NETWORK ADDRESSING

IP Address Hierarchy

As we saw earlier, the primary role of IP is to uniquely identify nodes on the network so that packets can be delivered properly. The addressing scheme used today was developed in the 1970s when there were only a very few networks. The current IP addressing model is known as IPv4 where v4 denotes version 4. Strictly speaking, this is not a version number, rather a protocol type number. IP is defined in RFC 791.

Since the IP address used widely today is IPv4, we will consider the details of such an address. An IP address consists of 4 octets or bytes in the form M**.**M**.**M**.**M where M is an integer in the range 0 to 255. Thus, each M position has 256 possible choices, giving an overall possibility for $(2^8)^4 = 256^4 = 4{,}294{,}967{,}296$ addresses.

8 bits	8 bits	8 bits	8 bits
M	M	M	M

Figure - IPv4 Address Format

A new form of IP address known as IPv6, denoting IP address Version 6, has been proposed. It uses 128-bit addressing instead of 32-bit addressing.

The IP addresses are arranged in five classes. Of these five classes, three are main classes labeled Class A, Class B, Class C and two other classes labeled Class D and Class E are for special uses.

The IP addresses are classified based on the first bit of the first octet as follows:

Class	**Pre-assigned leftmost bits of first octet**	**Integer value range for first octet**
A	0	0 - 127
B	10	128 - 191
C	110	192 - 223
D	1110	224 - 239
E	11110	240 - 247

Table - IP address first octet pattern

The IP addresses consist of a network part and a host part. Since there are four octets in an IP address, each of the three classes A, B, C are further classified as follows based on the number of bits available for the network part and the host part, respectively. In the following diagram, N denotes the network part of the address and H denotes the host part of the address:

Class A

8 bits	8 bits	8 bits	8 bits
N	H	H	H

Class B

8 bits	8 bits	8 bits	8 bits
N	N	H	H

Class C

8 bits	8 bits	8 bits	8 bits
N	N	N	H

Figure - IPv4 classes

Class A addresses are no longer assigned. Some of the companies that have a Class A address are: IBM, AT&T, HP, Merck, Stanford University.

Class B addresses are assigned to medium size organizations and most educational institutions of higher education. U of L has a Class B address.

Class C addresses are assigned to small size organizations. One Class C company in Louisville is IGLOU, Louisville's first ISP.

An organization that needs an IP address has to contact the Internet Assigned Numbers Authority (IANA) and provide justification for the class of IP address that it is seeking. It is not a matter of right for any organization to get the IP address they desire. For example, the cost for a Class C IP address is $2,500 for one year. It is worth pointing out in this regard that many individuals who have websites with addresses such as www.myname.com do not get a true IP address, rather an IP address assigned to them by a web hosting company.

Since IP addresses are getting depleted rapidly, IANA has set aside the following IP addresses as private use IP addresses that are available for local use only. These were specified in RFC 1918:

10.0.0.0 to 10.255.255.255
172.16.0.0 to 172.31.255.255
192.168.0.0 to 192.168.255.255

Masking and Subnetting

A mask is a bit pattern that when combined with another bit pattern produces a new bit pattern. Masking is an important part of network addressing as it enables the use of many addresses locally. Each IP address in use has a mask associated with it.

Example 1: IP address: 136.165.21.20 Mask: 255.255.128.0

First we write the IP address and the mask in bits and the masking is done using binary AND operation.

```
IP address in bits:        10001000.10100101.00010101.00010100
Mask:                      11111111.11111111.10000000.00000000
                           -----------------------------------------------
Result of AND operation:   10001000.10100101.00000000.00000000
                           -----------------------------------------------
```

In obtaining the above result, we use the truth table for AND, which is as follows:

AND	**0**	**1**
0	0	0
1	0	1

Table - Truth Table for AND

Thus, the resulting IP address is 136.165.0.0, which is a Class B address. What is the use of getting this IP address using the associated mask? When a node on the Internet wants to send a packet to 136.165.21.20, they really need not know much about that node, except that it belongs to the network address 136.165.0.0, a registered Class B address.

Instead of representing the mask in dotted-decimal notation like 255.255.0.0, one can also use an alternate notation known as the prefix notation. **Prefix notation** represents the total number of <u>continuous</u> ON bits (1s) in the mask. For example, 255.255.0.0 represents 11111111.11111111.00000000.00000000 would be represented as /16 in prefix notation.

