Chapter 5

IP Addressing and Subnetting

Outlines

- *IP Addressing*
- *Types of IP Addresses*
- *Portion of IP Address*
- *Classes of IP Address*
- *Special IP addresses*
- *Subnetting*
- *Variable length subnet mask*
- *Supernetting*

What is an IP Address?

- An IP address is an address used in order to uniquely identify a device on an **IP network.**
- The address is made up of 32 binary bits, which can be divisible into a network portion and host portion with the help of a subnet mask.
- The 32 binary bits are broken into four octets (1 octet=1 byte = 8 bits).
- The IP addresses are unique.

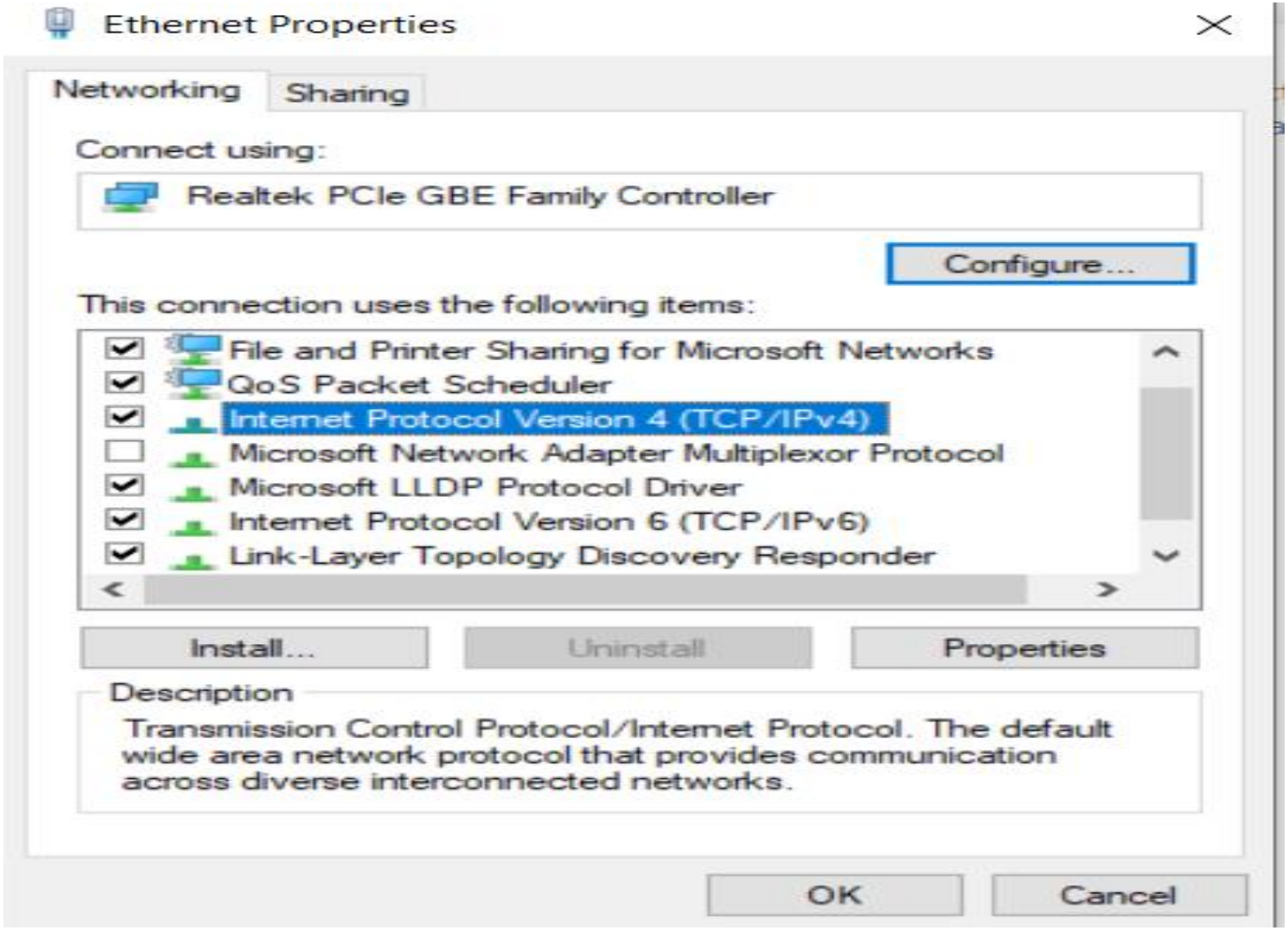
What is an IP Address?

- IP Address works similar to the home address by the identification of that anything reaches to your house.
- To communicate in the network each electronic device uses IP address.
- To identify the network size these IP address is categorized into various classes.
- All these types of IP address is assigned to the organizations, businesses or government operations.

Versions of IP Addresses

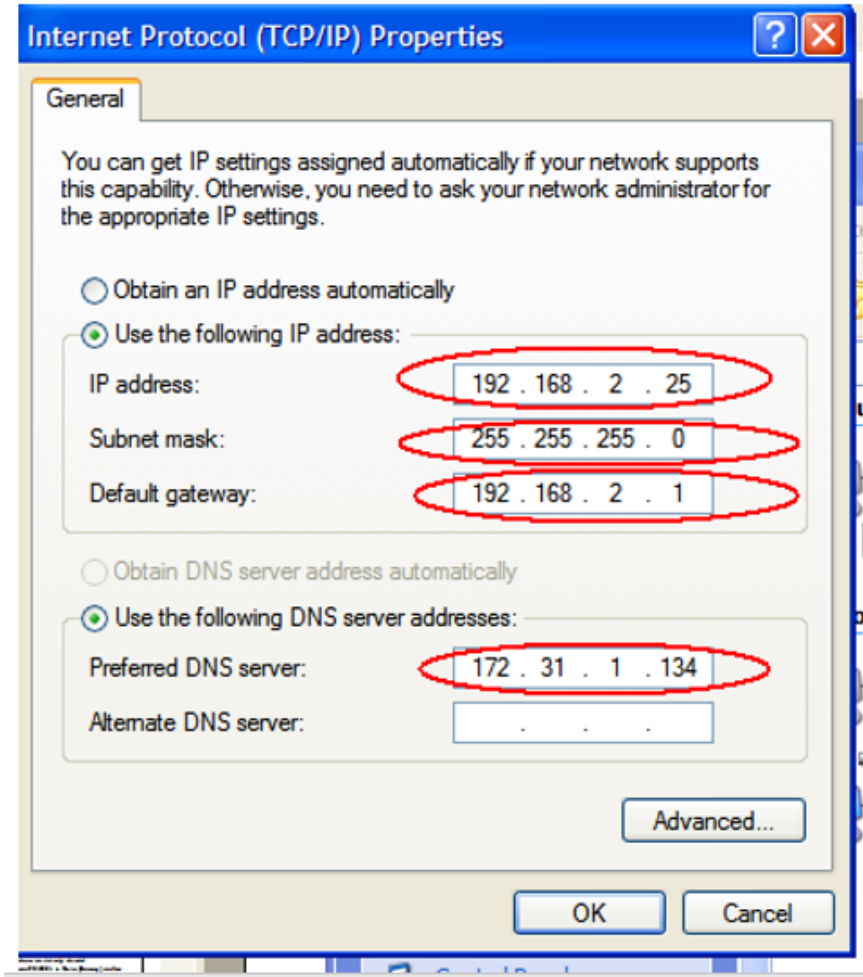
- IPV4 (Internet Protocol Version 4)
  - IPv4 address is structured as 32 bits
  - IPV4 is the most popular protocol in use today
  - **we are nearly out of the four billion addresses available in IPv4**
- IPV6 (Internet Protocol Version 6)
  - IPv6 addresses are 128 bits in length and are made up of hexadecimal characters.
  - **IPv6 could be the solution to many problems posed by IPv4**

