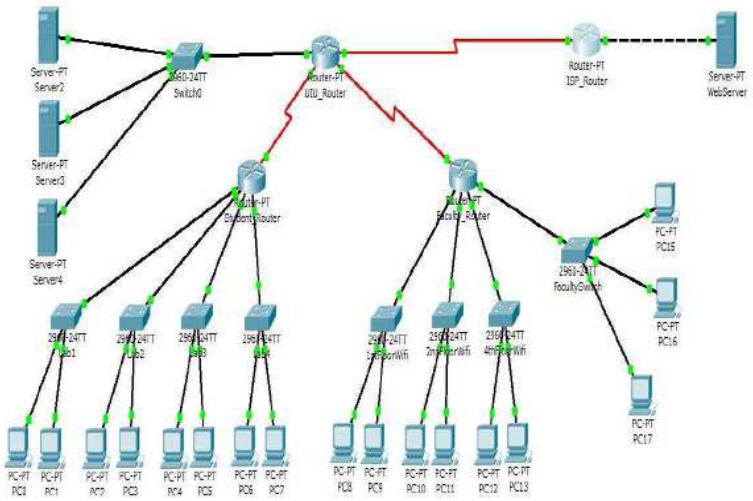
IP Addressing and Subnetting

How to identify a student in a university?

Create **student ID** to identify each student

University
Department
Batch # **Student #**

How to identify a PC in a network?



Create **ID** to identify each computer

IP Address (Network, Host)
Subnet Mask
Default Gateway

IP addresses are used to uniquely identify individual TCP/IP networks and hosts, such as computers and printers, on those networks in order for devices to communicate. Workstations and servers on a TCP/IP network are called **hosts** and each has a **unique IP address**. This address is referred to as its **host address**. In its basic form, the IP address has **two parts**:

- A **network address**
- A **host address**

The IP address of a workstation, or host is a **logical address**, meaning it can be changed. The Media Access Control (MAC) address of the workstation is a **48-bit physical address**. This address is burned into the network interface card (NIC) and cannot change unless the NIC is replaced. The combination of the logical IP address and the physical MAC address helps route packets to their proper destination.

Review IP address classes and their characteristics

Address classes

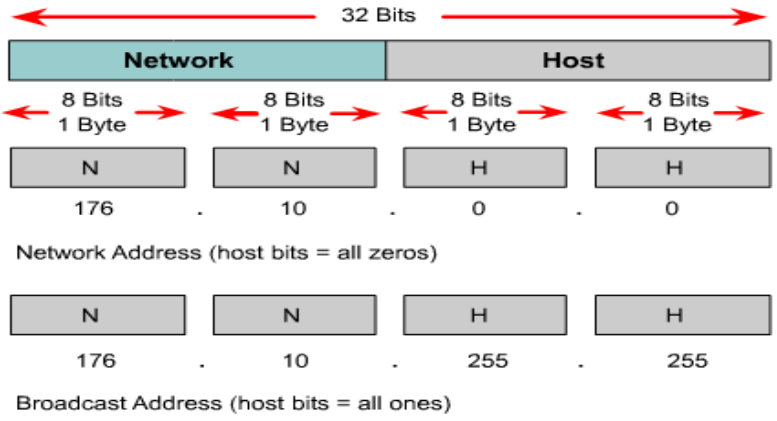
There are **five classes** of IP addresses, **A** through **E**. Only the **first three classes** are used commercially. A Class A network address is discussed in the **Table 1** to get started. 127 is reserved for loopback testing. The first octet alone defines the network ID for a Class A network address.

