# Data Communication and Computer Network

## Network Layer - Addressing

# IP Address (IPv4)

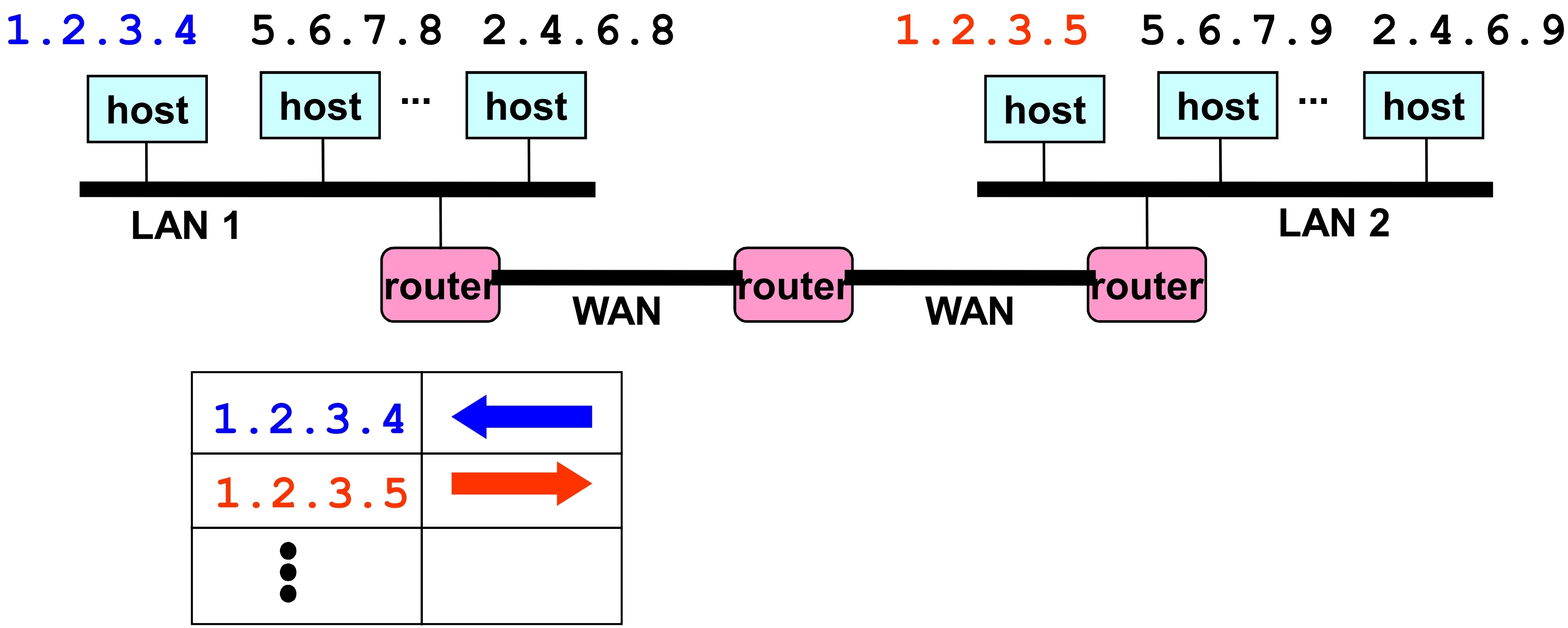
- A unique 32-bit number
- Each connection to a network (interface or network card) on each host connected to the Internet has a globally unique IP address

- Represented in dotted-quad notation W.X.Y.Z

| 12 | 34 | 158 | 5 |
|---|---|---|---|
| 00001100 | 00100010 | 10011110 | 00000101 |