Versions of IP Addresses

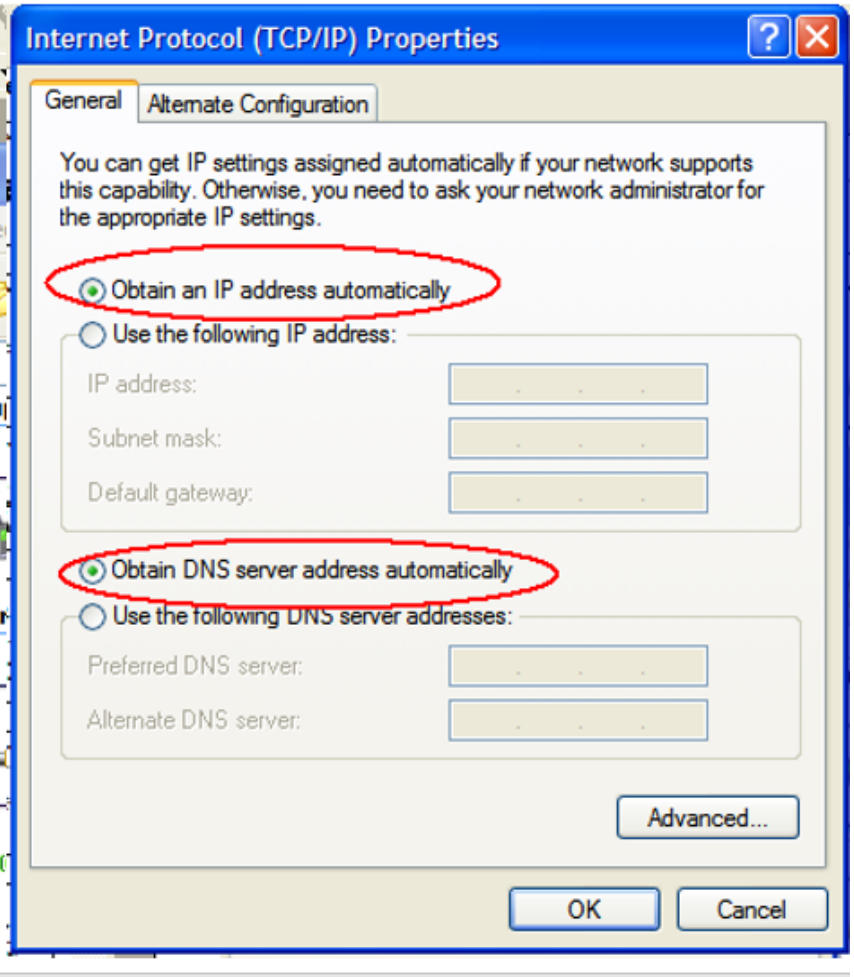


IP Configuration of an Interface

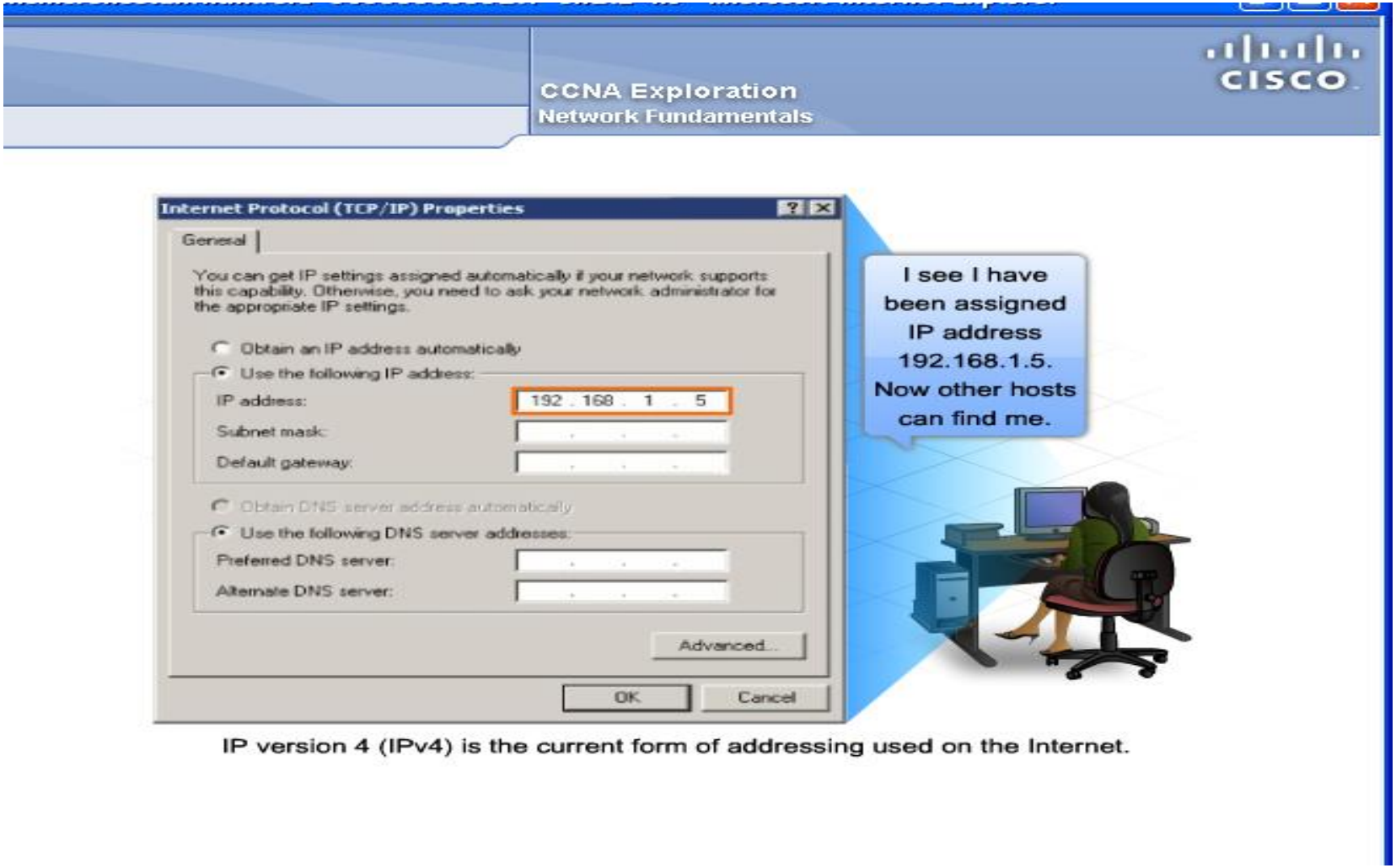
Static



DHCP



IP Addressing



IP version 4 (IPv4) is the current form of addressing used on the Internet.

IP Addressing Schemes.

There are two ways to represent the IP Addresses:

- Binary Notation: Base 2
- Dotted-Decimal Notation: Base 10

IP Addressing Schemes.

Binary Notation: Base 2

- In binary notation, an IPv4 address is displayed as 32 bits.
- An IPv4 address referred to as a 32-bit address, a 4-octet address (8 bits in each).
- Example of an IPv4 address in binary notation

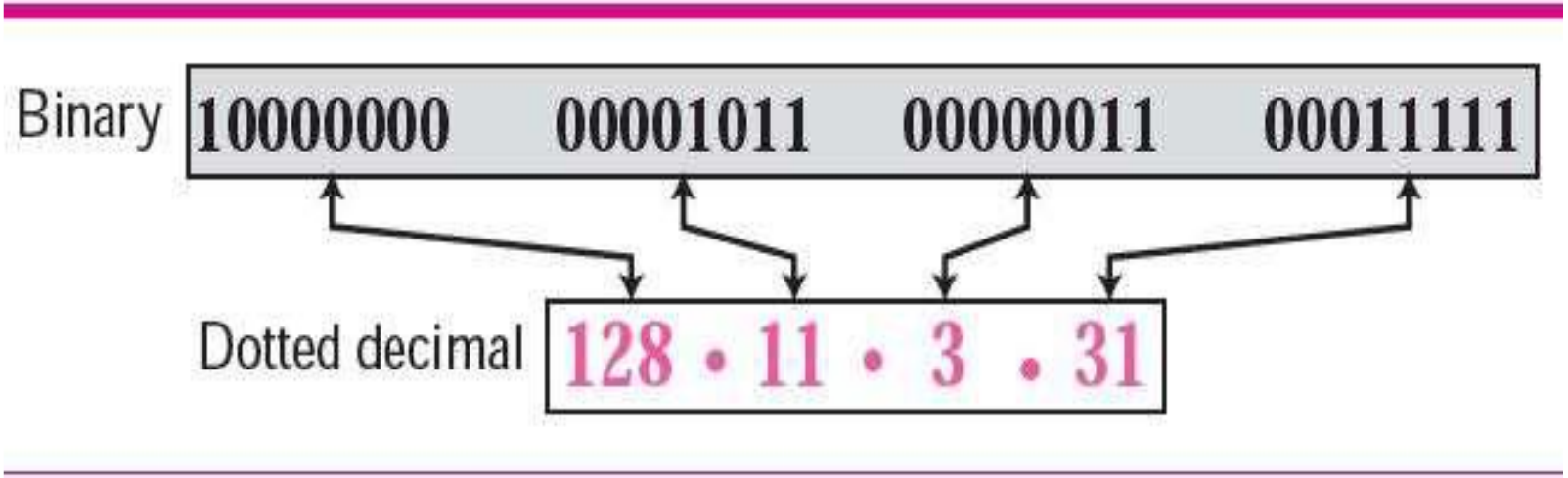
01110101 10010101 00011101 11101010

IP Addressing Schemes

Dotted-Decimal Notation: Base 10

- For us in the human network, a string of 32 bits is difficult to interpret and even more difficult to remember.
- Therefore, IPv4 addresses are represented using dotted decimal format.

IP Addressing Schemes



Because each byte (octet) is only 8 bits, each number in the dotted- decimal notation is between 0 and 255.

IP Addressing Schemes

- *Change the following IP address from binary notation to dotted-decimal notation.*

10000001 00001011 00001011 11101111

- ***Solution***

129.11.11.239

IP Addressing Schemes

- Change the following IP address from dotted-decimal notation to binary notation:

111.56.45.78

- ***Solution***

01101111 00111000 00101101 01001110

IP Addressing Schemes

- Find the error in the following IP Address

111.56.045.78

- Solution

There are no leading zeroes in Dotted-decimal notation (045)