The following masks are predetermined:

	<u>Mask</u>	<u>Prefix notation</u>
Class A	255.0.0.0	/8
Class B	255.255.0.0	/16
Class C	255.255.255.0	/24

Exercise 1: Represent the following masks in prefix notation:

255.255.192.0

255.255.128.0

255.224.0.0

We noted earlier that IP addresses are getting depleted rapidly. One way to conserve the use of IP addresses is by using subnets, which get their IP addresses from the main network to which they belong. This process is known as **subnetting**. We will illustrate subnetting using two examples below.

Before we discuss the details of the subnetting, let us make the following observation:

In the network address 192.168.1.0, the network part is '192.168.1' and the host part is '0' because it is a class C address. Writing the host portion in bit representation, we have 00000000. The possible values for host addresses in bit representation then are:

00000000 = decimal value 0
00000001 = decimal value 1
00000010 = decimal value 2
00000011 = decimal value 3
00000100 = decimal value 4
…..

11111110 = decimal value 254
11111111 = decimal value 255

If the host portion is all zeros, then it simply corresponds to the given network, namely 192.168.1.0. If the host portion is all 1s, then it corresponds to the broadcast address for the network, i.e., the broadcast address is 192.168.1.255. So we have to exclude all 0s and all 1s in the host part. That is why we subtract 2 in the formula $2^n - 2 >= m$ where m denotes the number of subnetworks required.

Example 2: Assume that you are given the network address 192.168.1.0 with mask /24. Find the subnet addresses and masks for 4 subnetworks connected to this main network such that each subnet has 20 nodes attached to it.

We are given a Class C address and so we have only the last octet to work with. We need 4 subnetworks. This requires finding the smallest value of 'n' so that $2^n - 2 >= 4$, the number of subnets required. The smallest value of 'n' in this case is 3. So we will borrow 3 bits from the last octet. This leaves us with 8 – 3 = 5 host bits. With 5 host bits we can have at most $2^5 - 2 = 32 - 2 = 30$ hosts on each subnet. Since we need only 20 hosts, we can design these subnetworks.

We will represent this information in the following diagram. In this diagram we have represented the first three octets in decimal notation and the last octet in bit notation. The first 3 octets denote the network part. In the last octet, n denotes subnetwork part and h denotes host part:

network part   host part

192.168.1.n n n | h h h h h

Figure - Subnetworking

The available subnetwork addresses are:

192.168.1.001 | 00000
192.168.1.010 | 00000
192.168.1.011 | 00000
192.168.1.100 | 00000
192.168.1.101 | 00000
192.168.1.110 | 00000

Note that we have excluded the addresses 192.168.1.000 | 00000
and 192.168.1.111 | 00000

for the reasons given in the earlier discussion.

We could choose 4 subnets from the available 6 subnet addresses that we have listed above. For each subnet, we simply list the host addresses successively.

To calculate the mask, we simply take the mask of the given address, namely 255.255.255.0 and replace the last octet with 11100000. The reason we are using three 1s in the leftmost position of the last octet is to reflect the three bits borrowed from the last octet. Thus the mask for calculating the subnet addresses from the given network address is /27 as we now have 27 consecutive on bits in the mask 255.255.255.11100000.

The IP addresses for each of the 4 subnets (plus the two additional subnets) are:

Last Octet	Dotted decimal	Description
00100000	192.168.1.32	IP address of first subnet
00100001	192.168.1.33	first host on first subnet
……		
00111110	192.168.1.62	last host on first subnet
00111111	192.168.1.63	broadcast address on first subnet
01000000	192.168.1.64	IP address of second subnet
01000001	192.168.1.65	first host on second subnet
……		
01011110	192.168.1.94	last host on second subnet
01011111	192.168.1.95	broadcast address on second subnet
01100000	192.168.1.96	IP address of third subnet
01100001	192.168.1.97	first host on third subnet
……		
01111110	192.168.1.126	last host on third subnet
01111111	192.168.1.127	broadcast address on third subnet
10000000	192.168.1.128	IP address of fourth subnet
10000001	192.168.1.129	first host on fourth subnet
……		
10011110	192.168.1.158	last host on fourth subnet
10011111	192.168.1.159	broadcast address on fourth subnet
10100000	192.168.1.160	IP address of fifth subnet
10100001	192.168.1.161	first host on fifth subnet
……		
10111110	192.168.1.190	last host on fifth subnet
10111111	192.168.1.191	broadcast address on fifth subnet
11000000	192.168.1.192	IP address of sixth subnet
11000001	192.168.1.193	first host on sixth subnet
……		