# Scalability Challenge

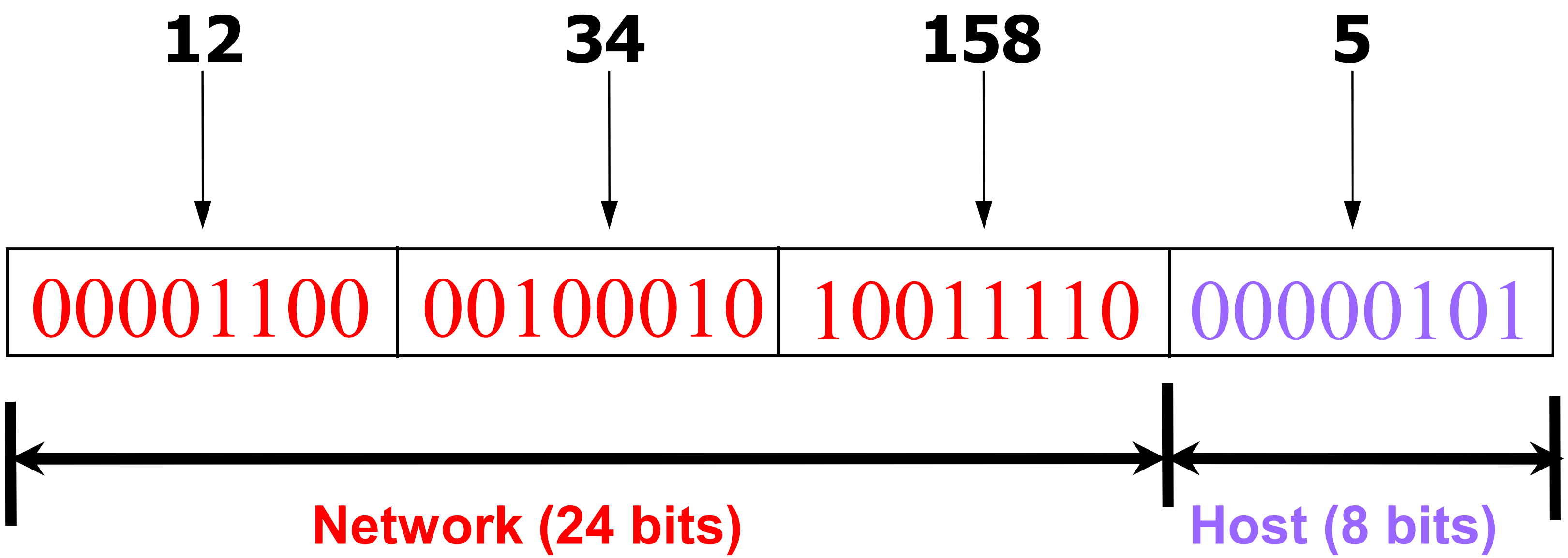
- Suppose hosts had arbitrary IP addresses
  - Then every router would need a lot of information to know how to direct packets towards every host
- Scalability challenge => introduce hierarchy




