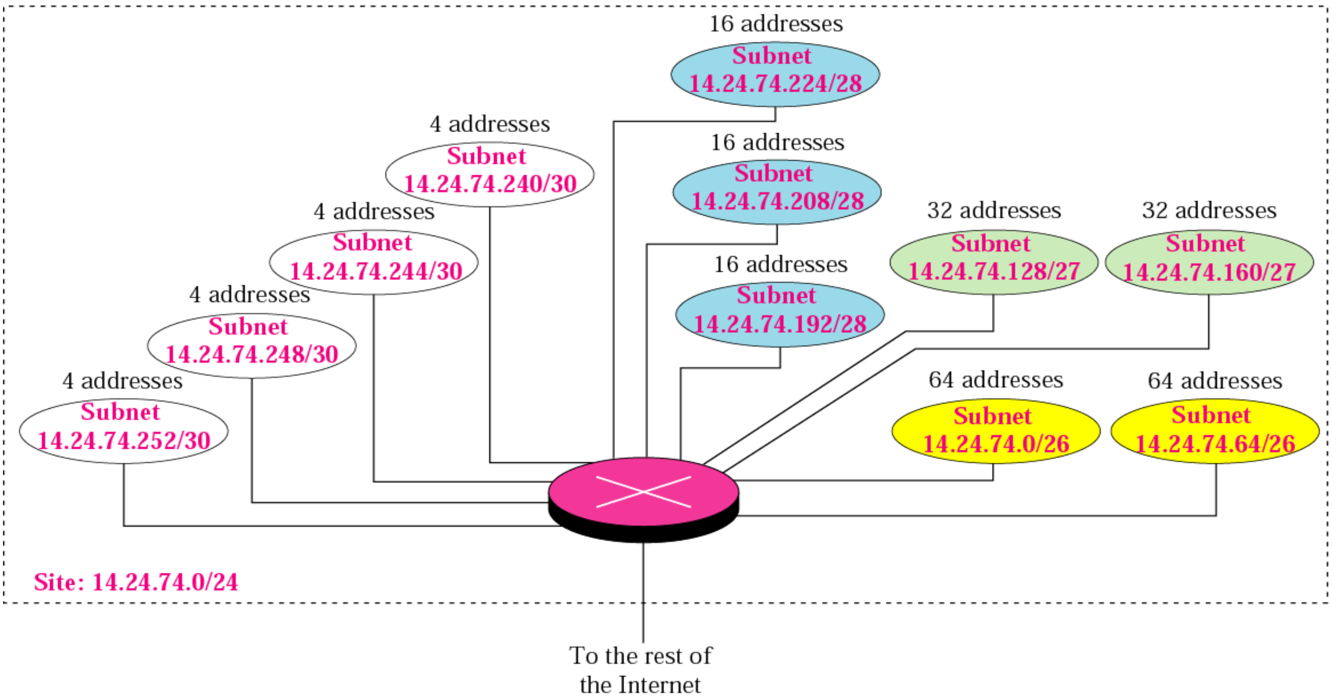
b. two subnets, each with 32 addresses.

c. three subnets, each with 16 addresses.

d. four subnets, each with 4 addresses.

Design the subnets.

Solution: Figure below shows the solution



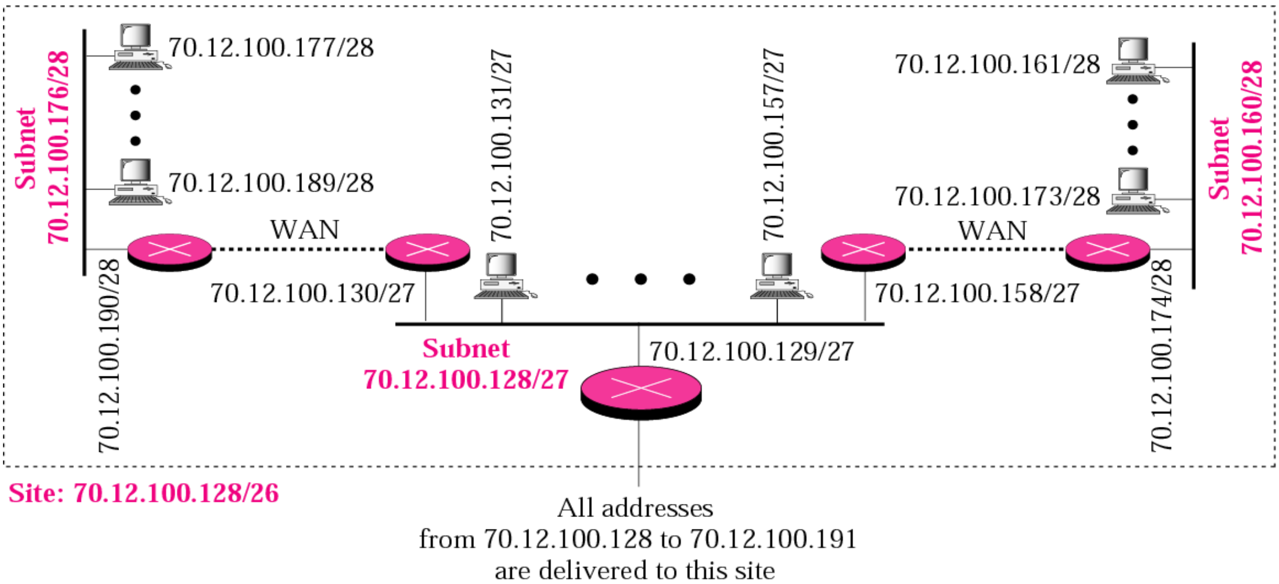
1-We use the first 128 addresses for the first two subnets, each with 64 addresses. Note that the mask for each network is /26. The subnet address for each subnet is given in the figure.