11011110	192.168.1.222	last host on sixth subnet
11011111	192.168.1.223	broadcast address on sixth subnet

Notice that the first subnet address is 192.168.1.32 and the second subnet address is 192.168.1.64. If we look at these numbers as a continuous stream of binary digits, we will notice that the first 25 bits are identical in both addresses. Consequently, 192.168.1.32/27 and 192.168.1.64/27 are **contiguous prefixes** as they are inside the same binary block 192.168.1.0/25.

<u>For routing purposes we need the prefixes to be unique, not necessarily contiguous. If the addresses are contiguous, then the hierarchy is easy to notice.</u>

Example 3: Find the subnets for a Class C node with two subnets. Use 200.1.1.0 as the network address for the node.

In this example we are already given the network address and it is a class C address. For every address we have, the host portion cannot be all 0s or all 1s. Recall that all 0s in the host part denotes the network portion of the address and all 1s in the host part denotes the broadcast address for the network. Since we need two subnets, the number of bits to borrow from the host part should be a number n such that $2^n - 2 >= 2$ and n is the smallest such number. Clearly n = 2 is the answer in this case. So we have to borrow 2 bits from the host part to make up the /26 prefix for the subnets. This leaves us with 6 host bits. All 0s in the subnet part of the host space gives the network address of 200.1.1.0. All 1s in the subnet part of the host space gives the address of 200.1.1.192. These two subnet addresses are not allowed. Thus, the two subnet addresses in bit notation for the last octet are: 200.1.1.01000000 and 200.1.1.10000000. In dotted-decimal notation these would be 200.1.1.64 and 200.1.1.128.

Take the first subnet. Its address is 200.1.1.64. To get the address range for all the hosts in this subnet we need to use the 6 host bits. If all host bits are zero, then we get the subnet address. So the host addresses will be in the range: 200.1.1.01000001 to 200.1.1.01111110. This translates in dotted-decimal notation to 200.1.1.65 to 200.1.1.126.

Similarly, for the second subnet the host address range is 200.1.1.129 to 200.1.1.190.

Exercise 2: Write the hosts for the two subnets listed above as well as the broadcast addresses for each of the two subnets above.

Exercise 3: Use a /28 prefix to derive the available subnets of 192.168.147.0. Derive the available host addresses of each subnet.

Exercise 4: You have been told to configure 192.168.13.175 on an interface with a /28 prefix. Is there a problem? If so, what is it?

Exercise 5: Find the IP addresses for 4 subnets, with each subnet to host 25 nodes. Give the range of IP addresses for the hosts on each subnet in dotted decimal along with the mask in /xx format. These subnets are linked to a router with IP address 197.15.22.0.

Exercise 6: You are given the responsibility to design a network that consists of 10000 subnetworks and each subnetwork has at most 1000 nodes. The IP address you have to work with is 126.0.0.0. Write the IP addresses for the following:

Subnet mask for the network you design

First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork

Exercise 7: You are given the responsibility to design a network that consists of 130000 subnetworks and each subnetwork has at most 85 nodes. The IP address you have to work with is 135.0.0.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 8: You are given the responsibility to design a network that consists of 145000 subnetworks and each subnetwork has at most 185 nodes. The IP address you have to work with is 125.0.0.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 9: You are given the responsibility to design a network that consists of 250000 subnetworks and each subnetwork has at most 50 nodes. The IP address you have to work with is 131.0.0.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 10: You are given the responsibility to design a network that consists of 2000 subnetworks and each subnetwork has at most 25 nodes. The IP address you have to work with is 132.127.0.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
25^{th} node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 11: You are given the responsibility to design a network that consists of 66000 subnetworks and each subnetwork has at most 24 nodes. The IP address you have to work with is 134.129.0.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork

First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 12: You are given the responsibility to design a network that consists of 250 subnetworks and each subnetwork has at most 174 nodes. The IP address you have to work with is 133.128.0.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 13: You are given the responsibility to design a network that consists of 30 subnetworks and each subnetwork has at most 5 nodes. The IP address you have to work with is 135.130.125.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 14: You are given the responsibility to design a network that consists of 14 subnetworks and each subnetwork has at most 12 nodes. The IP address you have to work with is 136.131.127.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

Exercise 15: You are given the responsibility to design a network that consists of 5 subnetworks and each subnetwork has at most 25 nodes. The IP address you have to work with is 137.132.128.0. Write the IP addresses for the following:

Subnet mask for the network you design
First subnetwork
First node in first subnetwork
Last node in first subnetwork
Broadcast address for first subnetwork
Second subnetwork.

