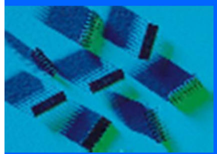


# Lecture 7
# IP Addressing and Subnets

Textbook: Ch.18

# Main Topics

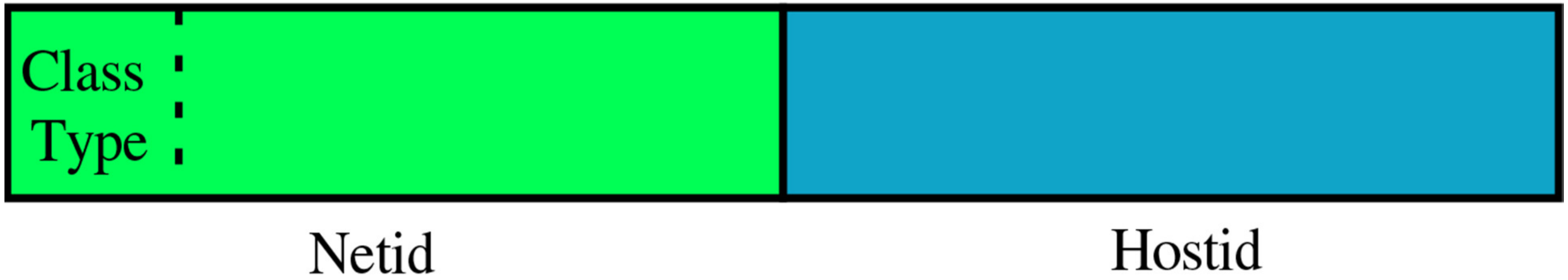
1. IPv4 Address
   - Classful and Classless Addressing
2. Network/Address Mask
3. Subnets
4. Design Examples

# 1) Internet Protocol (IPv4) Address

- Internet Protocol version 4 (IPv4)
- *An IPv4 address is a **32-bit** address that uniquely and universally defines the **connection** of a device (for example, a computer or a router) to the Internet. (It is a **logical address.**)*
- IPv4 address is commonly called ***IP address***
- The IP address is the address of the connection, not the host or the router
- All hosts on a given network have a ***common prefix*** in their IP address

# IP Address

An Internet address is made of four bytes (32 bits) that define a host's connection to a network.

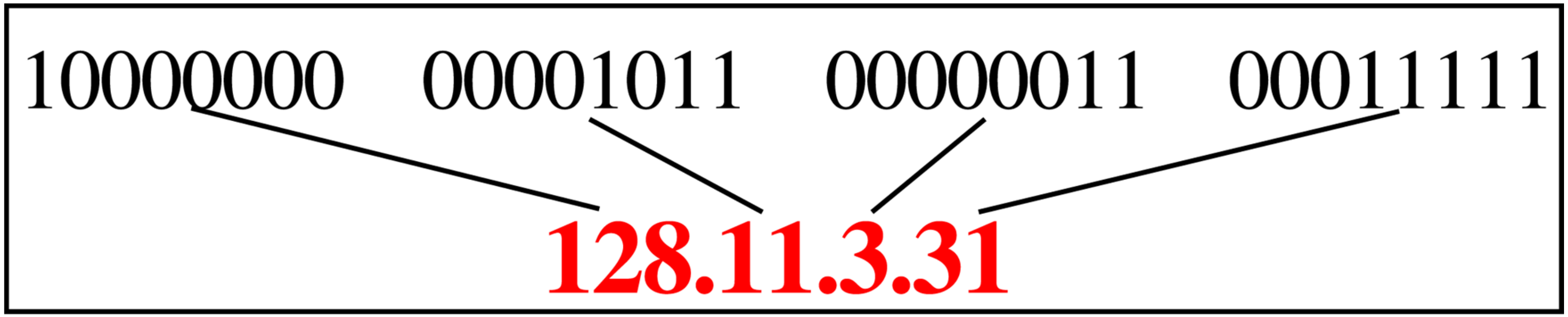



**An IPv4 address is 32 bits long.**

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

# IP Addresses in Dotted-Decimal Notation

- **Dotted Decimal Notation is for human memory and communication**




| Binary | Dotted-Decimal Notation |
|---|---|
| 10000001 00001011 00001011 11101111 | **129.11.11.239** |
| 11111001 10011011 11111011 00001111 | **249.155.251.15** |

# Example 1

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

a. 111.56.45.78

b. 75.45.34.79

## *Solution*

**We replace each decimal number with its binary equivalent:**

**a. 01101111 00111000 00101101 01001110**
**b. 01001011 00101101 00100010 01001111**

# Example 2

***Find the error, if any, in the following IPv4 addresses.***

a. 111.56.045.78

b. 221.34.7.8.20

c. 75.45.301.14

d. 11100010.23.14.67

***Solution***

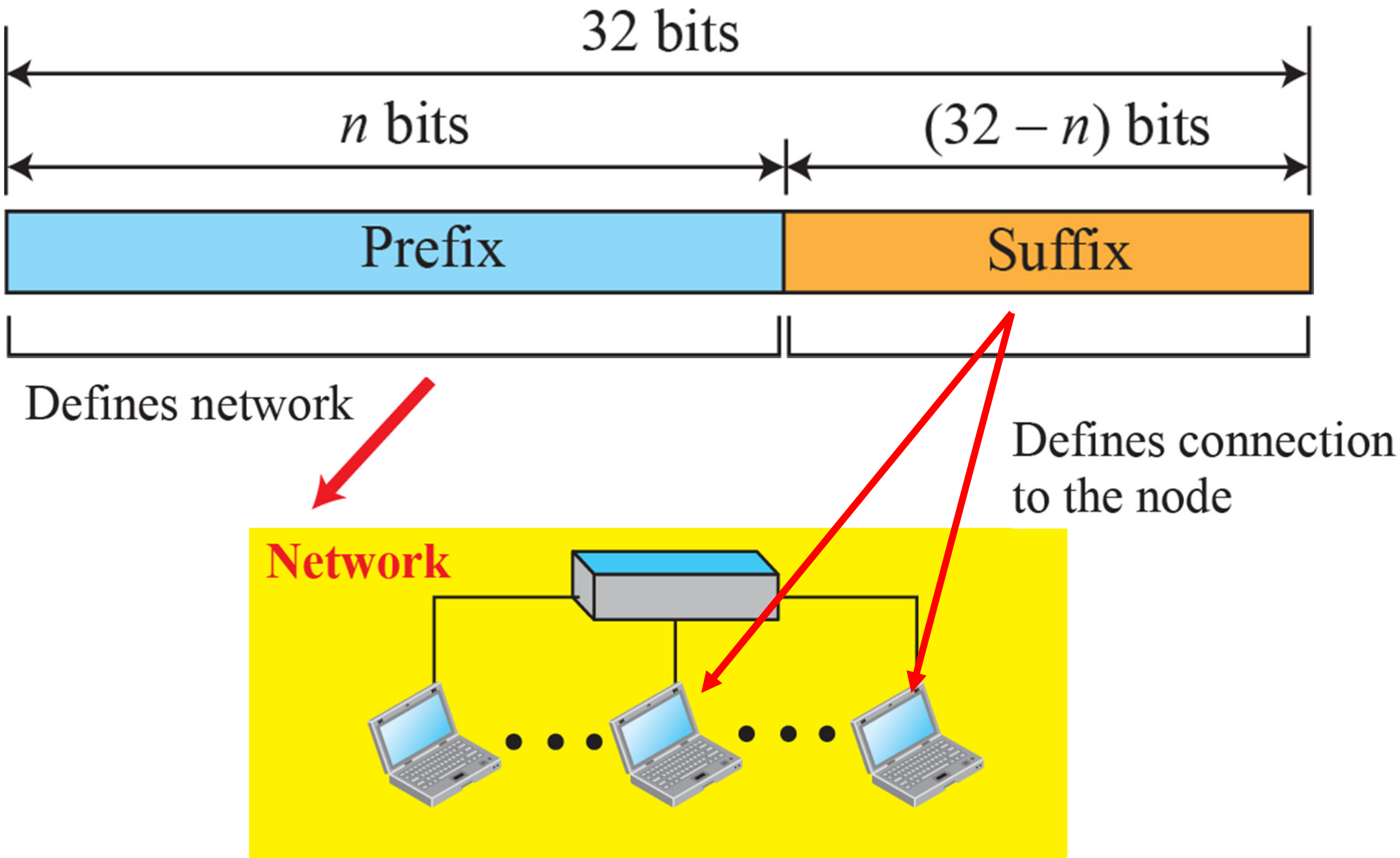
***a. There must be no leading zero (045).***