IP Addressing Schemes

- Find the error in the following IP Address

75.45.301.14

- Solution

In decimal notation each number is <= 255

301 is out of the range

Address Space Rule

- The address space in a protocol that uses n-bits to define an Address is:

$$2^n$$

- The address space of IPv4 is

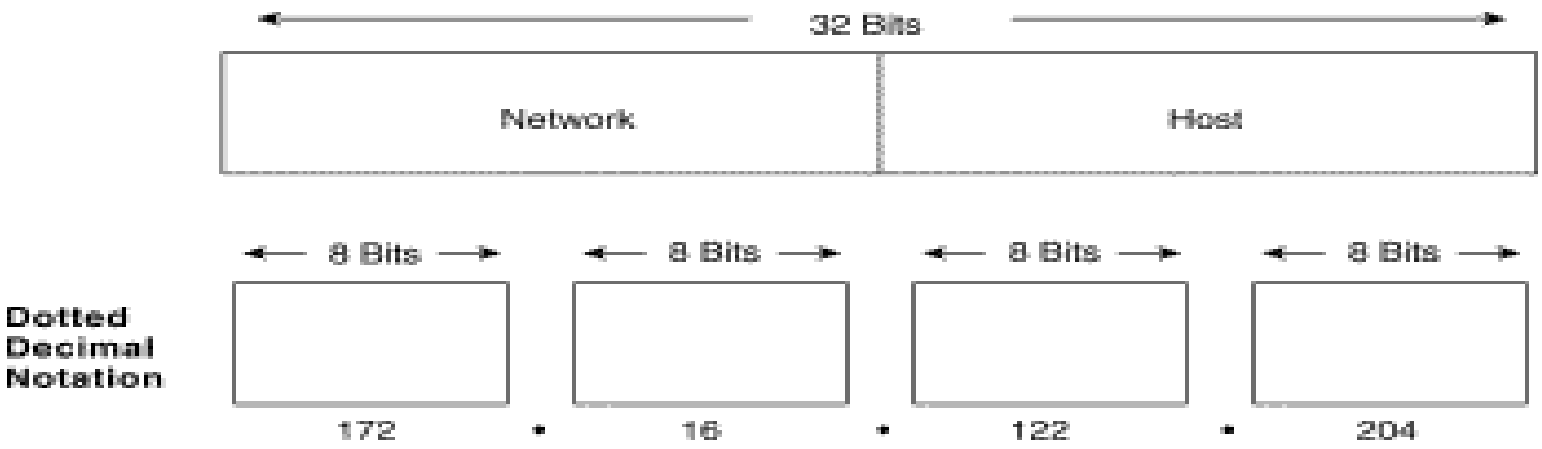
$$2^{32}$$

or

4,294,967,296

Portion of an IP Address

- In classful IP addresses, there are two fundamental parts:
  - NETWORK PORTION/NetID
  - HOST PORTION/HostID



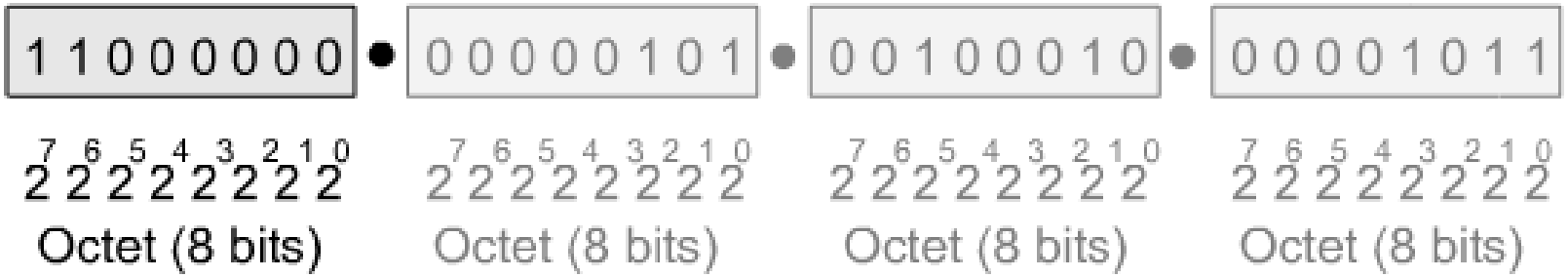
Network Address and Host Address

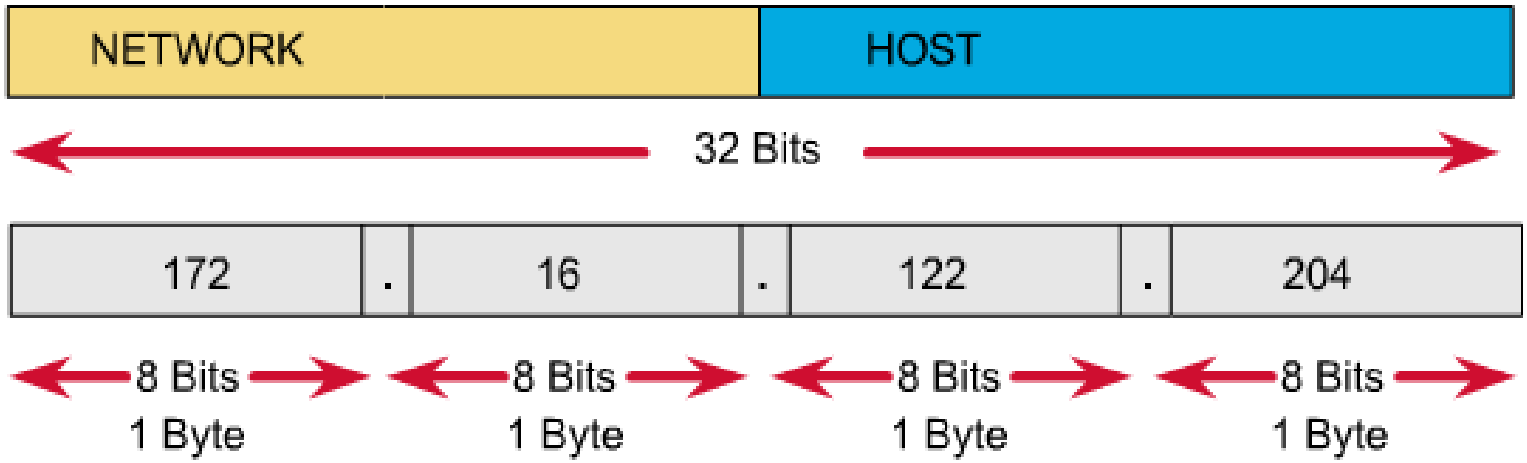
- The NETWORK PORTION, which describes the physical wire the device is attached to. The address by which we refer to the network

- The HOST PORTION, which identifies the host on that wire. The addresses assigned to the end devices in the network

Portion of an IP Address

IP Address as a 32-Bit Binary Number





CLASSFUL ADDRESSING

- At the Network layer, the packets of the communication need to be identified with the source and destination IP addresses of the two end systems

- All IP addresses are 32 bits long and are used in the Source address and Destination address fields of IP packets.

Classful IP Addressing

- The designers of the Internet created classes of networks based on network size.
- Subdividing an IP address into a network and host address is determined by the class designation of one's network.
- Every host on the Internet has an IP address, which encodes its network number and host number.

Classful Addressing

- The 32 bit IP address is divided into five sub-classes.
- These are:
  - Class A addresses
  - Class B addresses
  - Class C addresses
  - Class D addresses
  - Class E addresses
- IP addresses from the first three classes (A, B and C)can be used for host addresses.
- The other two classes are used for other purposes – class D for multicast and class E for experimental purposes.

Class A IP address

- For a large number of hosts, Class A IP addresses are used.
- The first octet of this class ranges from 1 to 126.
- Most of the IP address comes in Class A IP address.
- Address begins with bit 0
- It ranges from 0.0.0.0 to 127.255.255.255
- For the IP addresses from Class A,
  - the first 8 bits (the first decimal number) represent the network part, while the remaining 24 bits represent the host part.

Class A Addresses

- The designers of the IP address scheme said that the first bit of the first byte in a Class A network address must always be **off,** or **0**.
- This means a Class A address must be between 0 and 127, inclusive.

  First Octet **Range in Binary=** **0**0000000 - **0**1111111

  Range in Decimal = 0-127
- Class **A** network is defined in the first octet between 0 and 127
- **Network** HOST HOST HOST
- Default Subnet mask 255.0.0.0
- The 24 bits of host ID are used to determine the host in any network.
- 2^7-2= 128-2=**126 network ID** (Here 2 address is subtracted because 0.0.0.0 and 127.x.y.z are special address.)
- $2^{24} - 2 =$ **16,777,214 host ID**
- IP addresses belonging to class A ranges from 1.x.x.x – 126.x.x.x
- Example of Class A address: 112.10.25.25

Class B IP address

- Generally for the medium size networks this network is used.
- In the first octet of this class, IP range from 128 to 191

  (128.0.0.0 to 191.255.255.255)
- Address begins with bits 10.
- The first 16 bits (the first two octets) represent the network part, while the remaining 16 bits (the last two octets) represent the host part.

Class B Addresses

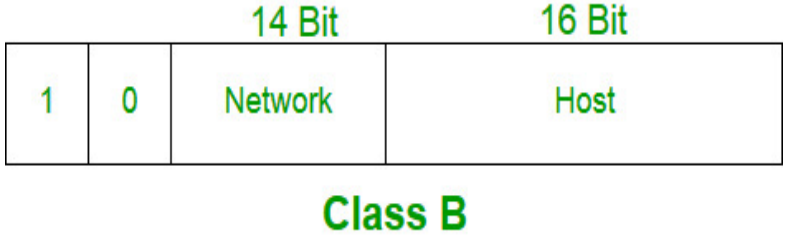
- The first bit of the first byte must always be turned on, but the second bit must always be turned off. (starts with 10)
- If you turn the other 6 bits all **OFF** and then all **ON**, you will find the range for a Class B network:

First Octet 10

Range: **10**000000 - **10**111111

Range: 128-191

- A Class B network ranges from 128 to 191.
- Network Network HOST HOST
- Default Subnet mask 255.255.0.0
- $2^{14} = 16,384$ network address
- $2^{16} - 2 = 65,534$ host address
- Example of Class B address: 145.24. 53.107



Class C IP address

- For the smaller network this IP address class is used.
- In this class three octets are used to identify the network.
- This IP ranges between 192 to 223 (range 192.0.0.0-to-223.255.255.255).
- A local area network use Class C IP address to connect with network.
- Address begins with bits 110.
- It has 24 bit network number and 8 bit host number.

Class C Addresses

- The first 2 bits of the first octet as always turned on, but the third bit can never be on.
- Following the same process as the previous classes, convert from binary to decimal to find the range.