IPv6 and NAT

IPv6, also known as **IP Next Generation** (IPng) is the new addressing standard proposed by the IETF as a replacement for IPv4. It is a 128-bit address. IPv6 has the capacity for 3 x 10^{38} addresses. This compares with IPv4 which has 4 x 10^{9} addresses.
IPv6 closely follows the ISO standard addressing method known as **CLNP** (Connection-less Network Layer Protocol). In IPv6, the number 6 denotes version 6. Even though IPv6 is the

addressing scheme intended as the successor to IPv4, there is no IPv5. It is worth noting that the numbers 4 and 6 in IPv4 and IPv6 strictly do not denote the version number. They actually denote the type in IETF's addressing scheme. The type 5 was assigned to some other service by IETF and so IPng was assigned IPv6. In actuality, the IPv6 addressing method does not need the version number. However, for the sake of continuity from IPv4, the type field was assigned type 6. IPv6 has not been widely accepted in U.S. where as in both South Korea and Japan it has been accepted as the standard. This has allowed these countries to assign IP addresses to mobile units such as PDAs and cell phones.

NAT stands for **Network Address Translation**. This is another tool available to share the available IP addresses among a large number of nodes. NAT is in between the Internet and the organization subnet. NAT is a hardware/software combination device that has a pool of IP addresses that it can assign on demand to nodes on a LAN in order to communicate over the Internet. NAT provides a temporary solution to IPv4 running out of IP addresses. NAT is widely used in U.S. by large organizations.

UDP, ARP, DHCP protocols

UDP stands for User Datagram Protocol. It is the principal means used by IP to transfer packets. User data program protocol is used as a resource saving tool. It is also known as 'best effort' protocol, which means that a packet when transmitted is not acknowledged individually but has a high probability of getting delivered correctly. When UDP is used some other higher layer in the protocol stack checks for overall data delivery and catches any errors in delivery at that level. This is a connection-less protocol. UDP is not designed to provide reliability, which is usually done by TCP. UDP sends out packets without first establishing a connection.

RFC 768 describes UDP.

UDP header consists of source port, destination port, length, and checksum information.

16 bits	16 bits
Source port #	Destination port #
Length	Checksum

Figure - UDP format diagram

Example of UDP: TFTP (Trivial File Transfer Protocol). TFTP is used when bootstrapping diskless systems as they have no place to store the configuration files.

TFTP is on UDP port 69

ARP stands for Address Resolution Protocol. Address Resolution Protocol supports TCP/IP. When an IP datagram leaves a router and enters a LAN, the destination address of the node has to be determined. This is what is known as 'Address Resolution.' Router advertises to all nodes on the LAN segment that it has a packet for the specified IP address. The node with the IP address responds with its MAC (Media Access Control) address. The packet is then sent to that MAC address. Thus, ARP's primary function is to translate the 32-bit IP address (which is logical) to the 48-bit MAC address (which is physical).

RFC 826 describes ARP.

DHCP stands for Dynamic Host Configuration Protocol. Dynamic Host Configuration Protocol addresses the problem of not having sufficient number of IP addresses for all nodes. Since not all nodes are on the Internet at the same time, DHCP enables better management of IP addresses. Nodes run DHCP client software. The client, when needing a session set up, informs the DHCP server. The DHCP server then assigns a temporary IP address for the duration of the session. When the session is over the IP address is returned to the IP address pool managed by the DHCP server. People using DSL or cable modem are the primary users of DHCP. It is also used in business environments to share IP addresses among several nodes on a network.

DHCP client uses UDP port 68 and the DHCP server uses UDP port 67.

Answer for Exercise 1:

255.255.192.0	Prefix notation	/18

Because 255.255.192.0 is represented in the binary form as
11111111.11111111.11000000.00000000 – there are 18 consecutive 1s.