Default subnet mask

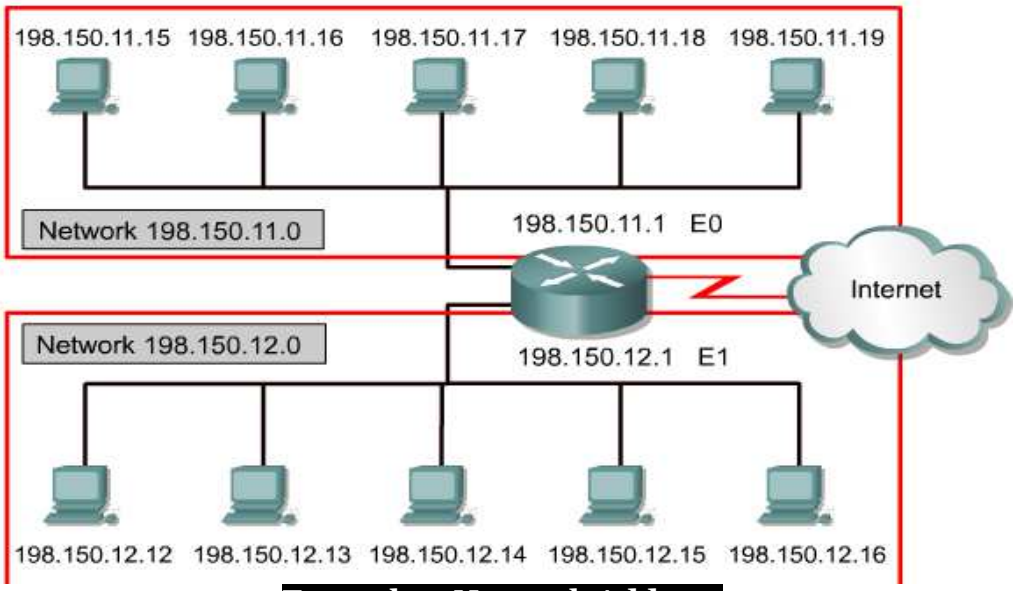
The **default subnet mask** uses all binary ones, decimal 255, to mask the first 8 bits of the Class A address, first 16 bits of the Class B addresses, and first 24 bits of the Class C addresses. The default subnet mask helps routers and hosts determine if the destination host is on this network or another one. It is common to subdivide the network into smaller groupings called subnets by using a **custom subnet mask**.

Network and host address

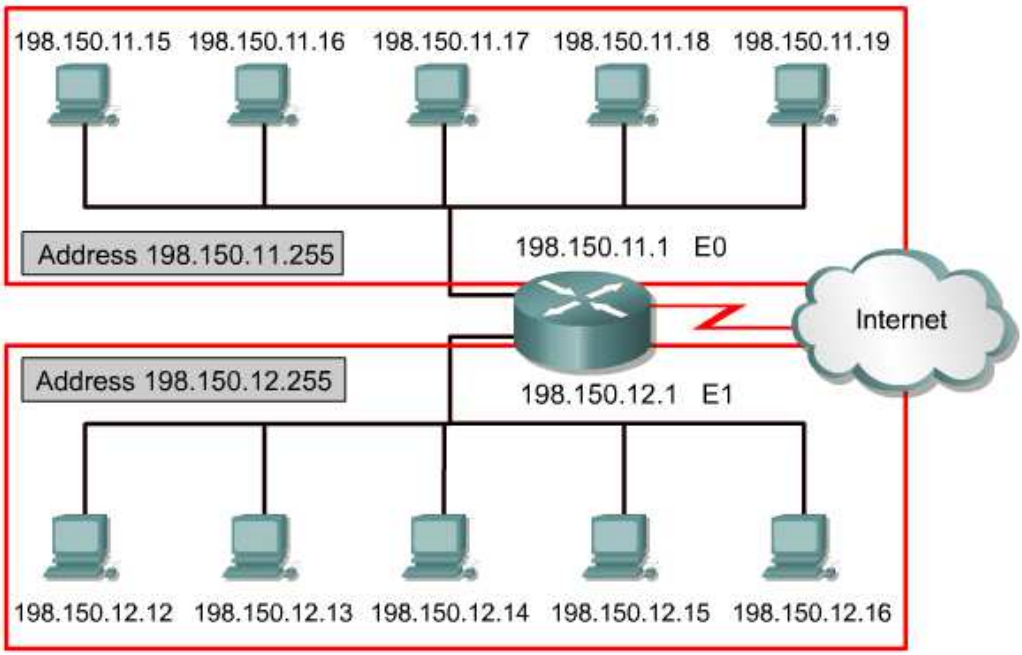
The network or host portion of the address **cannot be all ones or all zeros**. As an example, the Class A address of 118.0.0.5 is a valid IP address. The network portion, or first 8 bits, which are equal to 118, is not all zeros and the host portion, or last 24 bits, is not all zeros or all ones. If the host portion were all zeros, it would be the network address itself. If the host portion were all ones, it would be a broadcast for the network address. **The value of any octet can never be greater than decimal 255 or binary 11111111**.