First Octet

Range: **110**00000 -**110**11111

Range: 192- 223

NETWORK NETWORK NETWORK HOST

Default Subnet 255.255.255.0

- $2^{21} = 2{,}097{,}152$ network address
- $2^{8} - 2 = 254$ host address
- Example of Class C address 195.24.53.107

Default mask

- Class A 255.0.0.0 or (/8)
- Class B 255.255.0.0 or (/16)
- Class C 255.255.255.0 or (24)

/8, 8 bits are ON the network portion

11111111. 00000000.00000000.00000000

Class D IP address

- Class D addresses are used for multicasting;
- There is only one block in this class.
- Begins with 1110 in the first octet
- Multicast addresses (Class D):

  (224.0.0.0 to 239.255.255.255)

- Class D ranges from (224–239) and is used for multicast addresses

Class E IP address

- This type of IP address class is mostly used for the experimental or future use.
- There is only one block in this class.
- Class E ranges from (240 to 255) for scientific purposes

  (240.0.0.0 to 255.255.255.255)
- Begins with 1111, unused

- Show that Class A *has*

$$2^{31} = 2{,}147{,}483{,}648 \text{ addresses}$$

50% of the IP addresses are used by class A

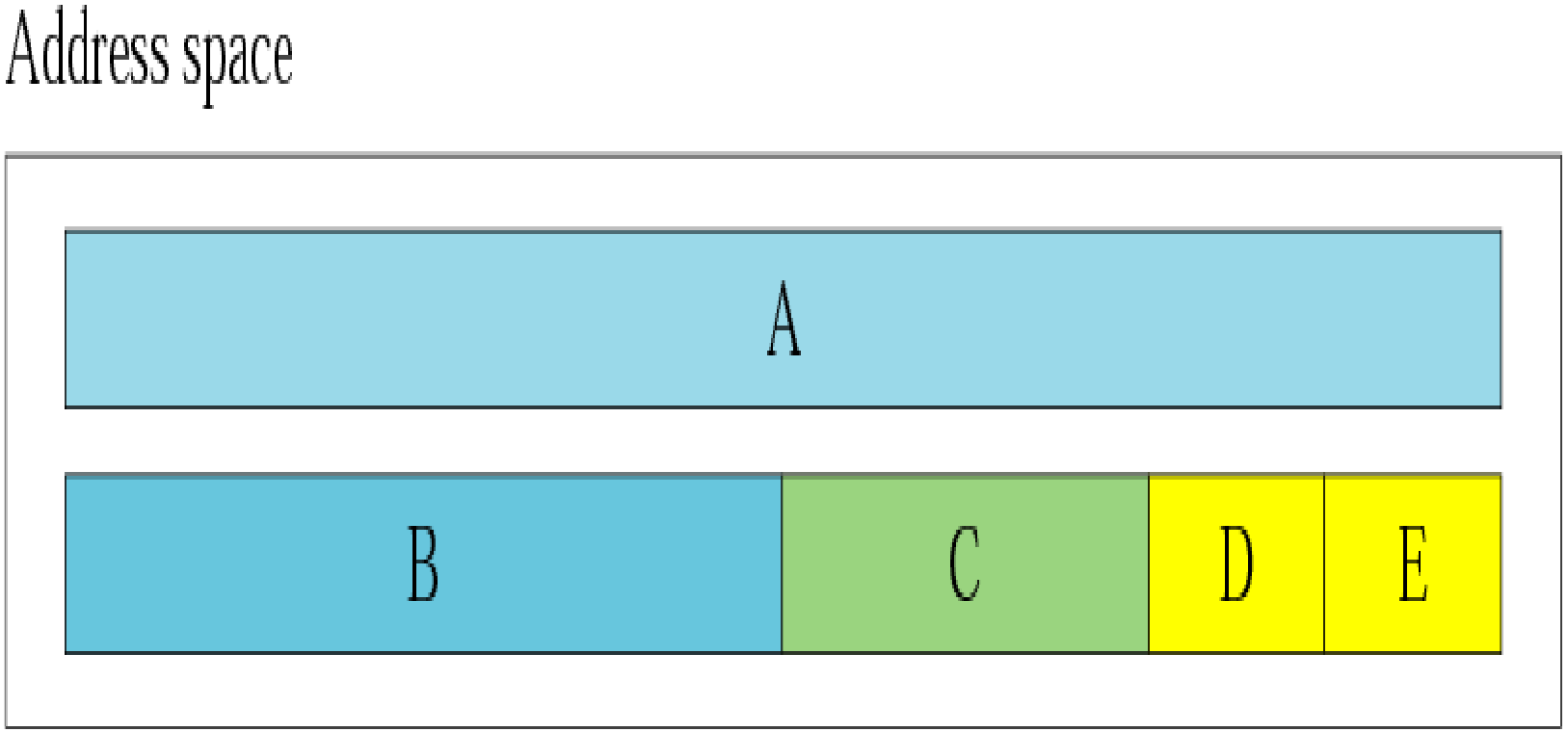
- Calculate the total IP address generated in Class B

2^n $n=?$

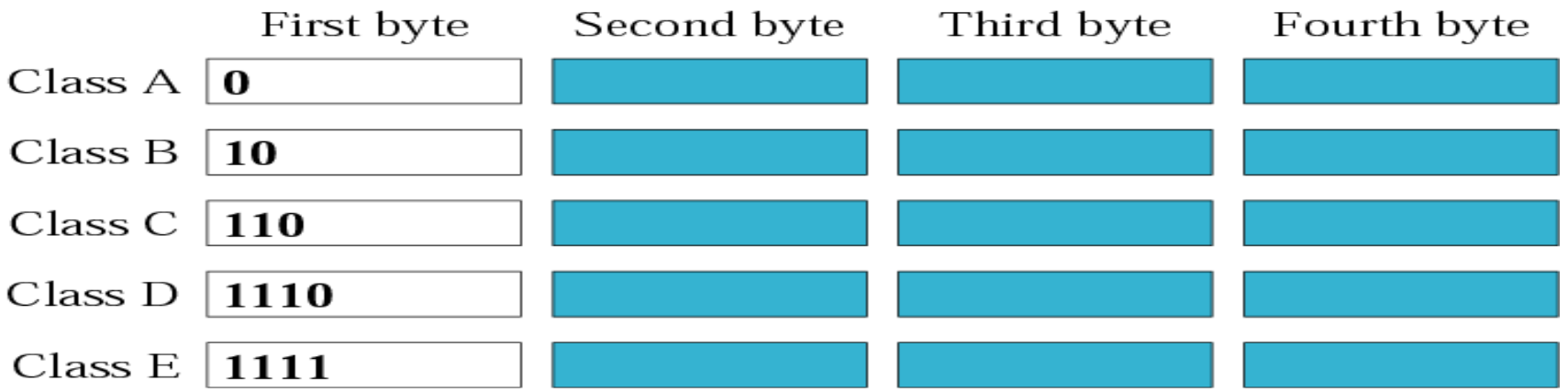
- Calculate the total IP address generated in Class C