2-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.

3- 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.

4. 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: As another example, 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. Figure below shows the configuration designed by the management.



The company will have three subnets, one at Central, one at East, and one at West. The following lists the subblocks allocated for each network:

a. 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.

b. 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.

c. 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.

ADDRESS ALLOCATION

Address allocation is the responsibility of a global authority called the Internet Corporation for Assigned Names and Addresses (ICANN). It usually assigns a large block of addresses to an ISP to be distributed to its Internet users.

Example: 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:

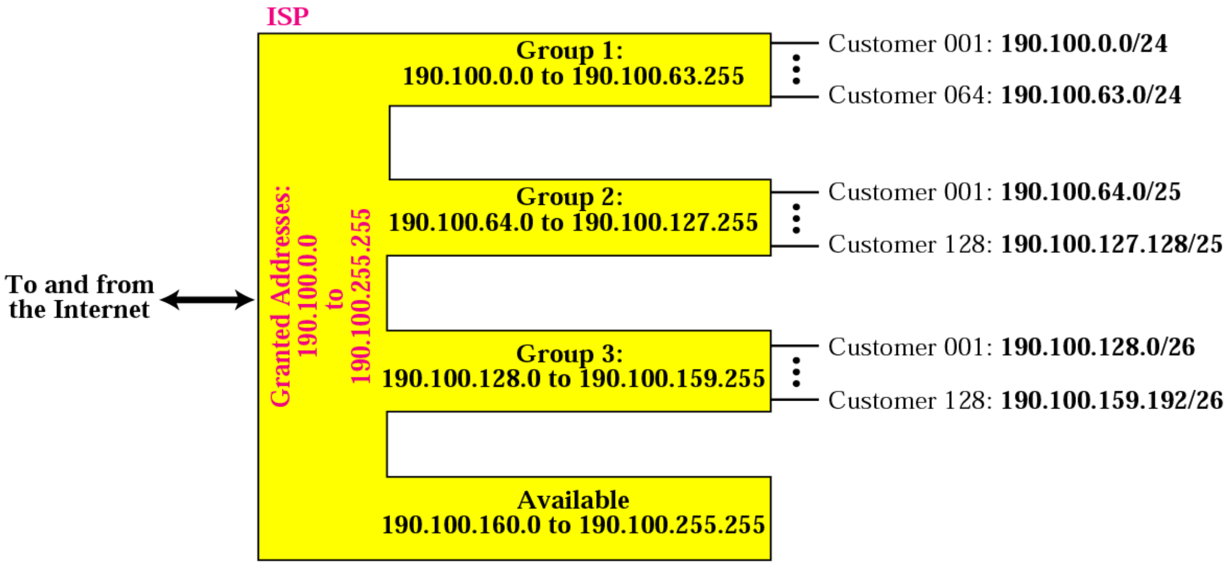
a.The first group has 64 customers; each needs 256 addresses.

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.

Solution: Figure below shows the situation.



Group 1:

For this group, each customer needs 256 addresses. This means the suffix length is 8 (28 =256). 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 the suffix length is 7 (27 =128). 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 the suffix length is 6 (26 = 64). 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 = 8,192

Number of granted addresses to the ISP: 65,536

Number of allocated addresses by the ISP: 40,960

Number of available addresses: 24,576