255.255.128.0	Prefix notation	/17

Because 255.255.128.0 is represented in the binary form as
11111111.11111111.10000000.00000000 – there are 17 consecutive 1s.

255.224.0.0	Prefix notation	/11

Because 255.224.0.0 is represented in the binary form as
11111111.11100000.00000000.00000000 – there are 11 consecutive 1s.

Answer for Exercise 2:

First host in first subnet	200.1.1.65
Second host in first subnet	200.1.1.66
….	
Last host in first subnet	200.1.1.126
Broadcast address for first subnet	200.1.1.127

First host in second subnet	200.1.1.129
Second host in second subnet	200.1.1.130
….	
Last host in second subnet	200.1.1.190
Broadcast address for second subnet	200.1.1.191

Answer for Exercise 3:

192.168.147.0 is a Class C IP address. The given prefix is /28. That leaves us with 4 host bits. The /28 prefix has borrowed 4 bits from the original host part of the Class C address. Thus, the number of possible subnets are $2^4 – 2 = 16 – 2 = 14$.

We will list below the 14 subnets. For subnet 1, we will list the first, second, and last host addresses as well as the broadcast address. Looking at the pattern in which the numbers change you can find out the similar addresses for all other subnets.

Subnet 1	192.168.147.0001 0000 = 192.168.147.16
Subnet 2	192.168.147.0010 0000 = 192.168.147.32
Subnet 3	192.168.147.0011 0000 = 192.168.147.48
Subnet 4	192.168.147.0100 0000 = 192.168.147.64
Subnet 5	192.168.147.0101 0000 = 192.168.147.80
Subnet 6	192.168.147.0110 0000 = 192.168.147.96
Subnet 7	192.168.147.0111 0000 = 192.168.147.112
Subnet 8	192.168.147.1000 0000 = 192.168.147.128
Subnet 9	192.168.147.1001 0000 = 192.168.147.144
Subnet 10	192.168.147.1010 0000 = 192.168.147.160
Subnet 11	192.168.147.1011 0000 = 192.168.147.176
Subnet 12	192.168.147.1100 0000 = 192.168.147.192
Subnet 13	192.168.147.1101 0000 = 192.168.147.208
Subnet 14	192.168.147.1110 0000 = 192.168.147.224

First node in first subnet	192.168.147.17
Second node in first subnet	192.168.147.18
…	
Last node in first subnet	192.168.147.30
Broadcast address for first subnet	192.168.147.31

Answer for Exercise 4:

192.168.13.175 is a Class C IP address. Given prefix is /28. This means that we have borrowed 4 bits from the 8-bit host part of the Class C address. This gives us the first 4 bits of the last octet to work with for the subnet part. The question asks if we could design a subnet 192.168.13.175. Let us write out the last octet value of 175 in binary to see if this is a possible subnet address.

$$175_{10} = 10101111_2$$

In the binary value we notice that we have used non-zero values in bit positions 1, 2, 3, and 4. These bit positions belong to the host part. Consequently, it is not possible to have a subnet address of 192.168.13.175 with a /28 prefix.

Answer for Exercise 5:

Given IP address is 197.15.22.0. This is a Class C IP address. So, we have 8 bits to work with in the host part. First we have to find the smallest value of n such that $2^n – 2 >= 4$. Hence, n = 3. This gives us $2^3 – 2 = 8 – 2 = 6$ subnets. That leaves us with 8 – 3 = 5 host bits. Therefore we can have a maximum of $2^5 – 2 = 32 – 2 = 30$ nodes in each subnet. Since we need only 25 nodes in each subnet, it is possible to design this network.

The subnet mask for each subnet is /27.

Range of IP addresses for hosts in first subnet: 197.15.22.33 to 197.15.22.62
Range of IP addresses for hosts in second subnet: 197.15.22.65 to 197.15.22.94
Range of IP addresses for hosts in third subnet: 197.15.22.97 to 197.15.22.126
Range of IP addresses for hosts in fourth subnet: 197.15.22.129 to 197.15.22.158
Range of IP addresses for hosts in fifth subnet: 197.15.22.161 to 197.15.22.190
Range of IP addresses for hosts in sixth subnet: 197.15.22.193 to 197.15.22.222

Answer for Exercise 6:

Given IP is 126.0.0.0. This is a Class A IP address. Therefore, we have 24 host bits to work with.