Example – IP Address



Example – Network Address



Example – Broadcast Address

Table 1

IP Address Classes

Address Class	1st octet range (decimal)	1st octet bits (green bits do not change)	Network(N) and Host(H) parts of address	Default subnet mask (decimal and binary)	Number of possible networks and hosts per network
A	1-127**	00000000-01111111	N.H.H.H	255.0.0.0	128 nets (2^7) 16,777,214 hosts per net (2^24-2)
B	128-191	10000000-10111111	N.N.H.H	255.255.0.0	16,384 nets (2^14) 65,534 hosts per net (2^16-2)
C	192-223	11000000-11011111	N.N.N.H	255.255.255.0	2,097,150 nets (2^21) 254 hosts per net (2^8-2)
D	224-239	11100000-11101111	NA (multicast)		
E	240-255	11110000-11111111	NA (experimental)		

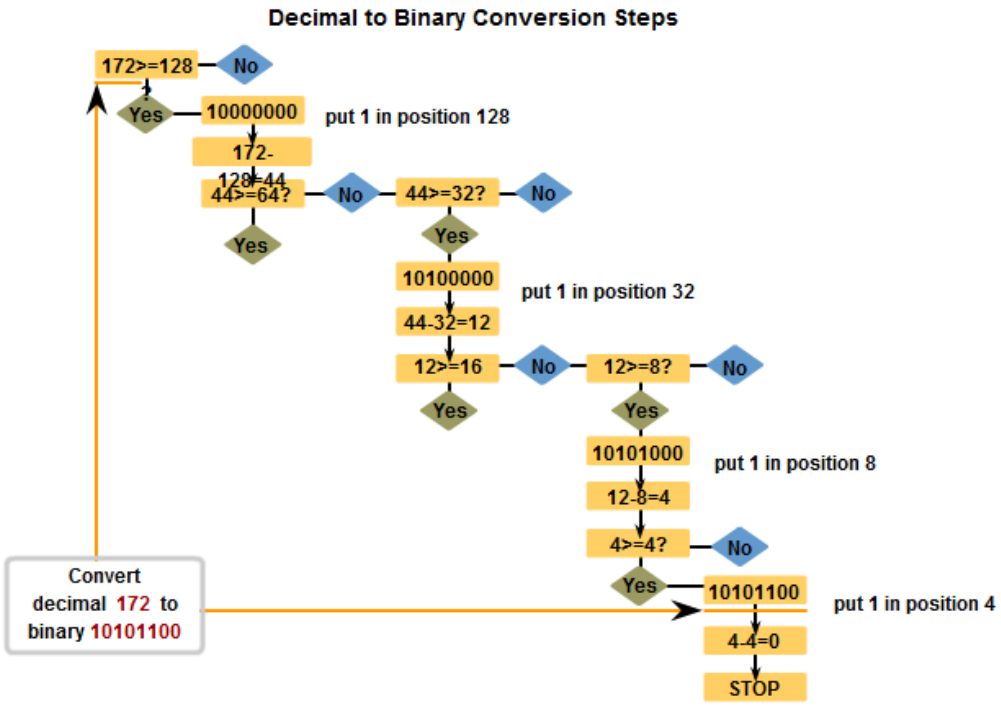
** All zeros (0) and all ones (1) are invalid hosts addresses.

Example:

Find the class of the following IP addresses.

a.	208.34.54.12	
b.	238.34.2.1	
c.	114.34.2.8	
d.	129.14.6.8	

Decimal-to-Binary and Binary-to-Decimal



Example:
Convert the following numbers into binary: 201, 511, 156.

Example:
Convert the following binary numbers into decimal: 11011101, 11110111, 10001100.