***b. There can be no more than four numbers.***

***c. Each number needs to be less than or equal to 255.***

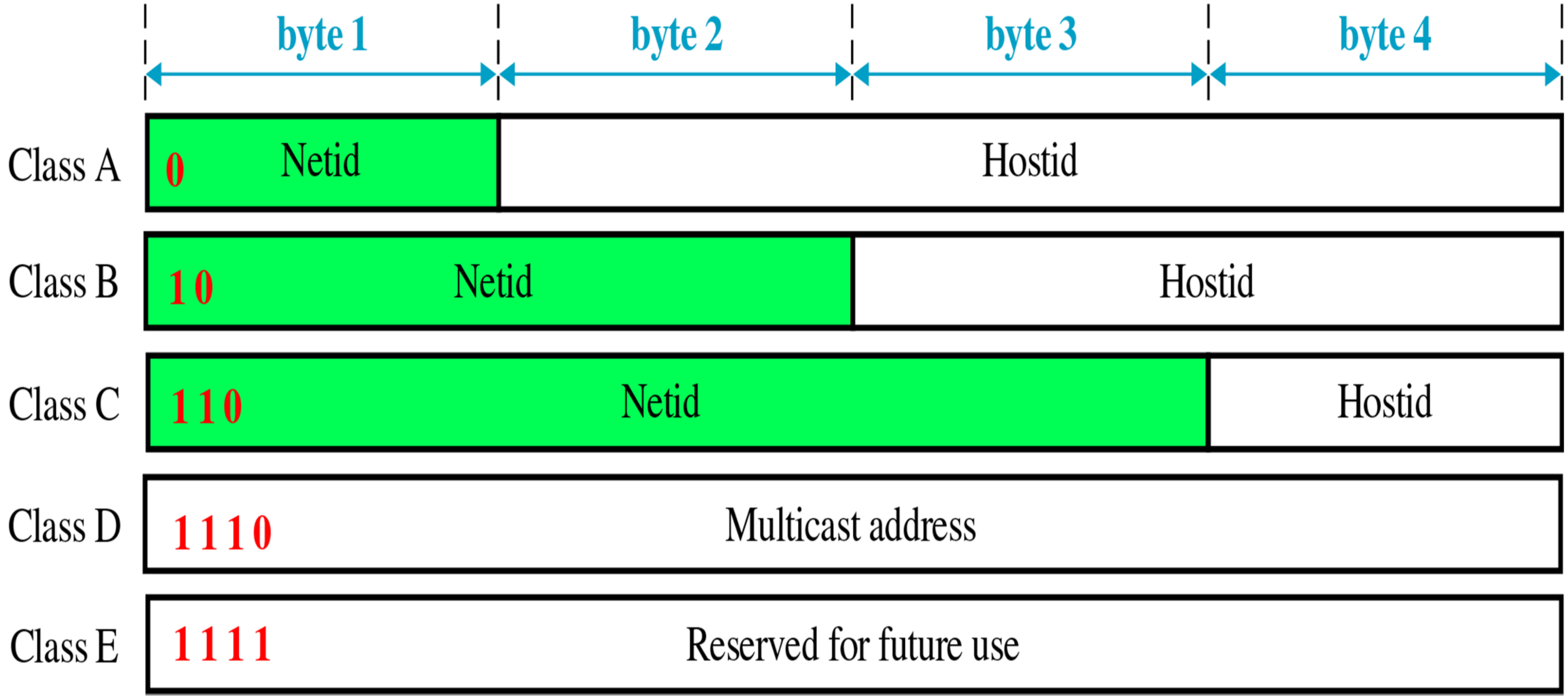
***d. A mixture of binary notation and dotted-decimal notation is not allowed.***

# Figure 18.17: Hierarchy in addressing



# Classful Addressing

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



# Class Ranges of Internet Addresses

**(IP for hosts in Class A: 1.0.0.1 to 126.255.255.254)**

**(**127.X.X.X is for ***loopback testing*** and should never be used for normal IP address**)**

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

b. Dotted-decimal notation

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

***Number of blocks and block size in classful IPv4 addressing***

# Example 3

Find the class of each address:

a. Binary: 00000001 00001011 00001011 11101111

b. DDN: 252.5.15.111

c. DDN: 134.11.78.56

## *Solution*

**a. The first bit is 0; this is a class A address.**
**b. The first byte is 252 (between 240 and 255); the class is E.**
**c. The first byte is 134 (between 128 and 191); the class is B.**

**Another method (besides memorizing) is to convert the first number to binary digits and then check the first few bits**

# Network Address and Broadcast Address

- The **network address** (*which represents the whole network*) is assigned by the *Internet Corporation for Assigned Names and Addresses* (**ICANN**)
  - Note: a network address is different from a netid
  - A network address has both netid and hostid, with all "0"s for the hostid.
- **Broadcast Address**
  - In the destination address, if the hostid of the IP address contains all "1"s, it means that all hosts within this network are the target destinations.

# 2) Network/Address Mask

- A 32-bit number made of contiguous 1s followed by contiguous 0s
- It is used to find the netid and hostid

*Default masks for classful addressing*

| Class | Binary | Dotted-Decimal | CIDR |
|---|---|---|---|
| A | 11111111 00000000 00000000 00000000 | 255.0.0.0 | /8 |
| B | 11111111 11111111 00000000 00000000 | 255.255.0.0 | /16 |
| C | 11111111 11111111 11111111 00000000 | 255.255.255.0 | /24 |

# Example 4

Given the address, find the default class, the network mask, the network address and the broadcast address of :

a) 23.56.7.91

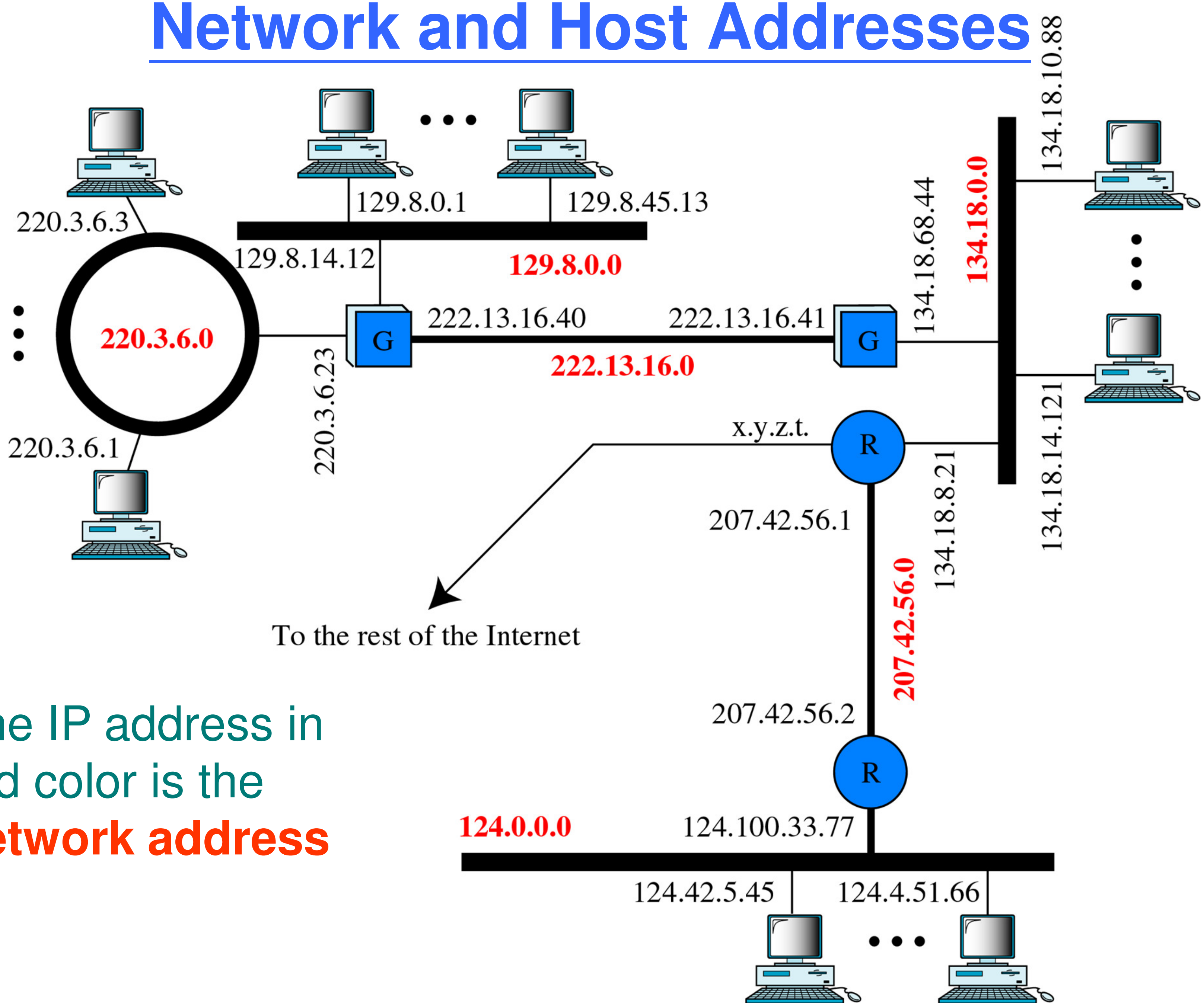
b) 132.6.17.85

***Solution***

a) The class is **A**.
The network mask :**255.0.0.0** (Only the first byte defines the netid.)
By replacing the hostid bytes (**56.7.91**) with 0s, the network address is **23.0.0.0.** The broadcast address is **23.255.255.255**