Number of bits required for 10000 networks
$2^n - 2 >= 10000$
Smallest value of n that satisfies the above inequality is 14 ($2^{14} = 16384$)
So we have to borrow14 bits from the host part of the given IP

Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 24 – 14 = 10
Thus, 10 bits are available for nodes.
So $2^{10} - 2 = 1024 - 2 = 1022 > 1000$ nodes can be placed on each network
Hence we can design this network. Subnet bits are in blue color.

Hence 126 . x x x x x x x x . x x x x x x x x . x x x x x x x x can be designed as follows:
subnetwork bits node bits

Subnet mask: 255 . 11111111 . 111111 00 . 00000000 = 255.255.252.0
In prefix notation, /22.

First subnetwork: 126 . 00000000 . 000001 00 . 00000000 = 126.0.4.0

First node in first subnetwork: 126 . 00000000 . 000001 00 . 00000001 = 126.0.4.1

Last node in first subnetwork: 126 . 00000000 . 000001 11 . 11111110 = 126.0.7.254

Broadcast address for first subnetwork: 126 . 00000000 . 000001 11 . 11111111 = 126.0.7.255

Second subnetwork: 126 . 00000000 . 000010 00 . 00000000 = 126.0.8.0

Answer for Exercise 7:

Given IP is 135.0.0.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 130000 networks
$2^n - 2 >= 130000$
Smallest value of n that satisfies the above inequality is 17 ($2^{17} = 131072$)
So we have to borrow17 bits from the host part of the given IP.

Since we have 16 bits only in the host part, the given network cannot be designed as a Class B network. However, if we change the IP address to a Class A IP address then we can design this network. For this reason we will change the IP address to 125.0.0.0.

Number of bits available for nodes
Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 24 – 17 = 7
Thus, 7 bits are available for nodes.
So $2^7 - 2 = 128 - 2 = 126 > 85$ nodes can be placed on each network
Hence we can design this network. Subnet bits are in blue color.

Hence 125 . x x x x x x x x . x x x x x x x x . x x x x x x x x can be designed as follows:
subnetwork bits node bits

Subnet mask: 255 . 11111111 . 11111111 . 1 0000000 = 255.255.255.128
In prefix notation, it is /25

First subnetwork: 125 . 00000000 . 00000000 . 10000000 = 125.0.0.128

First node in first subnetwork: 125 . 00000000 . 00000000 . 10000001 = 125.0.0.129

Last node in first subnetwork: 125 . 00000000 . 00000000 . 11111110 = 125.0.0.254

Broadcast address for first subnetwork: 125 . 00000000 . 00000000 . 11111111 = 125.0.0.255

Second subnetwork: 125 . 00000000 . 00000001 . 00000000 = 125.0.1.0

Answer for Exercise 8:

Given IP is 125.0.0.0. This is a Class A IP address. Therefore, we have 24 host bits to work with.

Number of bits required for 145000 networks
$2^n - 2 >= 145000$
Smallest value of n that satisfies the above inequality is 18 ($2^{18} = 262144$)
So we have to borrow18 bits from the host part of the given IP

Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 24 – 18 = 6
Thus, 6 bits are available for nodes.
So $2^6 - 2 = 64 - 2 = 62$. Hence a maximum of 62 nodes can only be placed.
But 62<185. So 185 nodes cannot be placed on each network

This network cannot be designed.

Answer for Exercise 9:

Given IP is 131.0.0.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 250000 networks
$2^n - 2 >= 250000$

Smallest value of n that satisfies the above inequality is 18 (2^{18} = 262144)
So we have to borrow18 bits from the host part of the given IP.

Since we have 16 bits only in the host part, the given network cannot be designed as a Class B network. However, if we change the IP address to a Class A IP address then we can design this network. For this reason we will change the IP address to 121.0.0.0.

Number of bits available for nodes
Nodes bits = Total number of host bits- Subnetwork bits borrowed
i.e. 24 – 18 = 6
Thus, 6 bits are available for nodes.
So $2^6 - 2 = 64 - 2 = 62$. 62 > 50 nodes can be placed on each network
Hence we can design this network. Subnet bits are in blue color.