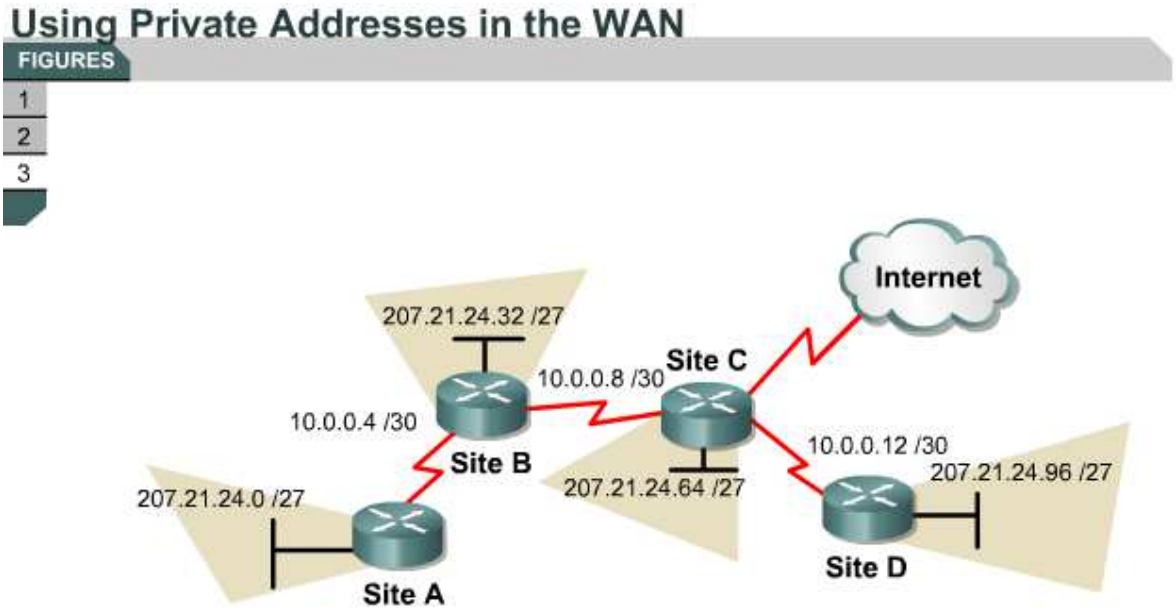
Example:
Change the following IP addresses from **dotted-decimal notation** to **binary notation**.

a.	114.34.2.8	
b.	129.14.6.8	
c.	208.34.54.12	
d.	238.34.2.1	

Example:
Find the **network ID** and the **host ID** of the following IP addresses

		Network id	Host id
a.	114.34.2.8		
b.	132.56.8.6		
c.	208.34.54.12		

Public and Private IP addresses



Private addresses can be used to address point-to-point serial links without wasting real IP addresses.

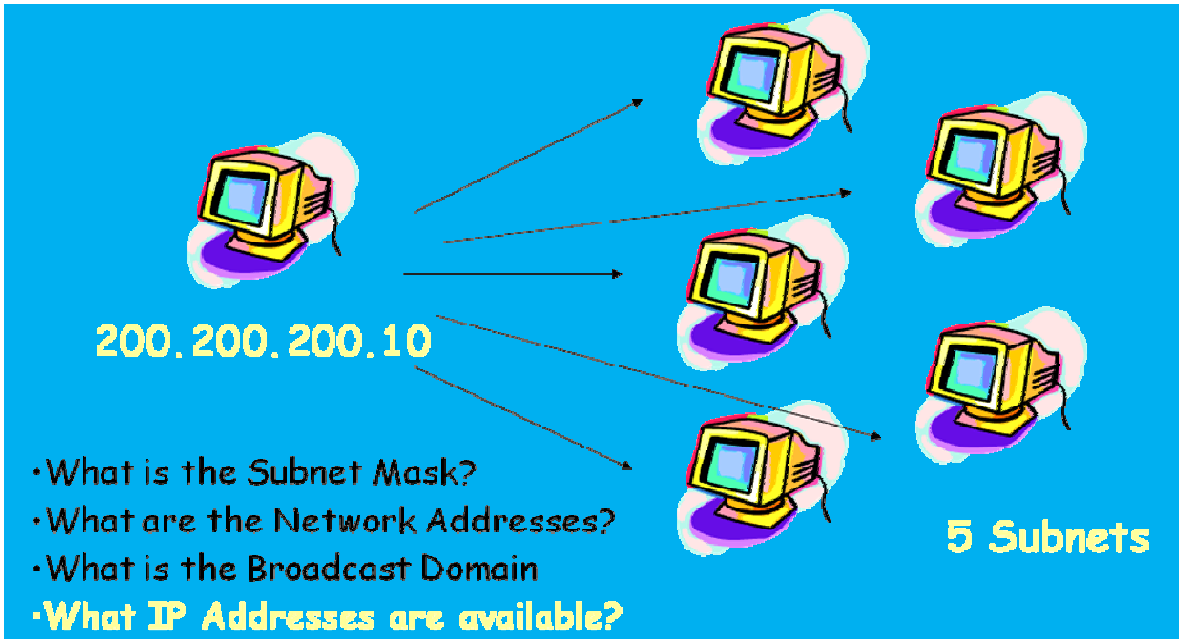
Class	RFC 1918 internal address range
A	10.0.0.0 to 10.255.255.255
B	172.16.0.0 to 172.31.255.255
C	192.168.0.0 to 192.168.255.255