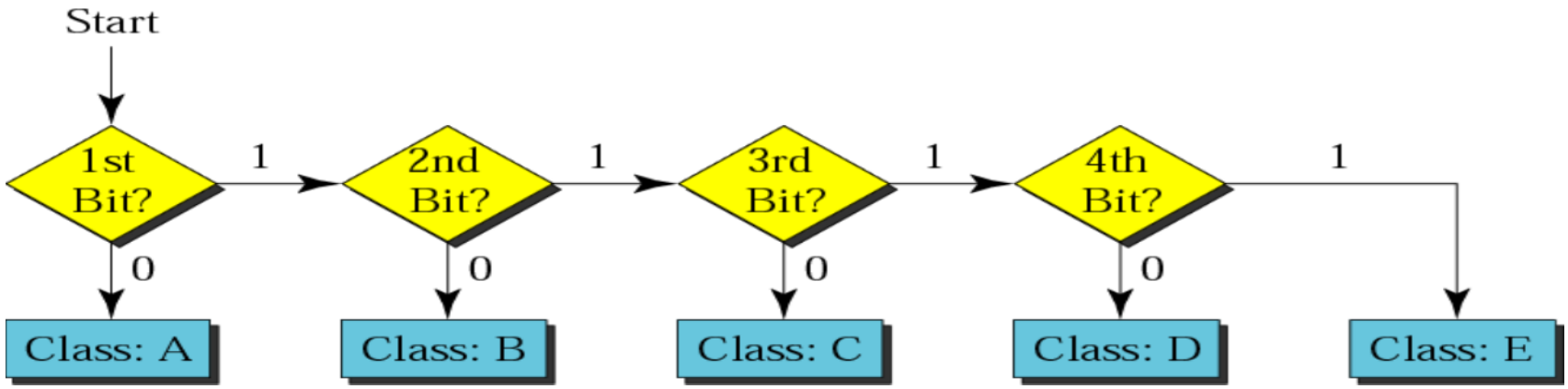
2^n $n=?$

Classful Addressing



Classes in binary notation





Example

Find the class of the following IP addresses

000000001 00001011 00001011 11101111

11000001 00001011 00001011 11101111

Solution

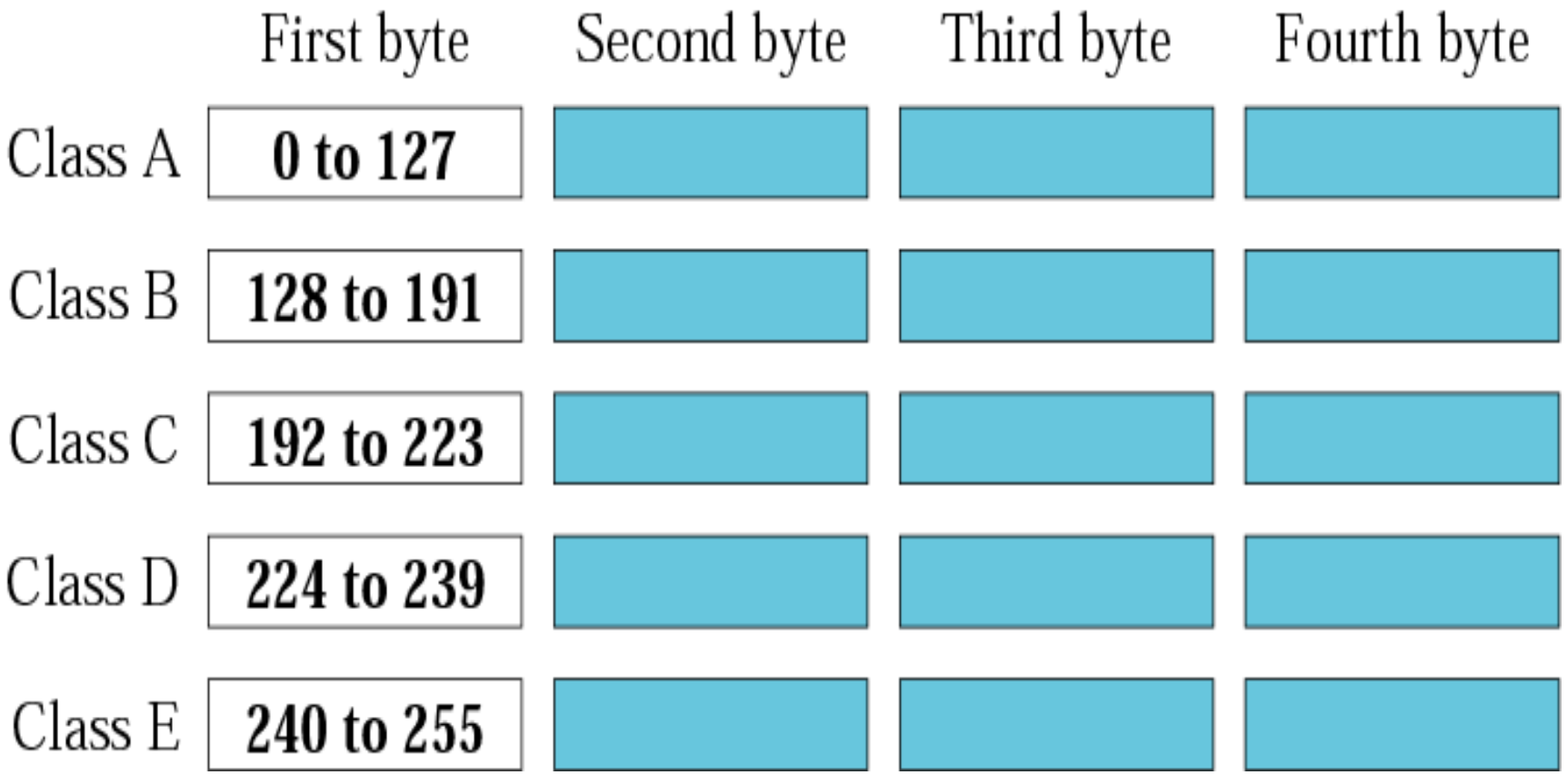
- **0**00000001 00001011 00001011 11101111

  1st is 0, hence it is Class A

- 11000001 00001011 00001011 11101111

  1st and 2nd bits are 1, and 3rd bit is 0 hence, Class C

Classes in Decimal notation



Example

- Find the class of the following addresses

  158.223.1.108

  227.13.14.88

- Solution

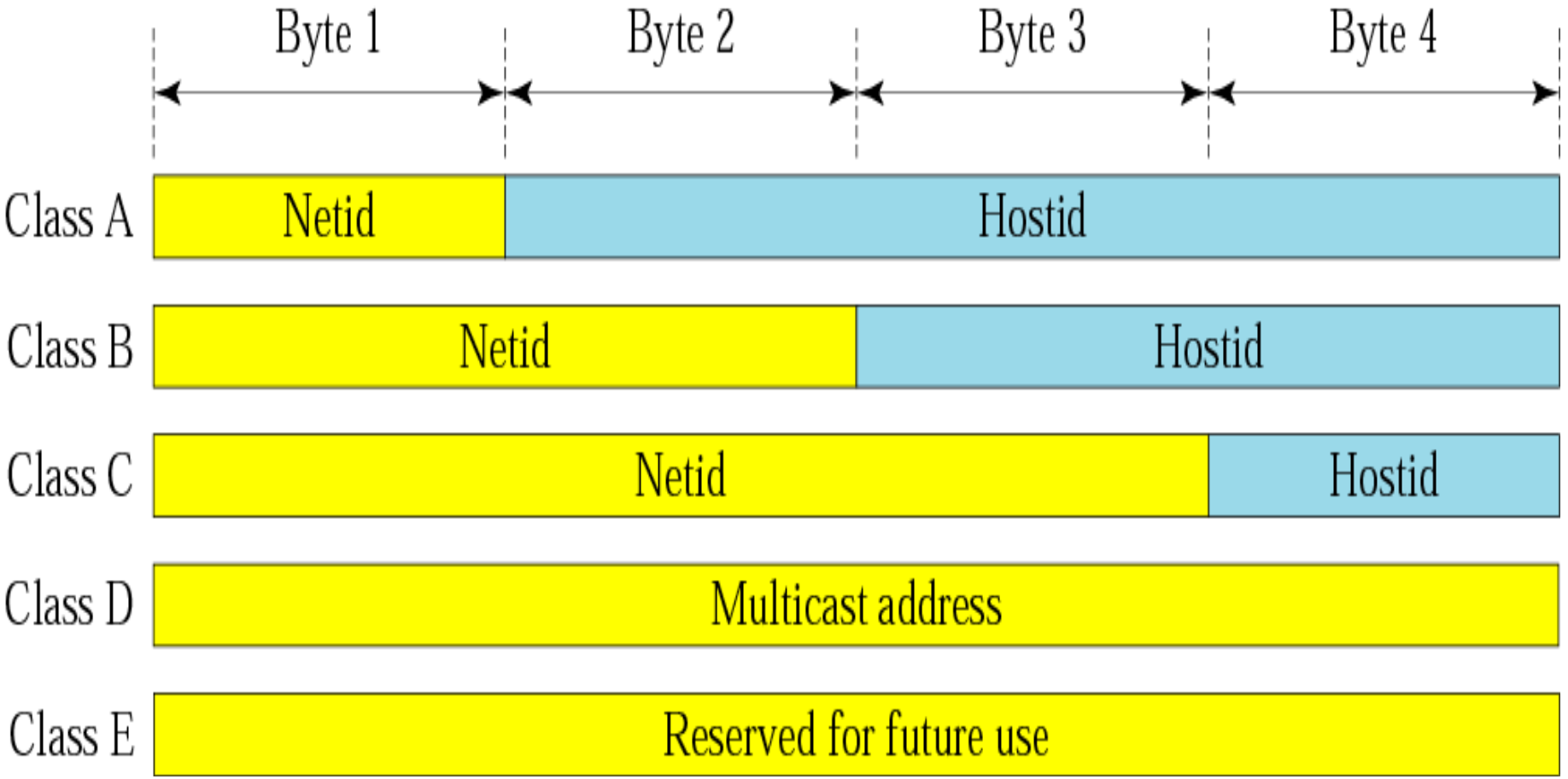
  158.223.1.108

  - 1st byte = 158 (128<158<191) class B

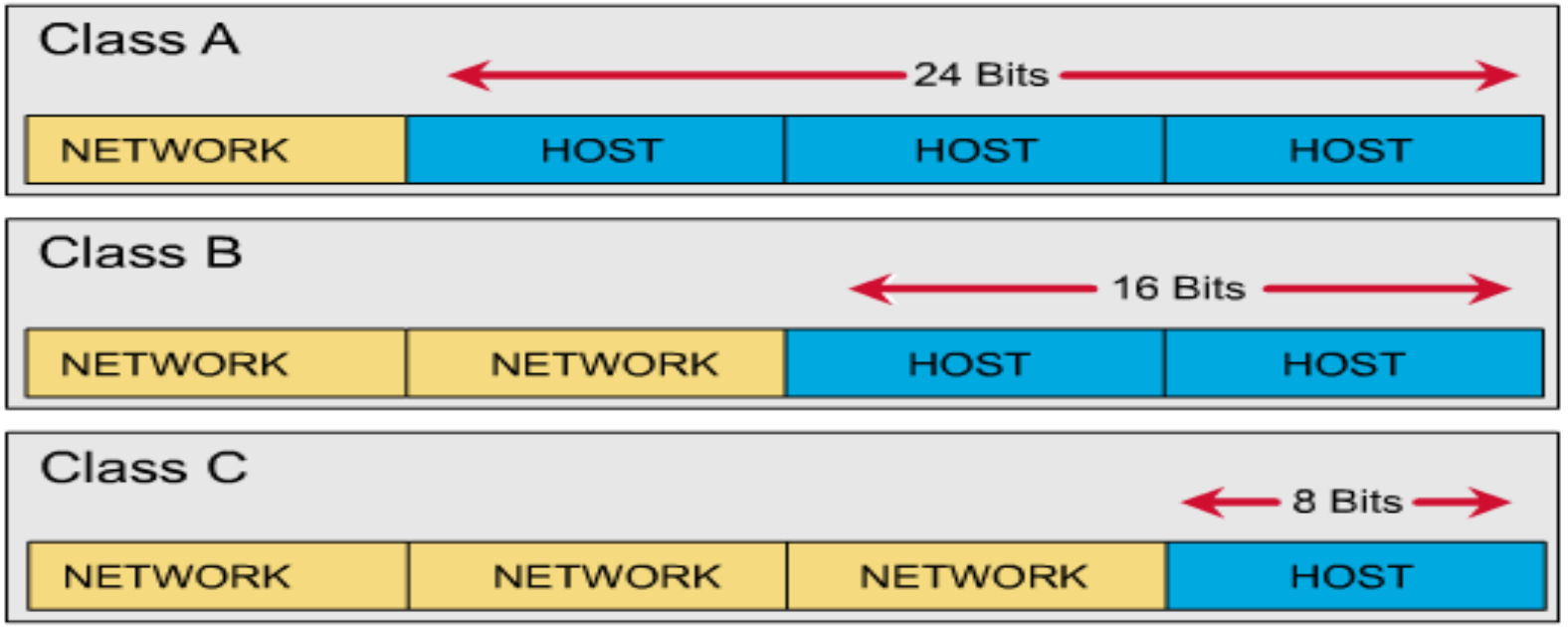
  227.13.14.88

  - 1st byte = 227 (224<227<239) class D

Netid and hostid



Hosts for Classes of IP Addresses



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

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

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

IP Addresses as Decimal Numbers

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

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

Class	First octet value	Subnet mask
A	0-127	8
B	128-191	16
C	192-223	24
D	224-239	-
E	240-255	-

Reserved IP addresses

- Expressed in dotted decimal format, the IPv4 address range is from:

0.0.0.0 to 255.255.255.255

- Not all of these addresses can be used as **host addresses** for communication.