Hence 121 . x x x x x x x x . x x x x x x x x . x x x x x x x x can be designed as follows:
subnetwork bits node bits

Subnet mask: 255 . 11111111 . 11111111 . 11000000 = 255.255.255.192
In prefix notation, /26

First subnetwork: 121 . 00000000 . 00000000 . 01000000 = 121.0.0.64

First node in first subnetwork: 121 . 00000000 . 00000000 . 01000001 = 121.0.0.65

Last node in first subnetwork: 121 . 00000000 . 00000000 . 01111110 = 121.0.0.126

Broadcast address for first subnetwork: 121 . 00000000 . 00000000 . 01111111 = 121.0.0.127

Second subnetwork: 121 . 00000000 . 00000000 . 10000000 = 121.0.0.128

Answer for Exercise 10:

Given IP is 132.127.0.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 2000 networks
$2^n - 2 >= 2000$
Smallest value of n that satisfies the above inequality is 11 (2^{11} = 2048)
So we have to borrow11 bits from the host part of the given IP

Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 16 – 11 = 5
Thus, 5 bits are available for nodes.
So $2^5 - 2 = 32 - 2 = 30$. 30 > 25 nodes can be placed on each network.
Hence we can design this network. Subnet bits are in blue color.

Hence 132 . 127 . x x x x x x x x . x x x x x x x x can be designed as follows:
subnetwork bits node bits

Subnet mask: 255 . 255 . 11111111 . 11100000 = 255.255.255.224
In prefix notation, /27

First subnetwork: 132 . 127 . 00000000 . 00100000 = 132.127.0.32

First node in first subnetwork: 132 . 127 . 00000000 . 00100001 = 132.127.0.33

25^{th} node in first subnetwork: 131 . 127 . 00000000 . 00111001 = 131.0.0.57

Last node in first subnetwork: 131 . 127 . 00000000 . 00111110 = 131.0.0.62

Broadcast address for first subnetwork: 131 . 127 . 00000000 . 00111111 = 131.0.0.63

Second subnetwork: 132 . 127 . 00000000 . 01000000 = 132.127.0.64

Answer for Exercise 11:

Given IP is 134.129.0.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 66000 networks
$2^n - 2 >= 66000$
Smallest value of n that satisfies the above inequality is (2^{17} =131072)
So we have to borrow 17 bits from the host part of the given IP.
But the number of bits available with given host is only 16. So with the given IP address 66000 subnetworks cannot be designed.

Answer for Exercise 12:

Given IP is 133.128.0.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 250 networks
$2^n - 2 >= 250$
Smallest value of n that satisfies the above inequality is 8 (2^8 = 256)
So we have to borrow 8 bits from the host part of the given IP

Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 16 – 8 = 8
Thus, 8 bits are available for nodes.
So $2^8 - 2 = 256 - 2 = 254$. 254 > 174 nodes can be placed on each network
Hence we can design this network. Subnet bits are in blue color.

Hence 133 . 128 . x x x x x x x x . x x x x x x x x can be designed as follows:
subnetwork bits node bits

Subnet mask: 255 . 255 . 11111111 . 00000000 = 255.255.255.0
In prefix notation, /24

First subnetwork: 133 . 128 . 00000001 . 00000000 = 133.128.1.0

First node in first subnetwork: 133 . 128 . 00000001 . 00000001 = 133.128.1.1

Last node in first subnetwork: 133 . 128 . 00000001 . 11111110 = 133.128.1.254

Broadcast address for first subnetwork: 133 . 128 . 00000001 . 11111111 = 133.128.1.255

Second subnetwork: 133 . 128 . 00000010 . 00000000 = 133.128.2.0

Answer for Exercise 13:

Given IP is 135.130.125.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 30 networks
$2^n - 2 >= 30$
Smallest value of n that satisfies the above inequality is 5 ($2^5 = 32$)
So we have to borrow 5 bits from the host part of the given IP

Number of bits available for nodes
Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e., 16 – 5 = 11
Thus, 11 bits are available for nodes.
So $2^{11} - 2 = 2048 - 2 = 2046$. 2046 > 5 nodes can be placed on each network.

Even though theoretically a network of this type can be designed, we have to check carefully to see if we could design a network with the given IP. In a Class B address the third octet is a host octet. We are borrowing the 5 leftmost bits from this octet. This gives us $2^5 - 2 = 32 - 2 = 30$ possible subnets. These 30 subnets will have the third octet values range from 00001 000 to 11110 000. Considering all possible subnet part values that are in blue, we will not be able to design the subnet 135.130.125.0.