Why Subnetting?

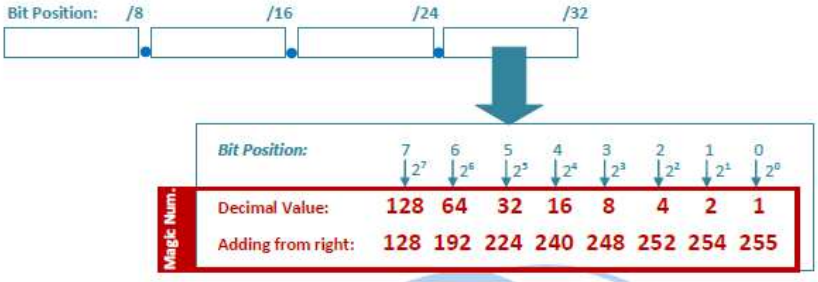
- Millions of Addresses Available
  - Over 16,000,000
- Efficiency
  - Non-subnetted networks are wasteful
  - Division of networks not optimal
- Smaller Network
  - Easier to manage
  - Smaller broadcast domains

- To create a subnet address, a network administrator borrows bits from the host field and designates them as the subnet field.

Subnetting:



Subnetting Example



1. Change "Prefix Length" to "Subnet Mask":

   128 192 224 240 248 252 254 255

   Example: /27 = /24 + 3 Then Subnet Mask is 255.255.255.224

   128 192 224 240 248 252 254 255

   /20 = /16 + 4 Then Subnet Mask is 255.255.240.0

2. Find number of all Host IDs per subnet (including Network ID and Broadcast IP) from Prefix Length:

   128 64 32 16 8 4 2 1

   Example: /26 = /24 + 2 Then this subnet has = 64 Host ID (IP)

   128 64 32 16 8 4 2 1

   /30 = /24 + 6 Then this subnet has = 4 Host ID (IP)

3. Steps

Example: 178.9.32.145/25 128 64 32 16 8 4 2 1

3.1) Number of all Host IDs per subnet /25 is 128 IP

3.2) Network ID is IP address in last byte of Network ID portion that is the multiply (x0, x1, x2, ...) of number of Host ID that is nearest the given IP address.

Then Network ID of 178.9.32.145/25 is 178.9.32.128/25 *(=128x1)*

3.3) Broadcast IP is the last IP of subnet. Then the first byte of Host ID portion will be "the value of last byte in Network ID portion + number of Host IDs - 1"

or we can say as "Network ID of next subnet minus one."