Class D- Multicast Addresses

- A block addresses (Class D) is reserved for special purposes (multicast address). It ranges from

  224.0.0.0 to 239.255.255.255

- This address is reserved for link local addresses.
- These addresses are to be used for multicast groups on a local network.
- A router connected to the local network should never forward them.

Class E- Experimental Addresses

- Class E addresses are special address reserved for experimental purposes
- It ranges from:

240.0.0.0 to 255.255.255.254

- Currently, these addresses are listed as reserved for future use. They cannot be used in IPv4 networks.
- These addresses could be used for research or experimentation.

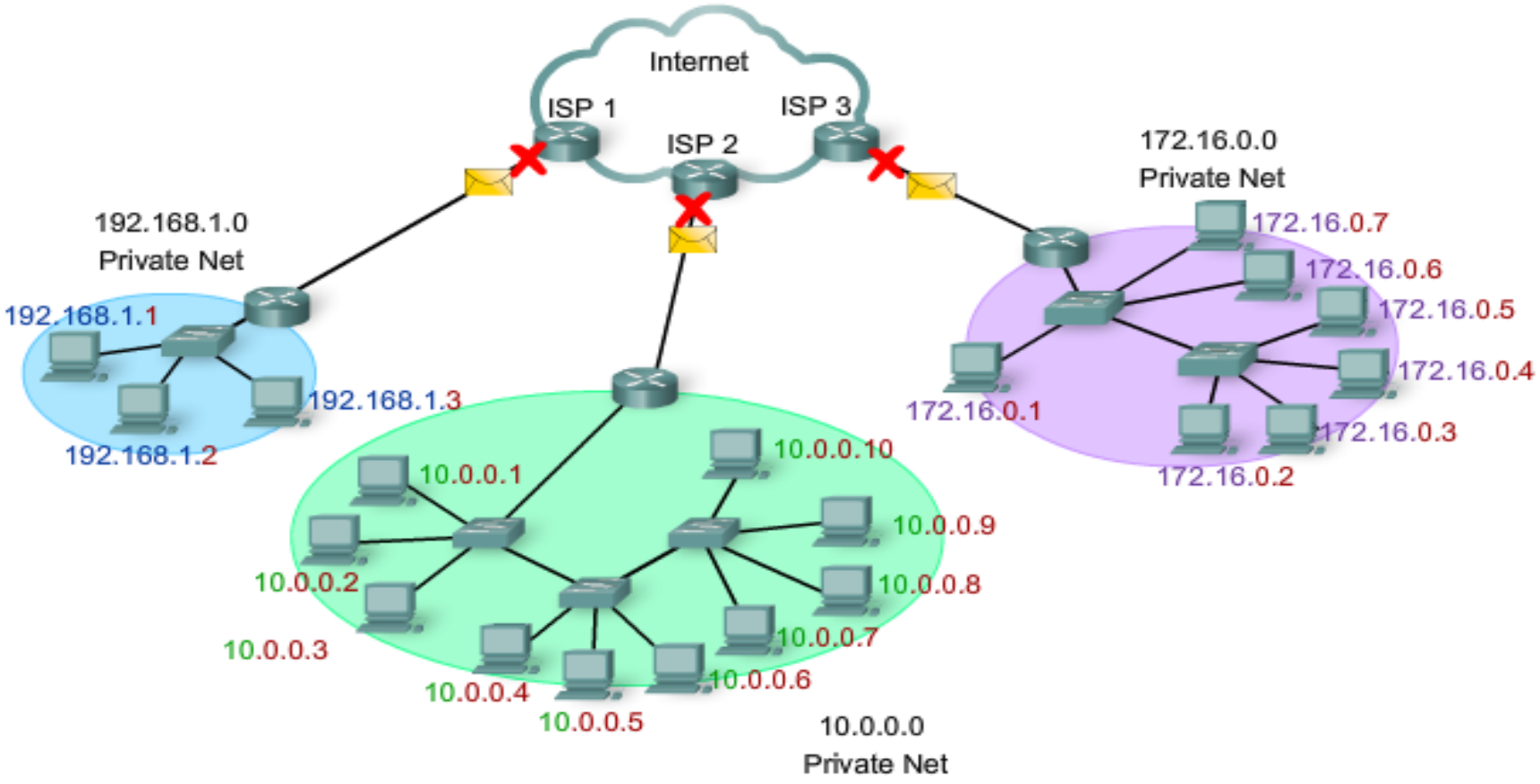
Special Addresses

- After accounting for the ranges reserved for experimental addresses and multicast addresses, this leaves an address range of **0.0.0.0 to 223.255.255.255** that could be used for IPv4 hosts.
- However, within this range are many addresses that are already reserved for special purposes.

Private Addresses

- Although most IPv4 host addresses are public addresses designated for use in the Internet, there are blocks of addresses that are used in networks that require limited or no Internet access.
- These addresses are called private addresses.
  - 10.0.0.0 to 10.255.255.255 – Class A
  - 172.16.0.0 to 172.31.255.255 Class B
  - 192.168.0.0 to 192.168.255.255 Class C

Private Addresses Used in Networks without NAT



Private Addresses

- Private addresses are set aside for use in private networks.
- The use of these addresses need not be unique among outside networks.
- Hosts that do not require access to the Internet at large may make unrestricted use of private addresses.
- Private IP address of a system is the IP address that is used to communicate within the same network.
- Using private IP data or information can be sent or received within the same network.

Public Addresses

- The vast majority of the addresses in the IPv4 unicast host range are public addresses.
- **Public IP address** of a system is the IP address which is **used to communicate outside the network.**
- Public IP address is basically assigned by the ISP (Internet Service Provider)
- These addresses are designed to be used in hosts that are publicly accessible from the Internet.

Loopback / localhost

- One such reserved address is the IPv4 loopback address 127.0.0.1.
- The loopback is a special address that hosts use to direct traffic to themselves.
- You can also ping the loopback address to test the configuration of TCP/IP on the local host.

Default Route

- 0.0.0.0 is the IPv4 default route.
- The default route is used as a "catch all“ route when a more specific route is not available.
- The use of this address also reserves all addresses in the 0.0.0.0 - 0.255.255.255
- (0.0.0.0 /8) address block.

Types of addresses in an IPv4 network

- The IPV4 network segment has three address types
  - Network Address (NA)
  - Host Address (HA)
  - Broadcast Address (BA)

Network Addresses

- The network address is the **first address** in a block.
- The network address defines the network to the rest of the Internet.
- In classful addressing, **the network address is the one that is assigned to the organization.**
- Some portion of the high-order bits represents the network address.

Network Address

- At Layer 3, a network is a group of hosts that have identical bit patterns in the network address portion of their addresses.
- To represent the network address, all of these host bits are '0'.

Network Addresses

- Given the network address, we can find the class of the address, the block, and the range of the addresses in the block
- Example: the network address is 132.21.0.0
  - find:
    - the class,
    - the block, and
    - the range of the addresses
- The 1st byte is between 128 and 191. Hence, Class B
- The block has a network address (Net-id) of 132.21.
- The addresses range from (132.21.0.0 -132.21.255.255)

Network Addresses

10.50.120.7 –this is a Class A address,

- the first number (**10**) represents the network part, while the remainder of the address represents the host part (**50.120.7**).
- This means that, in order for devices to be on the same network, the first number of their IP addresses has to be the same for **both devices**.
- In this case, a device with the IP address of **10.47.8.4 is on the same network.**
- The device with the **IP address 11.5.4.3 is not on the same network**, because the first number of its IP address is different.

Network Addresses

Consider the following IP addresses:

172.16.55.13 – this is a Class B address,

- The first two numbers (**172.16**) represent the network part, while the remainder of the address represents the host part **(55.13).**
- A device with the **IP address of 172.16.254.3 is on the same network**, while a device with the **IP address of 172.55.54.74 isn't.**

Broadcast Address

- Broadcast address is a special address for each network that allows communication to all the hosts in that network.
- To send data to all hosts in a network, a host can send a single packet that is addressed to the broadcast address of the network.
- The broadcast address uses the ***highest address*** in the network range. This is the address in which the bits in the host portion are all 1s.
- For the network 10.0.0.0 with network bits, the broadcast address would be 10.255.255.255. This address is also referred to as the directed broadcast.

Host Addresses

- Every end device requires a unique address to deliver a packet to a host.
- In IPv4 addresses, we assign the host address values between the network address and the broadcast address to the devices in that network.
- All 32 bits define the IPv4 address, there are a variable number of bits that are called the host portion of the address.