b) The class is **B**.
The network mask :**255.255.0.0** (The first 2 bytes defines the netid.)
By replacing the hostid bytes (**17.85**) with 0s, the network address is **132.6.0.0**. The broadcast address is **132.6.255.255**

# Network and Host Addresses




The IP address in red color is the **network address**

# Problems of Classful Addressing

- **Small no**. of Class A and B addresses, but too **large in size** in each class.

**In classful addressing, a large part of the available addresses were wasted.**

- Class C block is too small for most mid-size organization.

**Classful addressing is replaced with classless addressing.**

# Classless Addressing

- With the growth of the Internet, it was clear that a larger address space was needed
- It requires that the length of IP addresses be increased, which means the format of the IP packets needs to be changed
- Although the long-range solution has already been devised and is called IPv6 (128-bit address)
- A short-term solution, classless addressing, was also devised to use the same IPv4 address space but to change the distribution of addresses to provide a fair share to each organization

# Classless Addressing

- The addresses are still granted in blocks.
- There are no classes. The network mask is more flexible.
- An **address block** is a group of IP address, in which:
  1. Addresses in a block must be contiguous, one after another.
  2. Number of addresses in a block must be a power of 2 (1, 2, 4, 8..).
  3. … (skip the details)

# (Classless) Network Mask

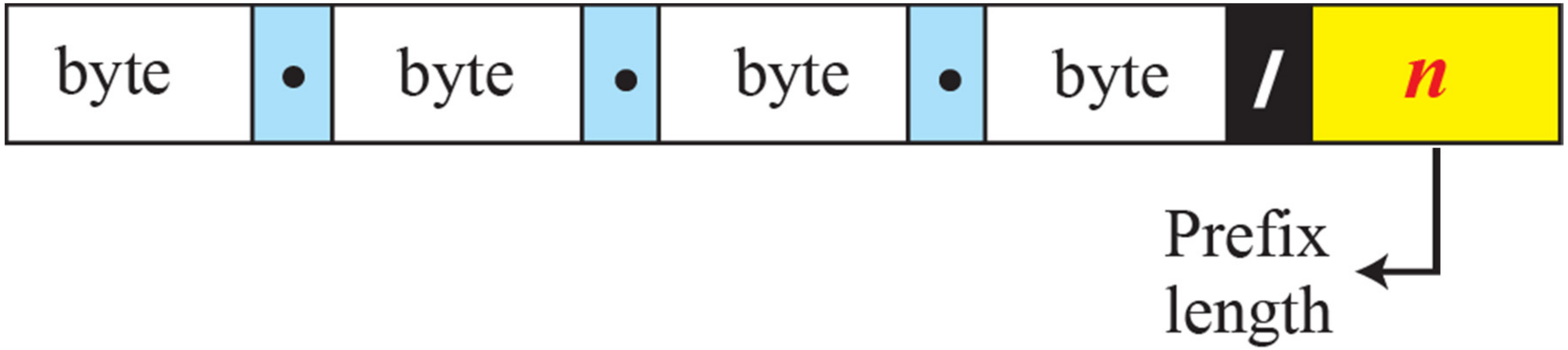
In IPv4 addressing, a block of addresses can be defined as

**x.y.z.t /*n***

in which x.y.z.t defines one of the addresses and the /*n* defines the mask.

- A mask is used to define an address block
- n can be 1 to 30 - *it is the length of the net-id*
- The notation (**/n**) is called **Classless Interdomain Routing (CIDR)** notation

# Figure 18.20: Slash notation (CIDR)




**Examples:**

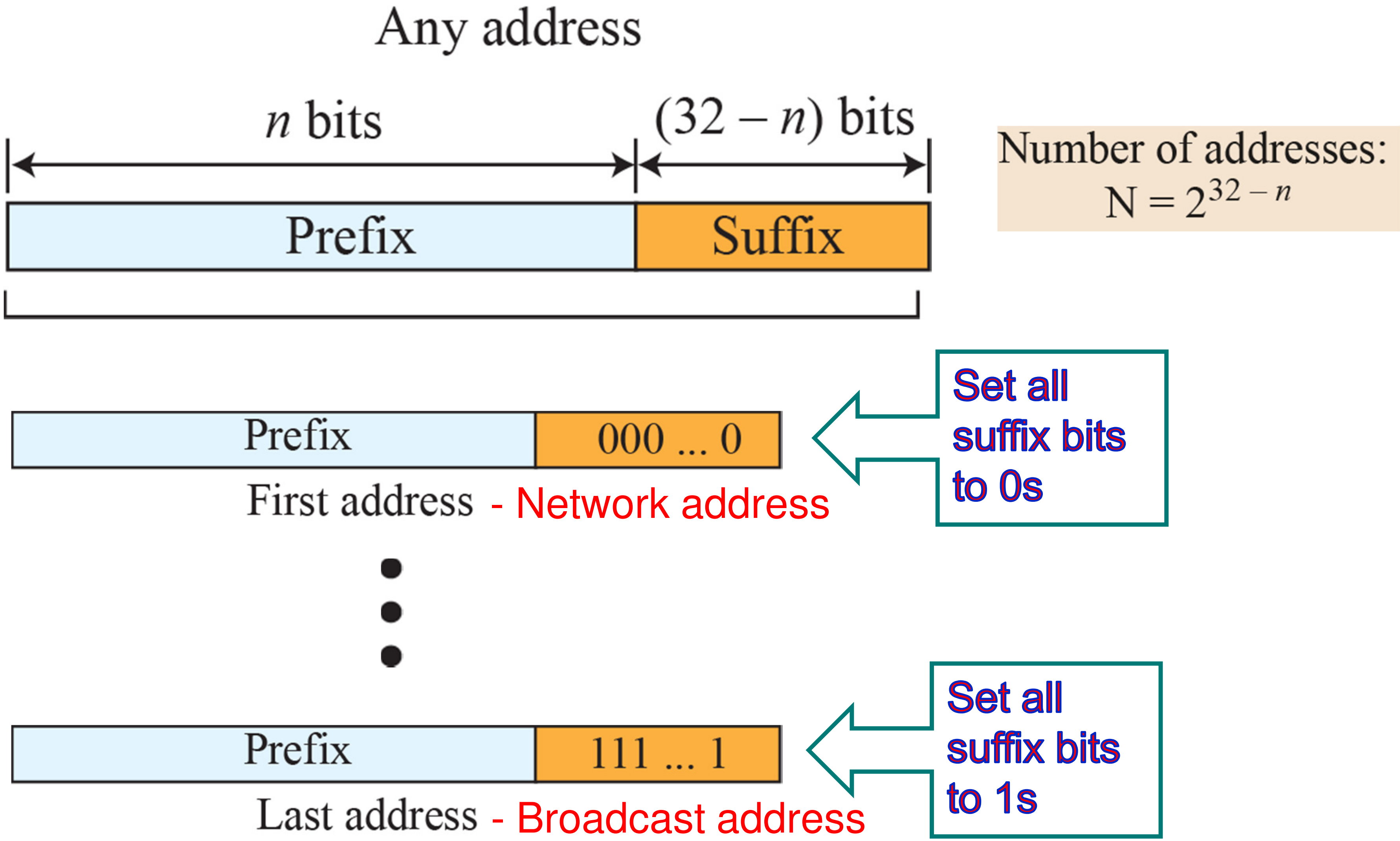
12.24.76.8/**8**

23.14.67.92/**12**

220.8.24.255/**25**

Figure 18.21:

# Information extraction in classless addressing



# Example 5

***A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.39/28. What is the first address (network address) in the block?***

***Solution***

***The binary representation of the given address is***

**11001101 00010000 00100101 00100111**

***We get the mask of 28 "1"s at the leftmost,***

**11111111 11111111 11111111 11110000**

***We get the network address ($1^{st}$ 28 bits + "0000")***

**11001101 00010000 00100101 00100000**

***or***

***205.16.37.32***

***(What is the last address? What is the usage?)***

## Example 18.1

A classless address is given as 167.199.170.82/27.
The number of addresses in the network is $2^{32-n} = 2^5 = 32$ addresses. The first address can be found by keeping the first 27 bits and changing the rest of the bits to 0s.

| | | | | |
|---|---|---|---|---|
| Address: 167.199.170.82/**27** | 10100111 | 11000111 | 10101010 | 01010010 |
| First address: 167.199.170.64/**27** | 10100111 | 11000111 | 10101010 | 01000000 |

The last address can be found by keeping the first 27 bits and changing the rest of the bits to 1s.

| | | | | |
|---|---|---|---|---|
| Address: 167.199.170.82/**27** | 10100111 | 11000111 | 10101010 | 01010010 |
| Last address: 167.199.170.95/**27** | 10100111 | 11000111 | 10101010 | 01011111 |

# (Classless) Network Mask

- For /n, the address mask is a 32-bit number in which
  - the n leftmost bits are 1s and the rest are 0s
- Use **bit-wise logical operation** to extract information from the IP address in a block
- **First Address = IP address AND mask**
- **Last Address = IP address OR (NOT mask)**

# Example 18.2

We repeat Example 18.1 using the mask. The mask in dotted-decimal notation is 255.255.255.224 The AND, OR, and NOT operations can be applied to individual bytes using calculators and applets at the book website.

| | |
|---|---|
| Number of addresses in the block: | N = **NOT** (mask) + 1 = 0.0.0.31 + 1 = 32 addresses |
| First address: | First = (address) **AND** (mask) = 167.199.170.64 |
| Last address: | Last = (address) **OR** (**NOT** mask) = 167.199.170.95 |

(The mask should be 255.255.255.224 !)

**The AND, OR, NOT operation should be done in binary numbers "bit-by-bit"**

# Example 18.2 (Cont.)

***Solution***

***IP address 167.199.170.82/27***

***The binary representation of the given address is***

```
      10100111 11000111 10101010 01010010
```

***We get the mask of 27 "1"s at the leftmost,***

```
      11111111 11111111 11111111 11100000
```

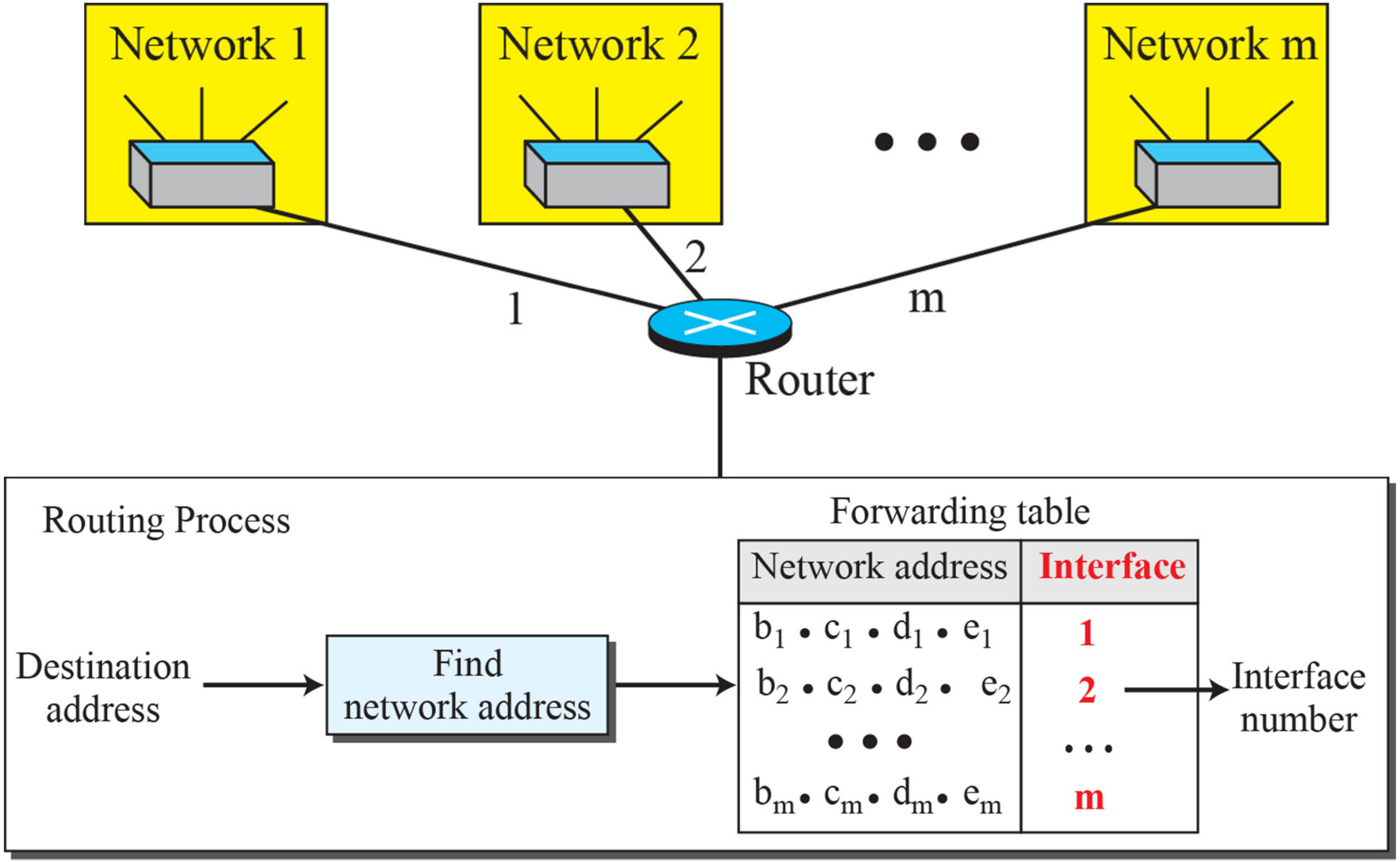
***(NOT mask) is***

```
      00000000 00000000 00000000 00011111
OR    10100111 11000111 10101010 01010010 (IP)
-----------------------------------------
      10100111 11000111 10101010 01011111
```

***After (address)OR(NOT mask)operation***

***We get the broadcast address 167.199.170.95/27***

Figure 18.22: Network address




The network address is the identifier of the network and it is used by the forwarding (or routing) table in the Internet

# How does a *host* get IP address

- Hard-coded by system admin in a file
- The network administrator can manually assign addresses to the individual hosts or routers

OR

- **DHCP: Dynamic Host Configuration Protocol**
- An application-layer program which allows a host to dynamically (and automatically) get address from a server
- Useful when the no. of hosts is more than the no. of available IP addresses but the no. of "active" hosts is not high