However, if we change the IP address to the Class C address 195.130.125.0, then we can design this network. We show the details of this Class C network below.

The subnet part is in blue color in the details given next.

Hence 195.130.125 . x x x x x x x x can be designed as follows:

Subnet mask: 255 . 255 . 255 . 11111000 = 255.255.255.248
In prefix notation, /29

First subnetwork: 195.130.125. 00001 000 = 195.130.125.8

First node in first subnetwork: 195.130.125. 00001 001 = 195.130.125.9

Last node in first subnetwork: 195.130.125. 00001 110 = 195.130.125.14

Broadcast address for first subnetwork: 195.130.125. 00001 111 = 195.130.125.15

Second subnetwork: 195.130.125. 00010 000 = 195.130.125.16

Answer for Exercise 14:

Given IP is 136.131.127.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 14 networks
$2^n - 2 >= 14$
Smallest value of n that satisfies the above inequality is 4 ($2^4 = 16$)
So we have to borrow 4 bits from the host part of the given IP

Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 16 – 2 = 14
Thus, 14 bits are available for nodes.
So $2^{14} - 2 = 16384 - 2 = 16382$. 16382 > 12 nodes can be placed on each network

Even though theoretically a network of this type can be designed, we have to check carefully to see if we could design a network with the given IP. In a Class B address the third octet is a host octet. We are borrowing the 4 leftmost bits from this octet. This gives us $2^4 - 2 = 16 - 2 = 14$ possible subnets. These 14 subnets will have the third octet values range from 0001 0000 to 1110 0000. Considering all possible subnet part values that are in blue, we will not be able to design the subnet 136.131.127.0.

However, if we change the IP address to the Class C address 196.131.127.0, then we can design this network. We show the details of this Class C network below.

The subnet part is in blue color in the details given next.

Hence 196.131.127 **.** x x x x x x x x can be designed as follows:

Subnet mask: 255 . 255 . 255 . 11110000 = 255.255.255.240
In prefix notation, /28.

First subnetwork: 196.131.127. 0001 0000 = 196.131.127.16

First node in first subnetwork: 196.131.127. 0001 0001 = 196.131.127.17

Last node in first subnetwork: 196.131.127. 0001 1110 = 196.131.127.30

Broadcast address for first subnetwork: 196.131.127. 0001 1111 = 196.131.127.31

Second subnetwork: 196.131.127. 0010 0000 = 196.131.127.32

Answer for Exercise 15:

Given IP is 137.132.128.0. This is a Class B IP address. Therefore, we have 16 host bits to work with.

Number of bits required for 5 networks
$2^n - 2 >= 5$
Smallest value of n that satisfies the above inequality is 3 ($2^3 - 2 = 6$)
So we have to borrow 3 bits from the host part of the given IP

Nodes bits = Total number of host bits – Subnetwork bits borrowed
i.e. 16 – 3 = 13
Thus, 13 bits are available for nodes.
So $2^{13} - 2 = 8192 - 2 = 8190$. 8190 > 25 nodes can be placed on each network.

Even though theoretically a network of this type can be designed, we have to check carefully to see if we could design a network with the given IP. In a Class B address the third octet is a host octet. We are borrowing the 3 leftmost bits from this octet. This gives us $2^3 - 2 = 8 - 2 = 6$ possible subnets. These 6 subnets will have the third octet values range from 001 0000 to 110 0000. Considering all possible subnet part values that are in blue, we will be able to design the subnet 137.132.128.0. However, this is a fixed subnet of 137.132.0.0. Consequently we cannot have 5 subnets of 137.132.128.0.

However, if we change the IP address to the Class C address 197.132.128.0, then we can design this network. We show the details of this Class C network below.

The subnet part is in blue color in the details given next.
Hence 197.132.128 . x x x x x x x x can be designed as follows:

Subnet mask:	255 . 255 . 255 . 11100000 = 255.255.255.224 In prefix notation, /27.
First subnetwork:	197.132.128. 001 00000 = 197.132.128.32
First node in first subnetwork:	197.132.128. 001 00001 = 197.132.128.33
Last node in first subnetwork:	197.132.128. 001 11110 = 197.132.128.62
Broadcast address for first subnetwork:	197.132.128. 001 11111 = 197.132.128.63
Second subnetwork:	197.132.128. 010 00000 = 197.132.128.64