Then Broadcast IP of 178.9.32.145/25 is 178.9.32.255/25 *(=128+128-1)*

3.4) Number of Host ID that is "Assignable/Valid" will be "no. of all Host IDs – 2"

Then no. of Assignable Host ID of 178.9.32.128/25 is 128 – 2 = 126 IP

Range: 178.9.32.129 – 178.9.32.254

4. Find no. of "same length" subnet from the given "Prefix Length" range:

Instead of using "2^n", n is no. of bits borrowed to divided subnet, such as:

From /20 to /25, borrowing the bits of Network ID for 25 – 20 = 5 bits or 2^5 = 32 Subnet

From /26 to /29, borrowing the bits of Network ID for 29 – 26 = 3 bits or 2^3 = 8 Subnet

We can use "Magic Number" to calculate more easy like:

128 64 32 16 8 4 2 1

Example: Subnets divided from /20 → /25 = 32 Subnets

128 64 32 16 8 4 2 1

Subnets divided from /26→/29 = 8 Subnets

Bit Patterns of Often Used Subnet Masks to Memorize

10000000 = 128
11000000 = 192
11100000 = 224
11110000 = 240
11111000 = 248
11111100 = 252
11111110 = 254
11111111 = 255

Applying the Subnet Mask

A device with address 192.0.0.1 belongs to network 192.0.0.0

	High order bits Prefix /16		Low order bits	
	192 . 0 . 0 . 1			
Host Address	11000000	00000000	00000000	00000001
Subnet Mask	255	255	0	0
	11111111	11111111	00000000	00000000
Network Address	11000000	00000000	00000000	00000000
Network	192 . 0 . 0 . 1			

Example:
Write the following masks in **slash notation** (/n).

a.	255.255.255.0	
b.	255.0.0.0	
c.	255.255.224.0	
d.	255.255.240.0	

A Simple Algorithm for Subnetting

Suppose,

Number of **network bits** before subnetting = N
Number of bits borrowed (**subnetting bits**) = S, and
Number of host bits remaining after subnetting = H.

Then, **N + S + H** must be equal to **32 bits**.
You can arrange the 32 bits in the following way:

N (Network Bits)	**S** (Subnetting Bits)	**H** (Host Bits)

If you need to find **m^{th} valid IP address** in the **n^{th} subnet** after subnetting, follow the steps below:

Step 1: Write down the network part in the "**N (Network Bits)**" part.
Step 2: Convert "**n**" into binary in **exactly S bits** and write in the "**S (Subnet Bits)**" part.
Step 3: Convert "**m**" into binary in **exactly H bits** and write in the "**H (Host Bits)**" part.
Step 4: Group the bits from right to left "**8-bits at a time**" and convert to the "**dotted decimal**" format.

Example:
You have the following IP **211.63.57.0**, this network is subnetted by **3-bits**. Find the **50^{th} IP address** of **subnet # 6**.

N	**S**	**H**

Example:
You have the following IP **7.0.0.0**, this network is subnetted by **11-bits**. Find the **500^{th} IP address** of **subnet # 60**.

N	**S**	**H**

Example:
You have the following IP **189.23.0.0**, subnetted by **9-bits**. Find **100^{th} IP address** of **subnet # 300**.

N	**S**	**H**

A Step by Step Guide to Subnetting

Address **172.16.0.0/16** = default subnet 255.255.0.0 ie **Class B** address

16 network bits

	Network	Host
IP Address	10101100.00010000	.00000000.00000000
Subnet Mask	11111111.11111111	.00000000.00000000

You may be asked to supply **500 subnets**; using the formula Subnets = 2^n, Where **n** = no. of bits to borrow

Step 1

From the table on the right; to obtain 500 subnets.

We need to borrow 9 host bits as subnet bits.

This will give us;
$2^9 = 512$ subnets

(Remember you may end up with unused subnets)

n	2^n
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024
11	2048
12	4096
13	8192
14	16384
15	32768
16	65536

Step 2

To determine the number of usable hosts per subnet we subtract the borrowed bits (9) from the total number of host bits (16) which gives us 7 remaining host bits. Using the formulae Hosts = $2^n - 2 = 2^7 - 2$. From the table $2^7 = 128$. Thus usable hosts = 128 – 2 =126 (Remember the first and last addresses are for network and broadcast, hence the minus 2 in the formula)

Step 3

Mark the borrowed bits as subnet bits

	Network	Subnet	Host
IP Address	10101100.00010000	.00000000	.00000000
Subnet Mask	11111111.11111111	.11111111	.10000000

Remember the borrowed bits in the mask change from 0 (zero) to 1 (one)

Step 4

Define the subnetted network;

Address **172.16.0.0/25** = subnet mask **255.255.255.128 (custom Subnet Mask)**

There are now 25 network bits. (16 original + 9 borrowed)

The first 3 octets (24 bits) are network bits, hence each octet = 255. The final octet has only the MSB (Most Significant Bit) as a network bit, hence 128.