Network Prefixes

- When we express an IPv4 network address, we add a ***prefix length*** to the network address.
- The *prefix length* is the number of bits in the address that gives us the *network portion*.
- For example, in 172.16.4.0 /24, the /24 is the prefix length - it tells us that the first 24 bits are the network address. This leaves the remaining 8 bits, the last octet, as the host portion

Network Prefixes

- The Subnet masks in 172.16.4.0 /24 can also be represented as 255.255.255.0 or

11111111 11111111 11111111 00000000

which is equivalent to /24

- Network prefix specifies the network portion of an IPv4 address to the network devices.
- 172.16.4.0 /16 is the same as 255.255.0.0

11111111 11111111 00000000 00000000

Calculating
Network, Host, and Broadcast addresses

- Given the address 172.16.20.25. calculate the NA, HA, and BA addresses
  - Network address: 172.16.0.0
  - First host: 172.16.0.1
  - Last host address: 172.16.255.254
  - Broadcast address: 172.16.255.255

Cont'd

- How many hosts can be represented in a network /24?

  11111111 11111111 11111111 00000000

  2^8-2 =254 hosts

- The minus two is because one is for the network address and the other is for the broadcast address.

Classless IP Addressing

Classless IP Addressing

- Classless addressing is an improved IP Addressing system.
- It makes the allocation of IP addresses more efficient.
- It replaces the older classful addressing system based on classes.
- It is also known as **Classless Inter-Domain Routing** (CIDR)
- **The number of bits used for the network portion of an IP address became variable instead of fixed.**

Subnet Mask

- Subnet mask determines which part of an IP address is the Network Field and which part is the **Host Field**
- Follow these steps to determine the subnet mask:
  1. Express the subnetwork IP address in binary form.
  2. Replace the **network and subnet portion** of the address with all **1**s and the **host portion** of the address with all **0**s.
  3. Convert the binary expression back to dotted-decimal notation.

Subnet Mask

11111111.11111111.11110000.00000000

Class B Network
16 bits for the Network
4 bits for the Subnetwork
12 bits for the Host

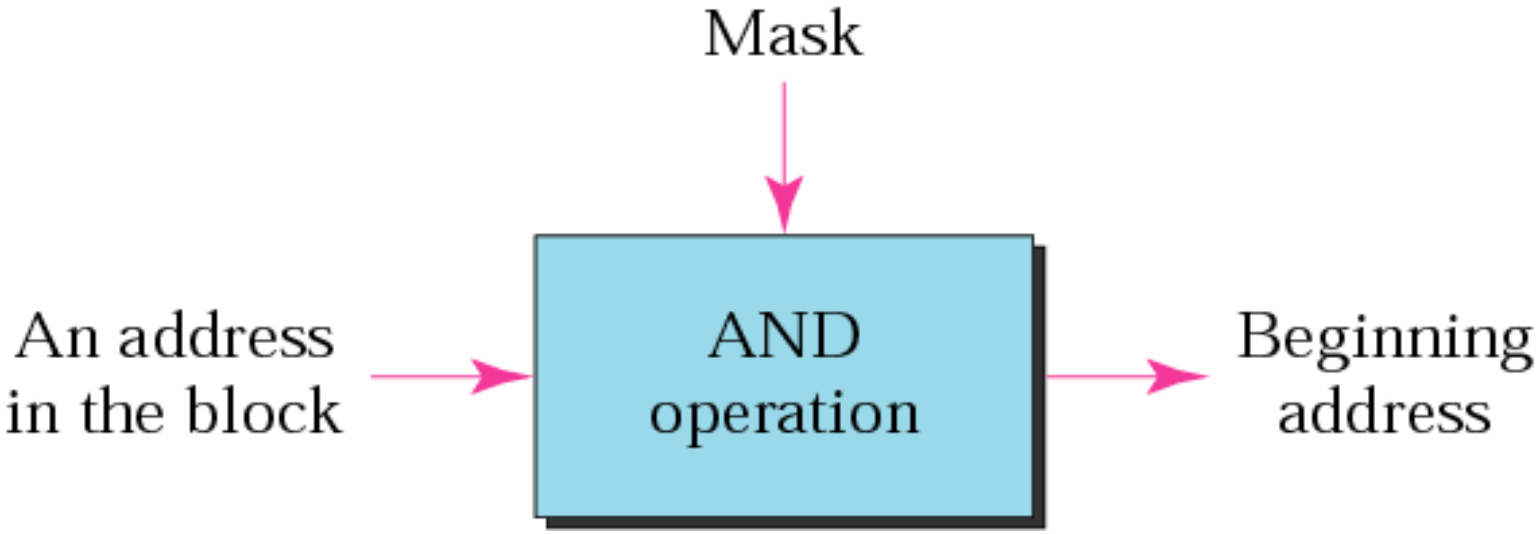
Subnet mask in decimal = 255.255.240.0

- 32 bits long
- Divided into four octets
- Network and subnet portions all 1's
- Host portion all 0's

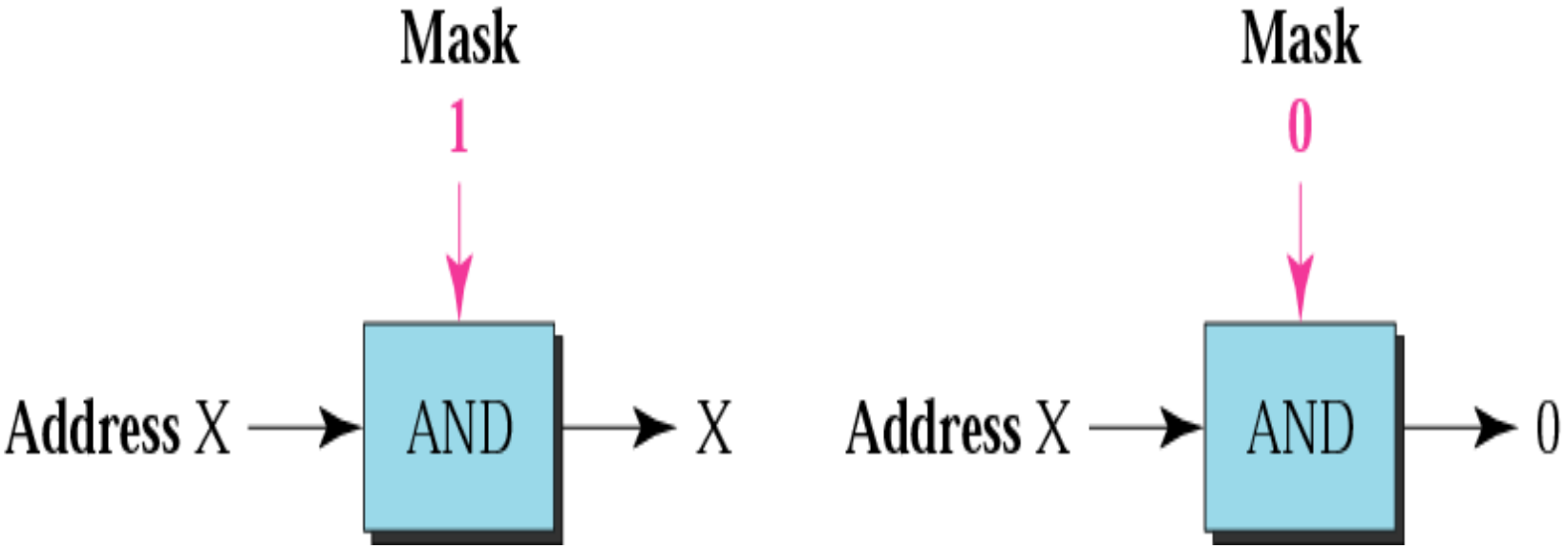
Subnet Mask

- A subnet mask is a 32-bit binary number.
- The **subnet mask is ANDed with an IP address** to get the block address **(Network address)**