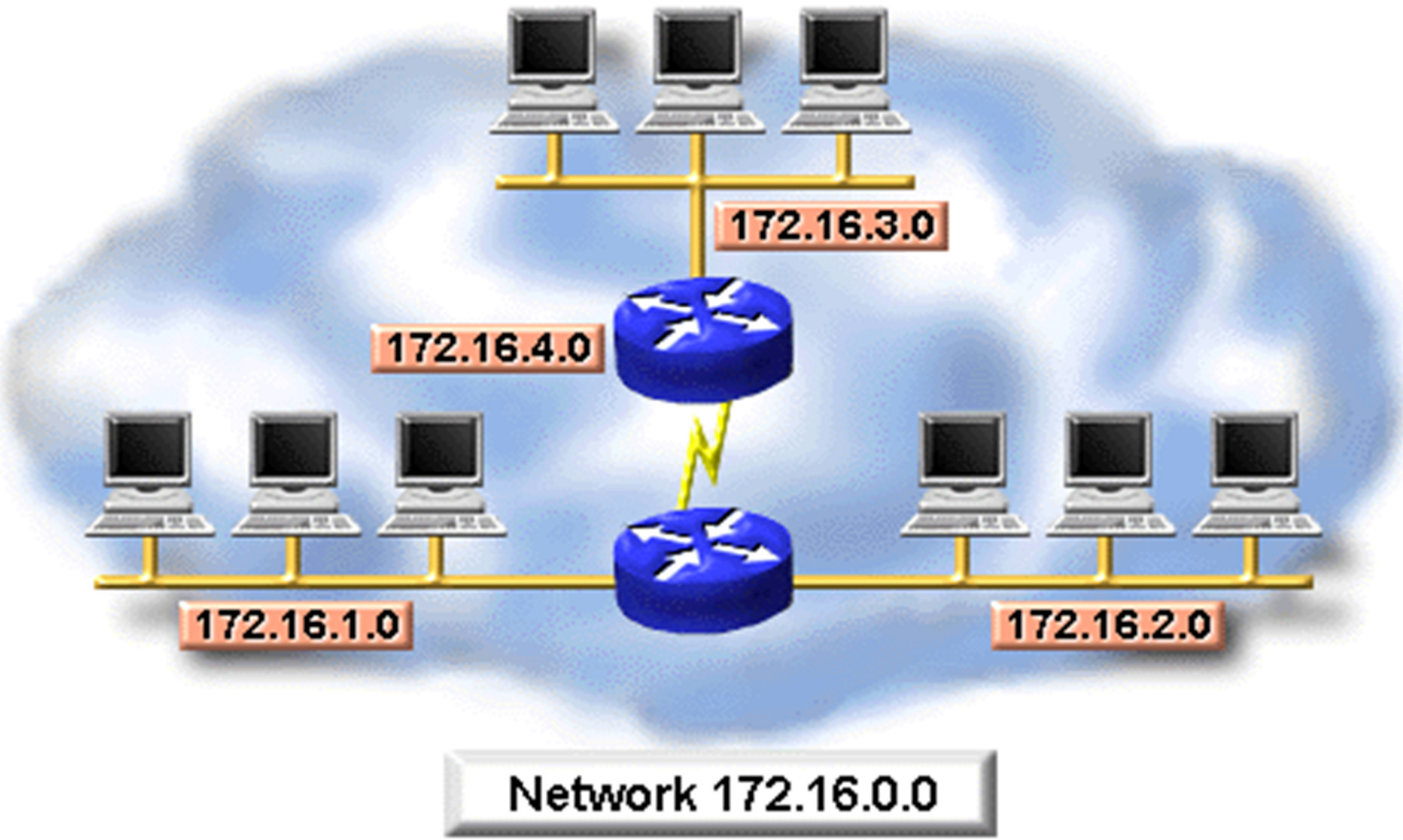
# 3) IP Subnetworks (Subnets)

- For transferal of data on the Internet, one network sees another as a single network and has no detailed knowledge of its internal structure
- The reason for this is that it helps keep routing tables small
- However large networks are often divided into smaller networks called subnetworks (subnets)

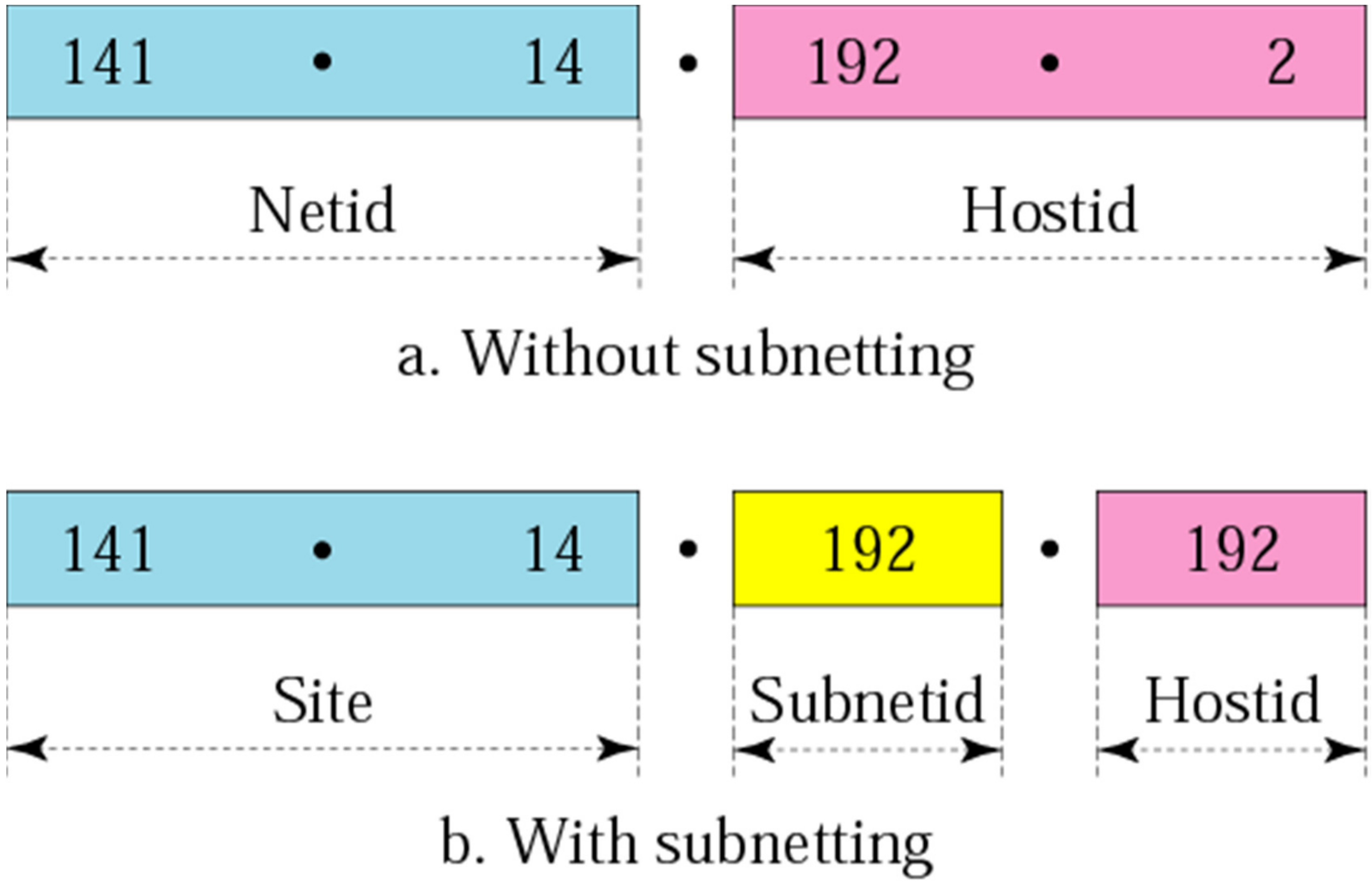
# Subnets

- The primary reason for using a subnet is to reduce the size of a broadcast domain (and hence reduce collisions)
- Subnets also improve the efficiency of addressing
- Adding subnets does not change how the *outside world* sees the network. Thus, a device on an outside network only sees the network ID and host ID of a device on another network.
- However, *internally*, networks can view themselves as being a series of smaller subnets.

# Addressing with Subnets



# Addresses in a network with and without subnetting



# Subnet Address

- Subnet addresses include a *network ID*, a *subnet ID* within the network, and a *host ID* within the subnet.
- To create a subnet address, a network administrator "borrows" bits from the host field and designates them as the subnet field.
- Network devices use **subnet masks** to identify which part of the address is considered as subnet ID and which part represents host addressing.

# Length of Subnet ID (1)

- For a network without subnets, when the host field of an IP address is all 0s, it is a network address.
- When the host field is all 1s, it is a broadcast address.
- Therefore, when we consider a network with subnets, **the combined field**

  **{<subnet> <host>}**

  **should NOT be all 0s or all 1s**

# Length of Subnet ID (2)

- The **minimum** number of bits that can be borrowed for subnet is **2**
- The **maximum** number of bits that can be borrowed for subnet can be any number that **leaves at least 2 bits for hosts**
  - (If only 1 bit for host, a 0-host number or a 1-host number will occur, which may cause a all-0 network address or a all-1 broadcast address.)

# Example Subnets

- With each subnet, you cannot use the first and last address (i.e. the network and the broadcast address).
- A **class B** network has 16 bits in the host field. Therefore **up to 14 bits** can be borrowed to create subnets.
- A **class C** network has only 8 bits in the host field. Therefore, only **up to 6 bits** can be borrowed to create subnets.