forwarding table

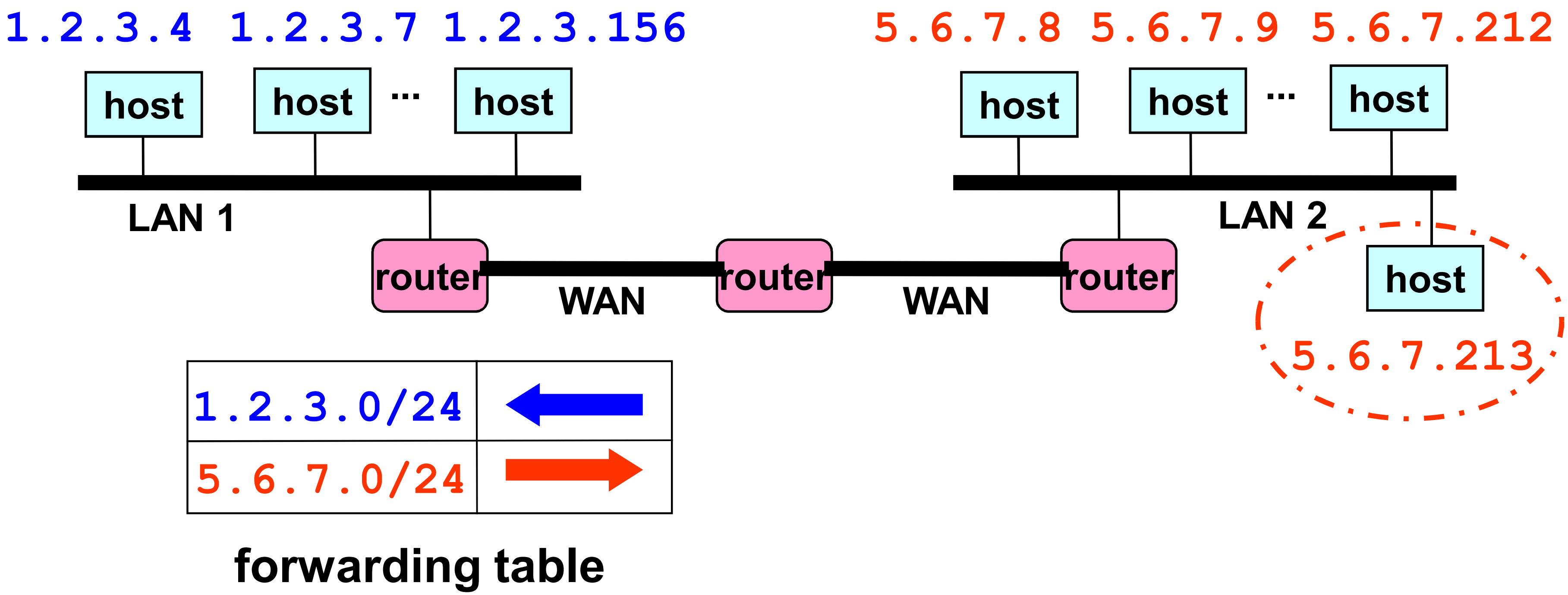
# Hierarchical Addressing: IP Prefixes

- IP address divided into two logical parts:
  - network number
  - host number (used to identify hosts within a network)
- All hosts in a network have same network number



# Easy to Add New Hosts

- No need to update the routers
  - E.g., adding a new host 5.6.7.213 on the right
  - Doesn't require adding a new forwarding-table entry



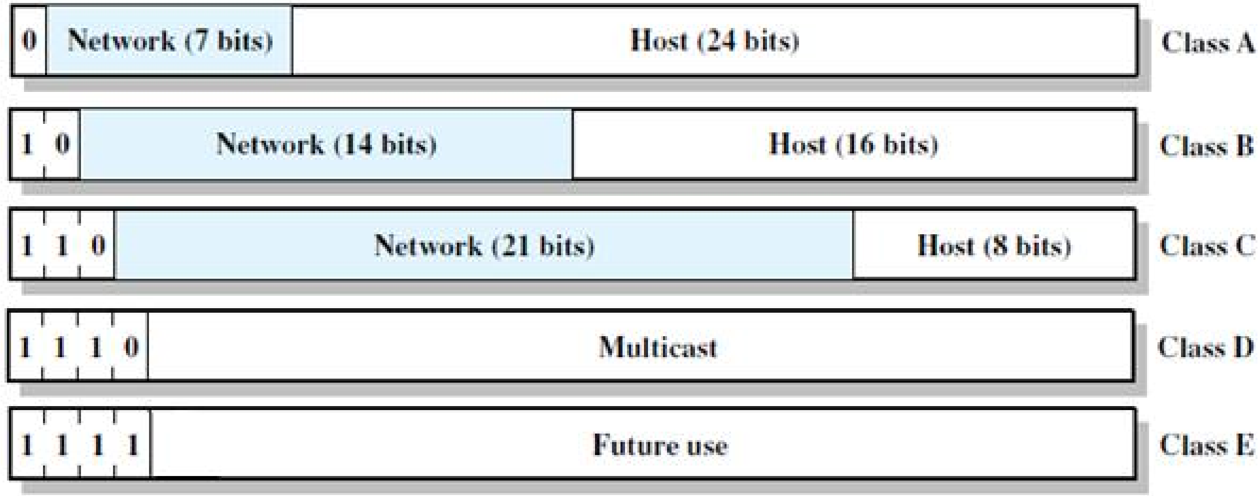
# Classful addressing

# IP address classes

- Partitioning of IP address into network & host part defines IP address classes
- Five defined classes for IP addresses:
  - Class A, Class B, Class C used for unicast
  - Class D for multicast, Class E reserved

| Class | Address Range | High-order bits | Network bits | Host bits |
|---|---|---|---|---|
| A | 0.0.0.0 – 127.255.255.255 | 0 | 7 | 24 |
| B | 128.0.0.0 – 191.255.255.255 | 10 | 14 | 16 |
| C | 192.0.0.0 – 223.255.255.255 | 110 | 21 | 8 |
| D | 224.0.0.0 – 239.255.255.255 | 1110 | | |
| E | 240.0.0.0 – 255.255.255.255 | 1111 | | |

# IP address classes




| *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 Class-A networks are 126 as network addresses with a first octet of 0 (binary 00000000) and 127 (binary 01111111) are reserved
- Actual number of hosts per network = 2^(Number of Host bits) – 2. Why?