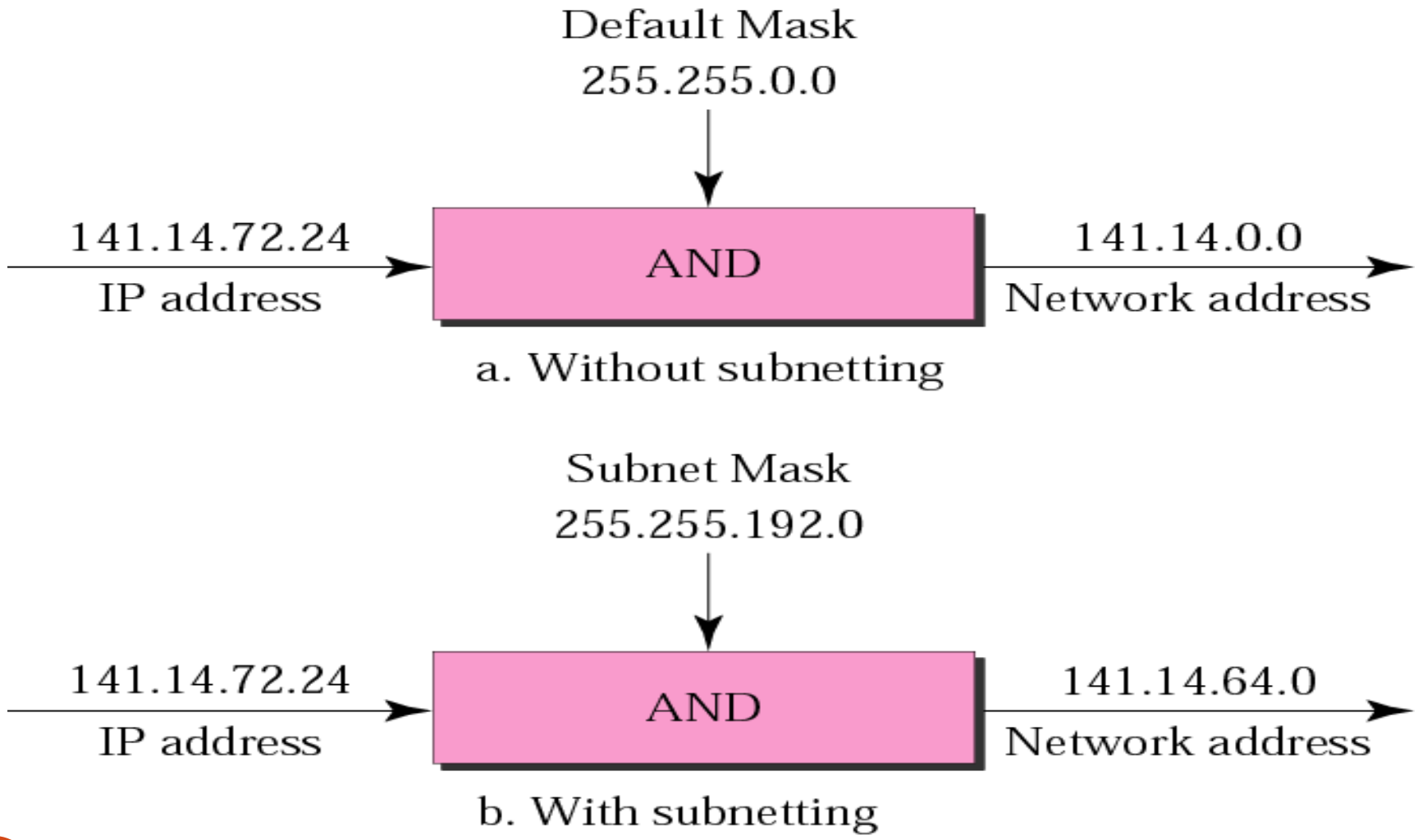
Mask **And** IP address = Block Address



AND operation



Default Mask and Subnet Mask



Finding the Subnet Address

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

- 11001000 00101101 00100010 00111000
- 11111111 11111111 11110000 00000000

11001000 00101101 00100000 00000000

The subnetwork address is 200.45.32.0

Classless Inter-Domain Routing (CIDR)

- Used to allocate an amount of IP address space to a given entity (company, home, customer, etc).

  Example: 192.168.10.32/28

- The slash notation (/) means how many bits are turned ON (1s) and tells you what your subnet mask is.

Calculating Network, Host and Broadcast addresses

Given the address 172.16.20.0 /25

Network address:

10101100 00010000 00010100 00000000 thus 172.16.20.0

First host:

10101100 00010000 00010100 00000001 thus 172.16.20.1

Last host address

10101100 00010000 00010100 01111110 thus 172.16.20.126

Broadcast address:

10101100 00010000 00010100 01111111 thus 172.16.20.127

Assigning Addresses

Network address

172 . 16. 20. 0/25

10101100.00010000.00010100.0**0000000**

|----------Network ----------|- host -|

0+0+0+0+0+0+0+0=0

Network address = 172.16.20.0

Step 1

First host address

172 . 16. 20. 1

10101100.00010000.00010100.0**0000001**

|----------Network ----------|- host -|

0+0+0+0+0+0+0+1=1

Lowest host address = 172.16.20.1

Step 2

Broadcast address

172 . 16. 20. 127

10101100.00010000.00010100.0**1111111**

|----------Network ----------|- host -|

0+64+32+16+8+4+2+1=127

Broadcast address = 172.16.20.127

Step 3

Last host address

172 . 16. 20. 126

10101100.00010000.00010100.0**1111110**

|----------Network ----------|- host -|

0+64+32+16+8+4+2+0=126

Highest host address = 172.16.20.126

Step 4

Calculating Network, Host and Broadcast addresses

1. Given the address 191.30.168.213/29

calculate the BA, NA, HA, and number of hosts represented.

2. 192.168.1.25/27

Calculate NA, HA and BA

Subnetting

- The process of splitting a network into smaller networks is called subnetting.
- The smaller networks formed are known as subnets
- If you break a major network (Class A, B, or C) into smaller subnetworks, it allows you to create a network of interconnecting subnetworks.

Subnetting

- In order to subnet a network, **extend** the subnet mask using some of **the bits from the host ID portion** of the address to create a subnetwork ID (address).
- Subnetting allows you to create **multiple logical networks (subnets)** that exist within a single Class A, B, or C network.
- If you do not subnet, you are only able to use one network from your Class A, B, or C network, which is unrealistic.
- **What happens if you wanted to take one network address and create six networks from it?**

Subnetting

- Subnets are connected to the rest of the network through address-resolving devices called routers.
- NAT (*network address translation) is* a way to map multiple local private addresses to a public one before transferring the information.
- Subnets can be freely assigned within the organization
  - Internally, subnets are treated as separate networks
  - Subnet structure is not visible outside the organization

Advantages of Subnetting

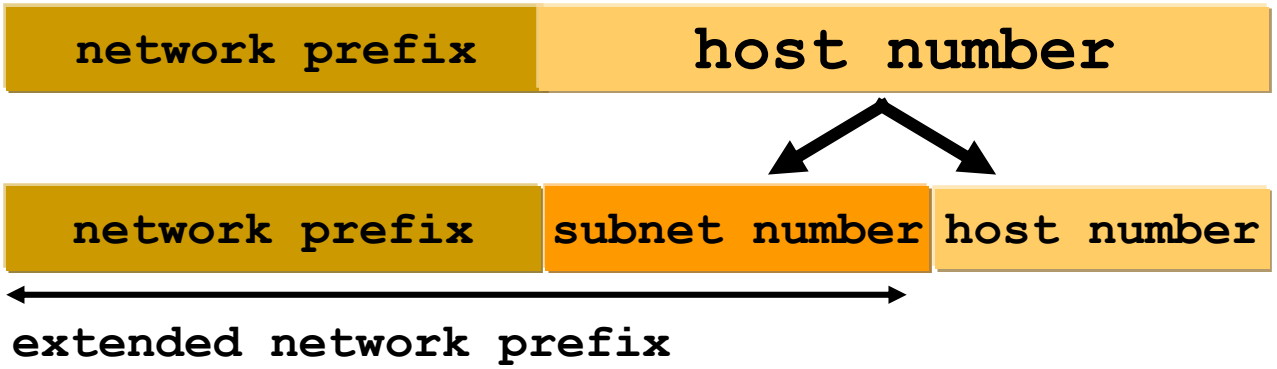
- Improves efficiency of IP addresses by not consuming an entire address space for each physical network.
- Reduces router complexity. Since external routers do not know about subnetting, the complexity of routing tables at external routers is reduced.
- Reduced network traffic
- Optimized network performance
  - This is a result of reduced network traffic.
- Simplified management
  - It's easier to identify and isolate network problems in a group of smaller connected networks than within one gigantic network

How to create subnets

- To create a subnet address, a network administrator should borrow bits from the **original host portion** and designates them as the **subnet field.**
- A network with no subnets will have one of these default subnet mask values depending upon its class address.
- However, when subnetting is implemented, the actual subnet mask value is calculated to determine valid IP addresses for hosts on a subnet.

Basic Idea of Subnetting

- Split the host number portion of an IP address into a **subnet number** and **host number**.
- Result is a 3-layer hierarchy



Subnetting Example

193.16.4.0 /24 divide it into four networks

First Subnet

- 00 000000 = 0 The network address (do this first)
- 00 000001 = 1 The first valid host
- 00 111110 = 62 The last valid host
- 00 111111 = 63 The broadcast address (do this second)

Second Subnet

- 01 000000 = 64 The network
- 01 000001 = 65 The first valid host
- 01 111110 = 126 The last valid host
- 01 111111 = 127 The broadcast address

Third Subnet

- 10 000000 = 128 The subnet address
- 10 000001 = 129 The first valid host
- 10 111110 = 190 The last valid host
- 10 111111 = 191 The broadcast address

Fourth Subnet

- 11 000000 = 192 The subnet address
- 11 000001 = 193 The first valid host
- 11 111110 = 254 The last valid host
- 11 111111 = 255 The broadcast address

Subnets	Network Address (First Address)	Range (Valid Host)	Broadcast Address (Last Address)
Subnet 1			
Subnet 2			
Subnet 3			
Subnet 4			
Subnet 5			
Subnet 6			
. .			

Exercises

1. You have a network that needs 29 subnets while maximizing the number of host addresses available on each subnet. How many bits must you borrow from the host field to provide the correct subnet mask?
2. You have the following address: 192.16.5.133/29, How many total bits are being used to identify the network, and how many total bits identify the host?
3. What is the full subnet mask for address 172.16.5.10/28?
4. Write the IP address 222.1.1.20 mask 255.255.255.192 in CIDR notation.

5. A company is granted the site address 201.70.64.0 (class C). The subnet mask is 255.255.255.224.

a. How many subnets?
b. How many total hosts in each subnet?
c. What are the Network address for each subnet?
d. What are the range of valid hosts in each subnet?
e. What are the Broadcast address for each subnet?

6. 172.16.0.0

255.255.255.224

a. 1. how many subnets?
b. 2. how many hosts?
c. 3. what are the network address of each subnet?
d. 4. what are the broadcast address for each subnet?
e. 5. what are the valid hosts?

7. If an Ethernet port on a router were assigned an IP address of 172.16.112.1/25, what would be the valid subnet address of this host?

A. 172.16.112.0

B. 172.16.0.0

C. 172.16.96.0

D. 172.16.255.0

8. A company would like to break its Class B private IP address 172.16.0.0 into as many subnets as possible provided that they can get at least 300 clients per subnet. Find ranges of IP addresses for each subnet and new mask.

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