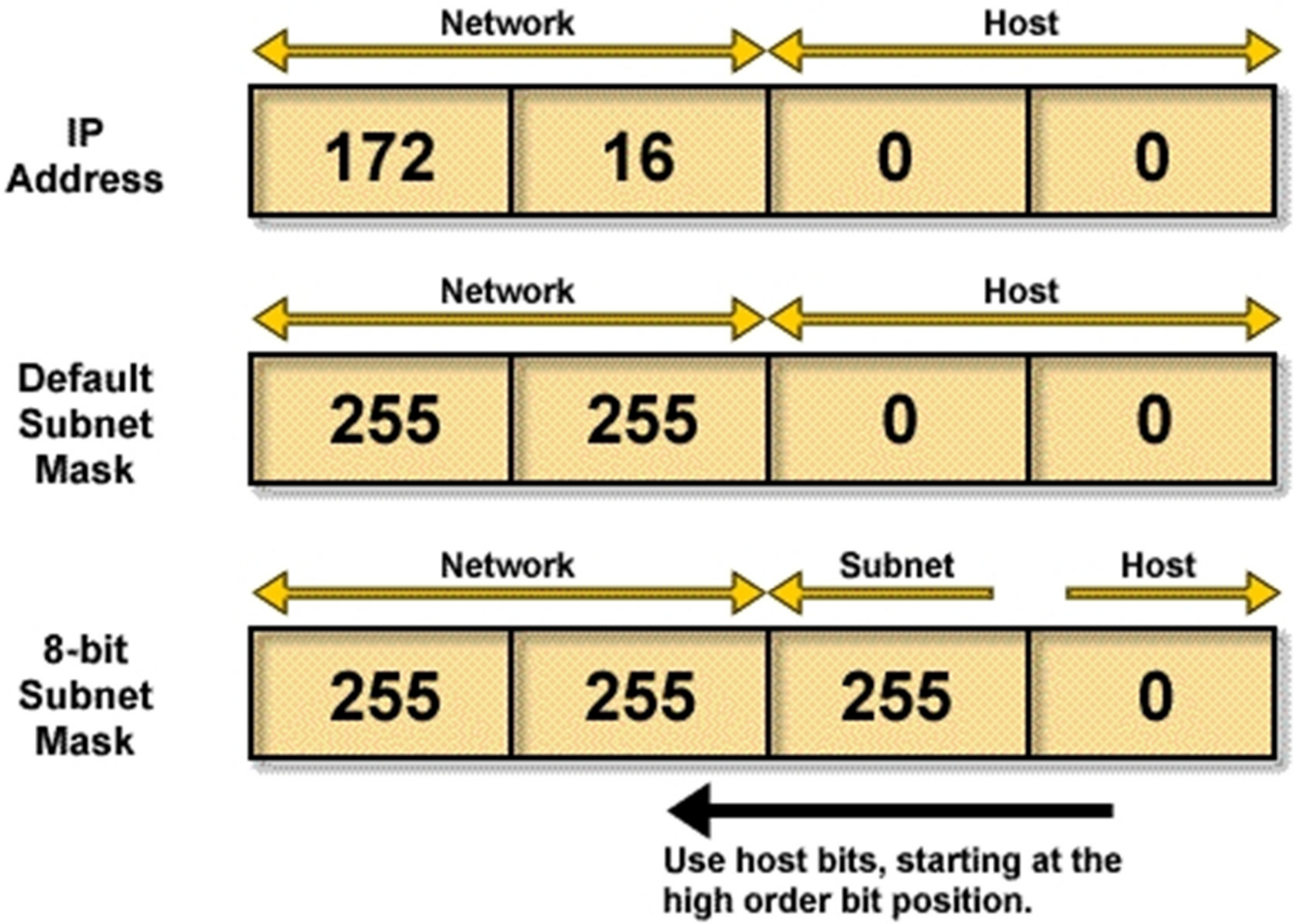
# Subnet Mask

- Once a packet has arrived at an organization's gateway with its unique network ID, it can be routed within the organization's internal routers using the subnet ID, which is found by a subnet mask.
- The subnet mask identifies which part of an IP address is the network address (net-ID), which part is the subnet ID, and which part is the host ID.
- **A subnet mask is 32 bits long**.
- *It contains all 1s in the network portion **and** the subnet portion, and contains all 0s in the host portion.*

# Subnet Mask Examples

- By default, if no bits are borrowed (i.e. no subnet), the subnet mask for a class "B" network would be 255.255.0.0
- However, if 8 bits are borrowed to form subnets, the subnet mask for the same class "B" network would be 255.255.255.0
- All networks have **default subnet masks** (for no subnet).
  - E.g. For the network, 172.16.0.0, the default subnet mask is 255.255.0.0

# Subnet Mask

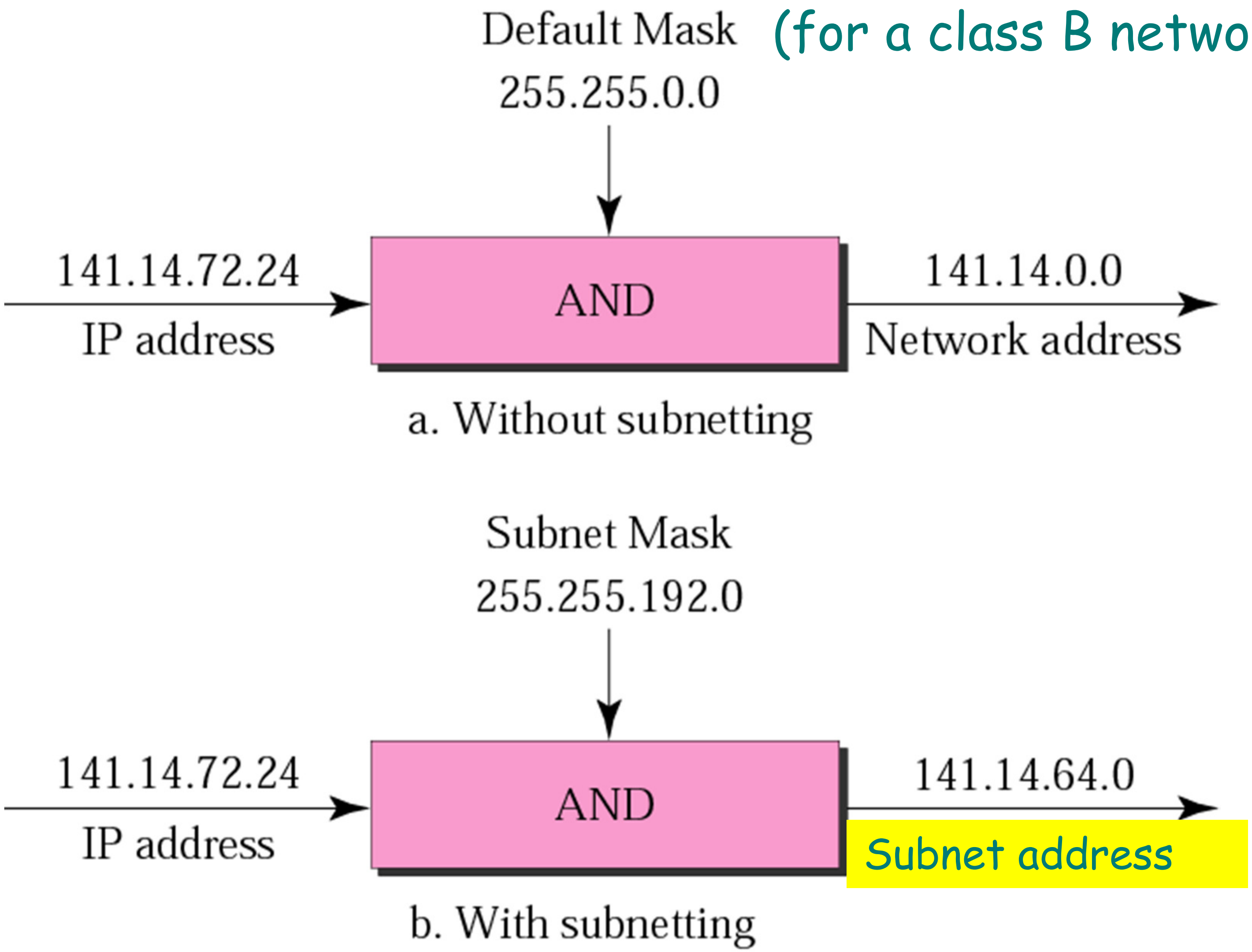

Network
Host
IP Address
172
16
0
0
Network
Host
Default Subnet Mask
255
255
0
0
Network
Subnet
Host
8-bit Subnet Mask
255
255
255
0
Use host bits, starting at the high order bit position.