# Network and Directed Broadcast addresses

- An IP address with all bits of hostid portion equal to zero (and a network portion) used to refer to the network itself (14.0.0.0)

- Any IP address with all bits of hostid portion equal to 1 (and a network portion) reserved for directed broadcast within the network (14.255.255.255)

- No host in a network should be given a hostid of all 0s or all 1s

# Finding the classes in binary and dotted-decimal notation

| | First byte | Second byte | Third byte | Fourth byte |
|---|---|---|---|---|
| Class A | 0 | | | |
| Class B | 10 | | | |
| Class C | 110 | | | |
| Class D | 1110 | | | |
| Class E | 1111 | | | |

a. Binary notation

| | 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

**Find the class of each address.**

a) 00000001 00001011 00001011 11101111
b) 11000001 10000011 00011011 11111111
c) c. 14.23.120.8
d) d. 252.5.15.111

**Solution**

a) The first bit is 0. This is a class A address.
b) The first 2 bits are 1; the third bit is 0. This is a class C address.
c) The first byte is 14; the class is A.
d) The first byte is 252; the class is E.

# Some special IP addresses

- Not all possible 32-bit addresses have been assigned to classes

- Loopback address
  - The network prefix 127.0.0.0 (a value from the class A range) reserved for loopback
  - Used to test TCP / IP and for inter-process communication **within a host**

- All 32 bits zero (0.0.0.0)→ this host on this network

- All 32 bits one (255.255.255.255)→ limited broadcast on this (local) network

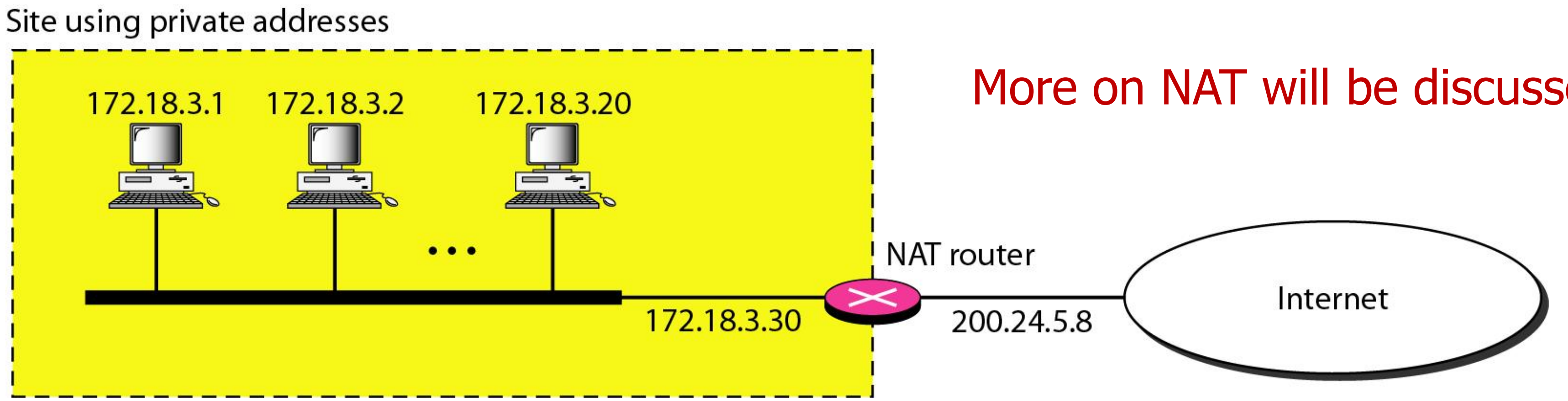
# Limited and Directed Broadcast addresses

- Broadcast traffic is sent to all stations on a LAN.
- There are two types of IPv4 broadcast addresses: limited broadcast and directed broadcast.
- The limited broadcast address is 255.255.255.255.
  - It is "limited" because it is never forwarded across a router, unlike a directed broadcast.
- The directed (also called net-directed) broadcast address of the 192.0.2.0/24 network is 192.0.2.255 (the host portion of the address is all "1"s in binary, or 255).
  - It is called "directed" broadcast, because traffic to these addresses may be sent from remote networks (it may be "directed").