Step 5: Calculate the subnet addresses and usable hosts for each subnet

	Network	Subnet	Host
IP Address	10101100.00010000.	00000000.	00000000
Mask	11111111.11111111.	11111111.	10000000

We are only interested in this part of the address when calculating the subnets

00000000.00000000

For each subnet, the binary value of the subnet bits will increment by 1, so the first 5 subnets and last 2 are; *See **appendix**

00000000.0 ← (zero subnet, may not be used)
First usable network → 00000000.1
00000001.0
00000001.1
00000010.0
…etc.
Last usable network → 11111111.0
11111111.1 ← (one subnet, may not be used)

Thus first usable subnet (Subnet 1) = 10101100.00010000.00000000.10000000
= 172 . 16 . 0 . 128
the first usable host (Subnet 1) = 10101100.00010000.00000000.10000001
172 . 16 . 0 . 129
the last usable host (Subnet 1) = 10101100.00010000.00000000.11111110
172 . 16 . 0 . 254
the broadcast address (Subnet 1) = 10101100.00010000.00000000.11111111
172 . 16 . 0 . 255

Thus host range (Subnet 1) =
10101100.00010000.00000000.10000001 to 10101100.00010000.00000000.11111110
172 . 16 . 0 . 129 172 . 16 . 0 . 254

Thus 2nd usable subnet (Subnet 2) = 10101100.00010000.00000001.00000000
= 172 . 16 . 1 . 0
the first usable host (Subnet 2) = 10101100.00010000.00000001.00000001
172 . 16 . 1 . 1
the last usable host (Subnet 2) = 10101100.00010000.00000001.01111110
172 . 16 . 1 . 126
the broadcast address (Subnet 2) = 10101100.00010000.00000001.01111111
172 . 16 . 1 . 127

Thus host range (Subnet 2) =
10101100.00010000.00000001.00000001 to 10101100.00010000.00000001.01111110
172 . 16 . 1 . 1 172 . 16 . 1 . 126

the host range (Subnet 3) =
10101100.00010000.00000001.10000001 to 10101100.00010000.00000001.11111110
172 . 16 . 1 . 129 172 . 16 . 1 . 254

and the host range (Subnet 4) =
10101100.00010000.00000010.00000001 to 10101100.00010000.00000010.01111110
172 . 16 . 1 . 129 172 . 16 . 1 . 126

and so on……

Appendix

IP Value	128	64	32	16	8	4	2	1	128	64	32	16	8	4	2	1
Subnet Number	256	128	64	32	16	8	4	2	1							
Subnet 0(Not Used)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subnet 1 Address	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Subnet 1 Host 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Subnet 1 Host 126	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
Subnet 1 Broadcast	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Subnet 2 Address	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Subnet 2 Host 1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Subnet 2 Host 126	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	0
Subnet 2 Broadcast	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1
Subnet 3 Address	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Subnet 3 Host 1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1
Subnet 3 Host 126	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
Subnet 3 Broadcast	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
	etc.…															
Subnet 510 Address	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Subnet 510 Host 1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1
Subnet 510 Host 126	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
Subnet 510 Broadcast	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
Subnet 511(Not Used)	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0

Note: Only the final two octets are shown for clarity.

Example:

An organization is granted the address block **130.56.0.0/16**. The administrator wants to create **512 subnets**.

a.	Find the subnet mask.	
b.	Find the number of addresses in each subnet.	
c.	Find the first and last addresses in subnet 1.	
d.	Find the first and last addresses in subnet 512.	

Example:

In a block of addresses, we know the IP address of one host is **182.44.82.16/26**. What are the **network address** and the **broadcast address** in this block?

Example:

Assume: **Network:** 170.60.0.0, **SM**: 255.255.255.128. Which of the following table is an **invalid IP**? **WHY**?

IP	Validity	reason
170.60.25.1		
170.60.26.127		
170.60.40.139		
170.60.212.212		
170.60.255.190		
170.60.252.16		
170.60.100.63		