# Use of Subnet Mask

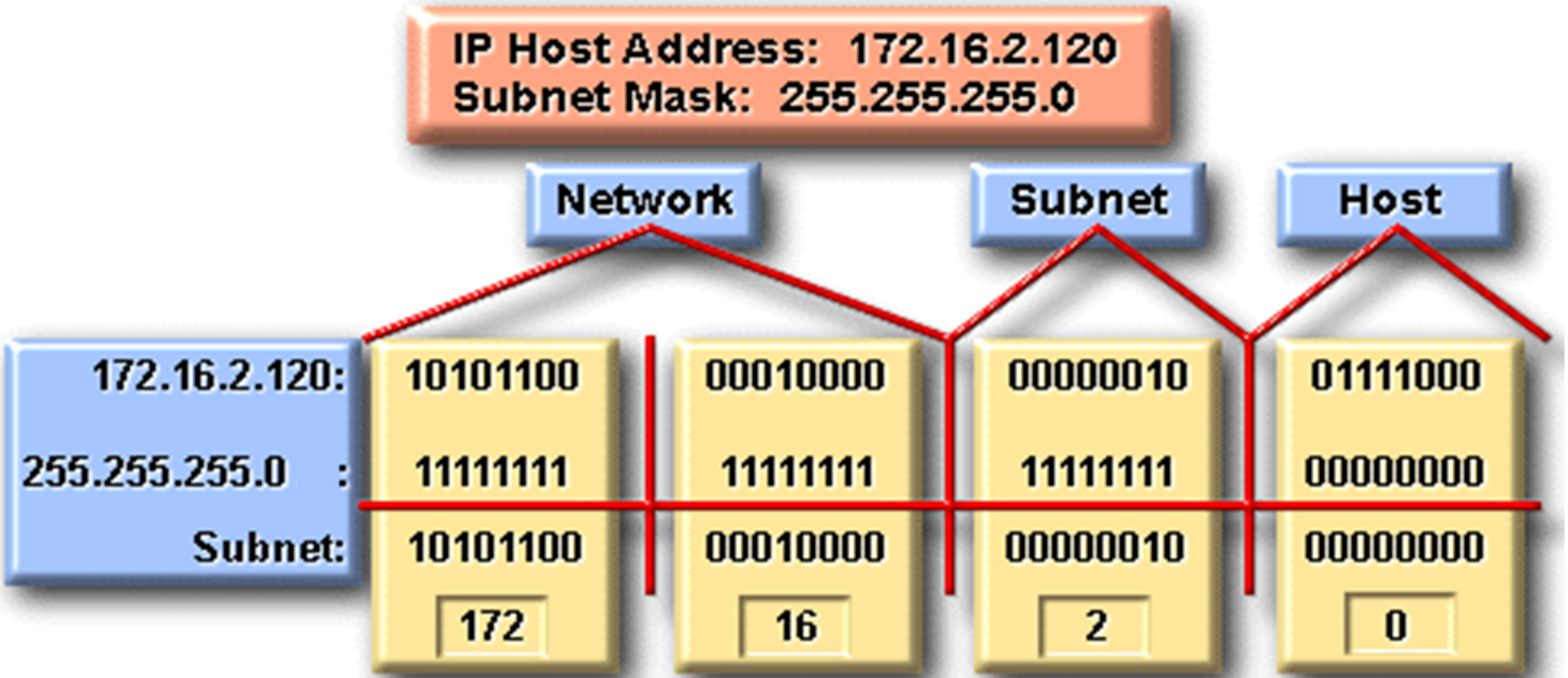
- In order to find the address of a subnet, a router must take the incoming IP address and the subnet mask, and then apply the **logical "AND" operation** between their binary forms.
- The resulting number is the network or subnet address.

# 4) Default mask and subnet mask

(for a class B network)

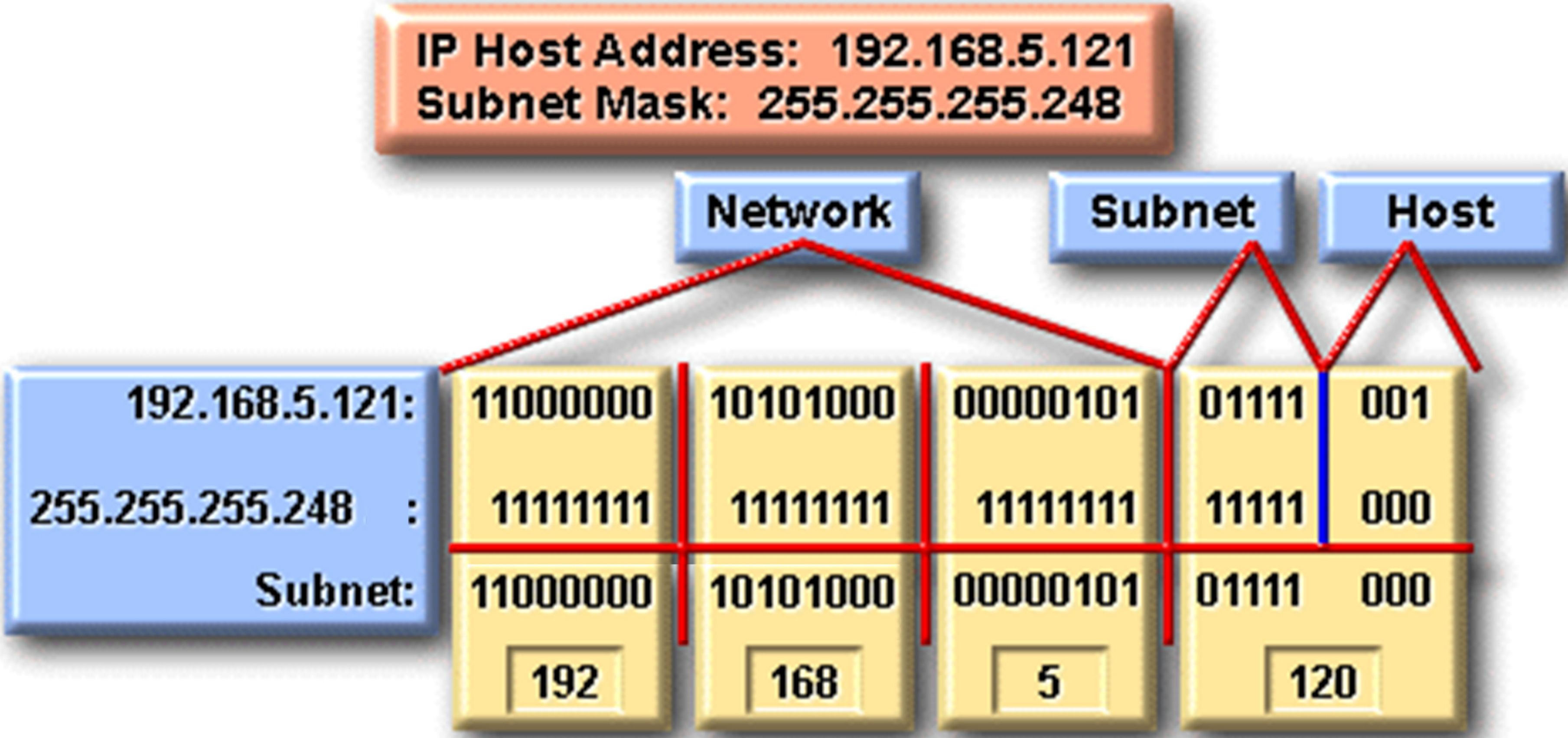


# Class B Subnet Planning Example




- Subnet Address = 172.16.2.0
- Host Addresses = 172.16.2.1 - 172.16.2.254
- Broadcast Address = 172.16.2.255
- Eight bits of subnetting

# Class C Subnet Planning Example




- Subnet Address = 192.168.5.120
- Host Addresses = 192.168.5.121 - 192.168.5.126
- Broadcast Address = 192.168.5.127
- Five bits of subnetting

# Consider a Class B network, 16 bits are used for network ID, and the remaining 16 bits are used for subnet and host ID:

| #bits borrow | subnet mask |
|---|---|
| 0 | 255.255.0.0 |
| 1 | n/a *(min. 2 bits)* |
| 2 | 255.255.192.0 |
| 4 | 255.255.240.0 |
| 6 | 255.255.252.0 |
| 8 | 255.255.255.0 |
| 14 | 255.255.255.252 |
| 15 | n/a *(at least 2 bits left for host id)* |
| 16 | n/a (not applicable) |

*In each subnet, the total number of hosts is **2 less than** the maximum number of possible host IDs.*

# Finding the Subnet Address

## Straight Method

Use binary notation for both the address and the mask and then apply the AND operation to find the subnet address

# *Example 1*

What is the subnet 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 1111**0000** **00000000**

11001000 00101101 0010**0000** **00000000**

The subnet address is **200.45.32.0**.

# Short-Cut Method

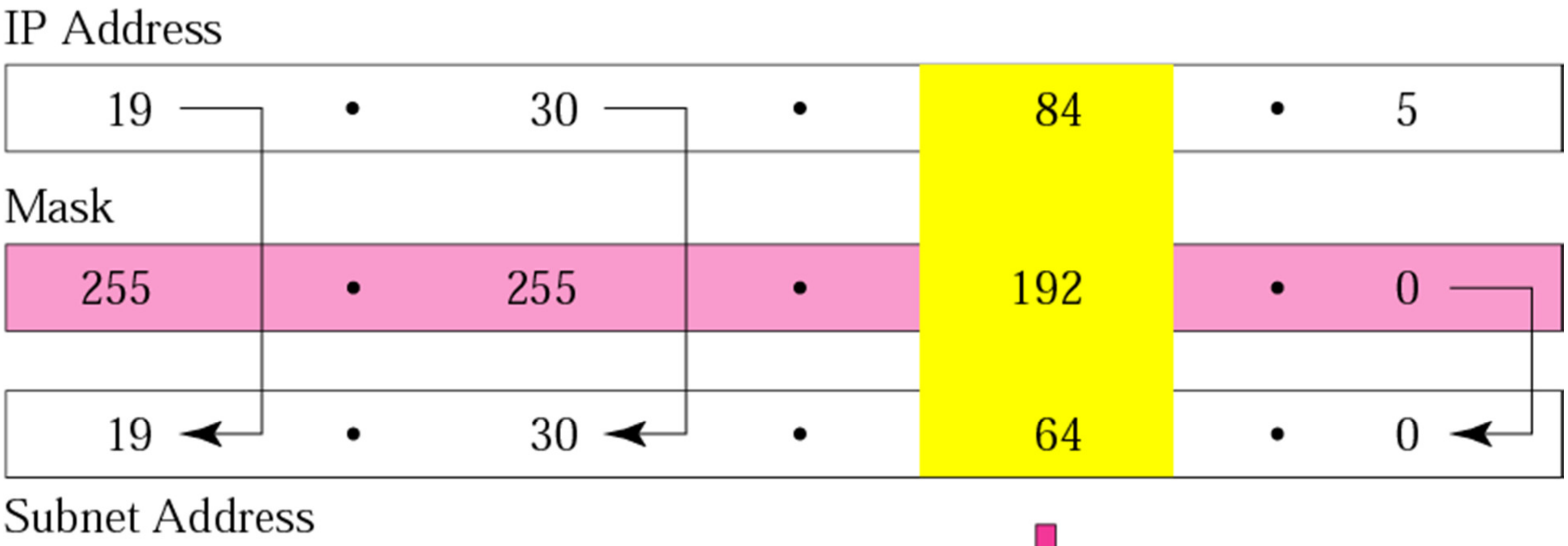
** If the byte in the mask is 255, copy the byte in the address.

** If the byte in the mask is 0, replace the byte in the address with 0.

** If the byte in the mask is neither 255 nor 0, we write the mask and the address in binary and apply the AND operation.

# Example 2

What is the subnet address if the destination address is 19.30.80.5 and the mask is 255.255.192.0?




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 84 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| 192 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

## *Example 3*

A company is granted the site (network) address 201.70.64.0 (class C). The company needs six subnets. Design the subnets.

## *Solution*

The number of 1s in the default mask is 24 (class C).

The company needs six subnets. This number 6 is not a power of 2. The next number that is a power of 2 is 8 ($2^3$). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3).

The total number of 0s is 5 (32 – 27). The mask is

# *E.g. 3 Solution (Continued)*

**11111111 11111111 11111111 111**00000

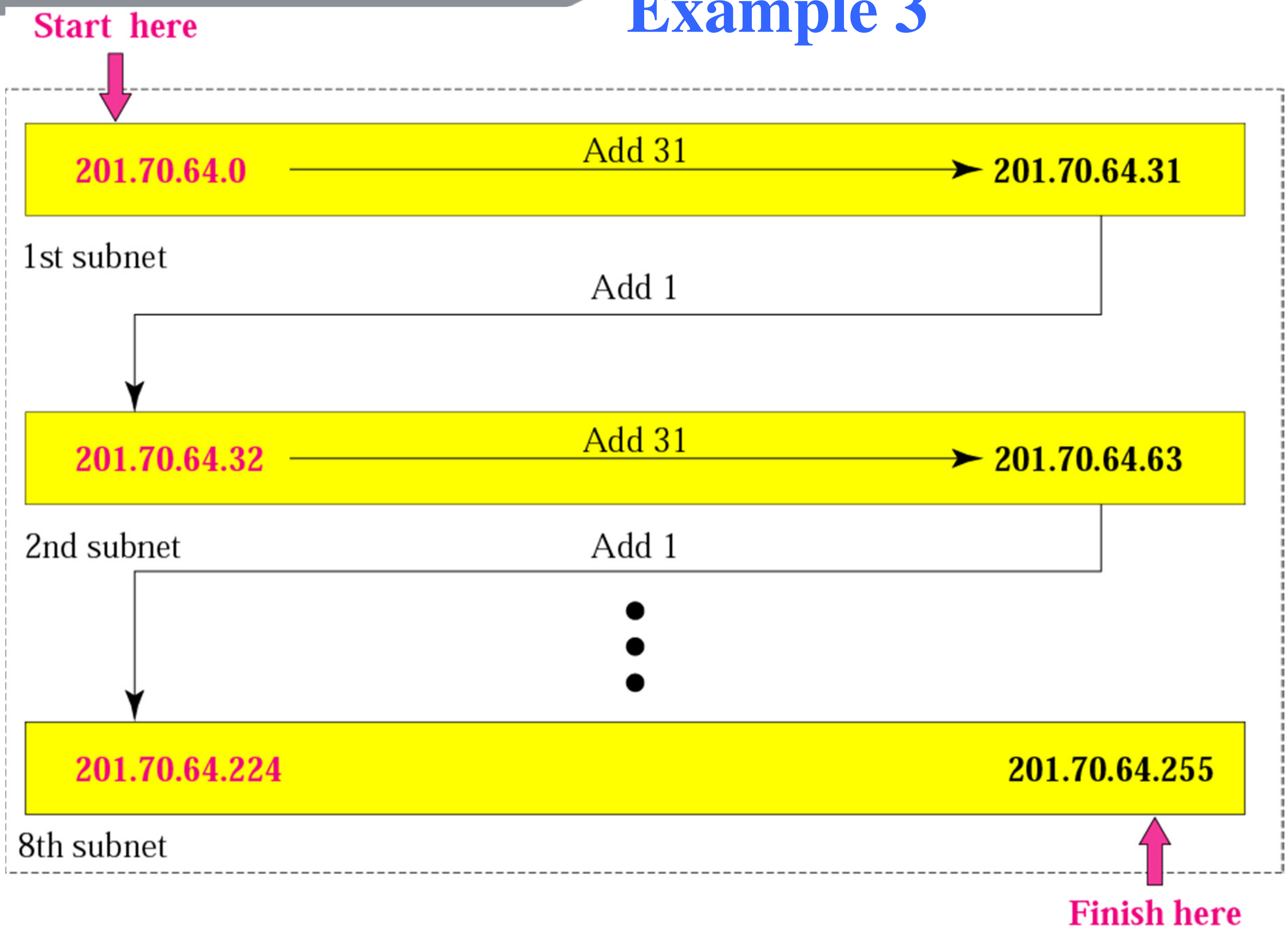
or **255.255.255.224**

The number of subnets is 8.

The number of addresses in each subnet is $2^5$ (5 is the number of 0s) or 32 ***(but only 30 are host addresses).***

See next slide

# Example 3




**Usually the first and the last subnets are not used**

# Summary

- IPv4 Address – 32 bits
  - Classful: 5 classes A to E (phase out)
  - Classless: \n (currently use)
  - IPv6: 128 bits (long term solution)
- Network/Address Mask
  - Use logical "AND" to find the network address
- Subnets – smaller networks within the same organization (network)

- Revision Quiz
  - http://highered.mheducation.com/sites/0073376221/student_view0/chapter18/quizzes.html