# Private IP Address

- To separate the addresses used inside the home or business and the ones used for the Internet, the Internet authorities have reserved three sets of addresses as private addresses

| Class | Private IP Addresses (RFC 1918) | Number of Networks | Hosts per Network | Total Hosts |
|---|---|---|---|---|
| A | 10.0.0.0 to 10.255.255.255 | 1 | 16,777,214 | 16,777,214 |
| B | 172.16.0.0 to 172.31.255.255 | 16 | 65,534 | 1,048,544 |
| C | 192.168.0.0 to 192.168.255.255 | 256 | 254 | 65,024 |




More on NAT will be discussed later

# Internet Addressing Authority

- To ensure that the address assigned to a network is globally unique
- A central organization that sets policy and assigns values for addresses, constants used in protocols
  - Originally Internet Assigned Number Authority (IANA)
  - Later, the Internet Corporation for Assigned Names and Numbers (ICANN)
- To connect its network to the Internet, a firm contacts an Internet Service Provider
  - ISPs assigned blocks of IP addresses by the central authorities

## Problems with IP address classes

- Main problem with classful addressing:
  - Fast depletion of available network addresses
  - Wastage of IP addresses (organizations may not need a full class)
  - Class B addresses getting most rapidly depleted
- Cause: exponential growth in number of networks over the years
- Also, routing tables become too large
- <u>Classful addressing, which is almost obsolete, is replaced with classless addressing.</u>

# Mechanisms to conserve IP address prefixes

## IP Subnets

- Subnet – a subset of a class A, B or C network
- Host portion of IP address partitioned into **subnet part** and **host part**
- Uses a 32-bit subnet mask to specify the division
  - In binary, the mask is a series of contiguous 1's (identifies network portion) followed by a series of contiguous 0's (identifies host portion)
    - ✓ Eg 11111111 11111111 11111111 11000000
    - ✓ Equivalent dotted decimal 255.255.255.192
- Allows more efficient address space allocation (close to what is necessary)
  - less wastage of IP addresses

# Space allocation - an example

- 4 organizations, each apply for 50 IP addresses
- Instead of assigning one class C address to each, only one class C address 200.10.12.0 assigned
  - Network divided into four subnets
  - Each organization needs 6-bit host numbers
  - 2 msb's of the host number used to distinguish among the four subnets
  - Subnet mask used: 255.255.255.192

# Space allocation - an example

- 4 organizations, each apply for 50 IP addresses
- Instead of assigning one class C address to each, only one class C address (lets assume 200.10.12.0) assigned
- Each organization needs 6-bit host numbers
- 2 msb's of the host number (the 8 lsb's in a class C address) used to distinguish among subnets

| Last byte | Host num range | Network addr | Subnet mask |
|---|---|---|---|
| 00 000000 (0) | Org 1: 0-63 | 200.10.12.0 | 255.255.255.192 |
| 01 000000 (64) | Org 2: 64-127 | 200.10.12.64 | 255.255.255.192 |
| 10 000000 (128) | Org 3:128-191 | 200.10.12.128 | 255.255.255.192 |
| 11 000000 (192) | Org 4:192-255 | 200.10.12.192 | 255.255.255.192 |

# Space allocation - an example (2)

- 3 organizations, in which Org-1 applied 115 address, Org-2 and Org-3 applied 55 address
- Instead of assigning one class C address to each, only one class C address (lets assume 200.10.12.0) assigned

| Last byte | Host num range | Network addr | Subnet mask |
|---|---|---|---|
| **0 0000000 (0)** | **Org 1: 0-127** | **200.10.12.0** | **255.255.255.128** |
| **10 000000 (128)** | **Org 2:128-191** | **200.10.12.128** | **255.255.255.192** |
| **11 000000 (192)** | **Org 3:192-255** | **200.10.12.192** | **255.255.255.192** |

# More about Subnet mask

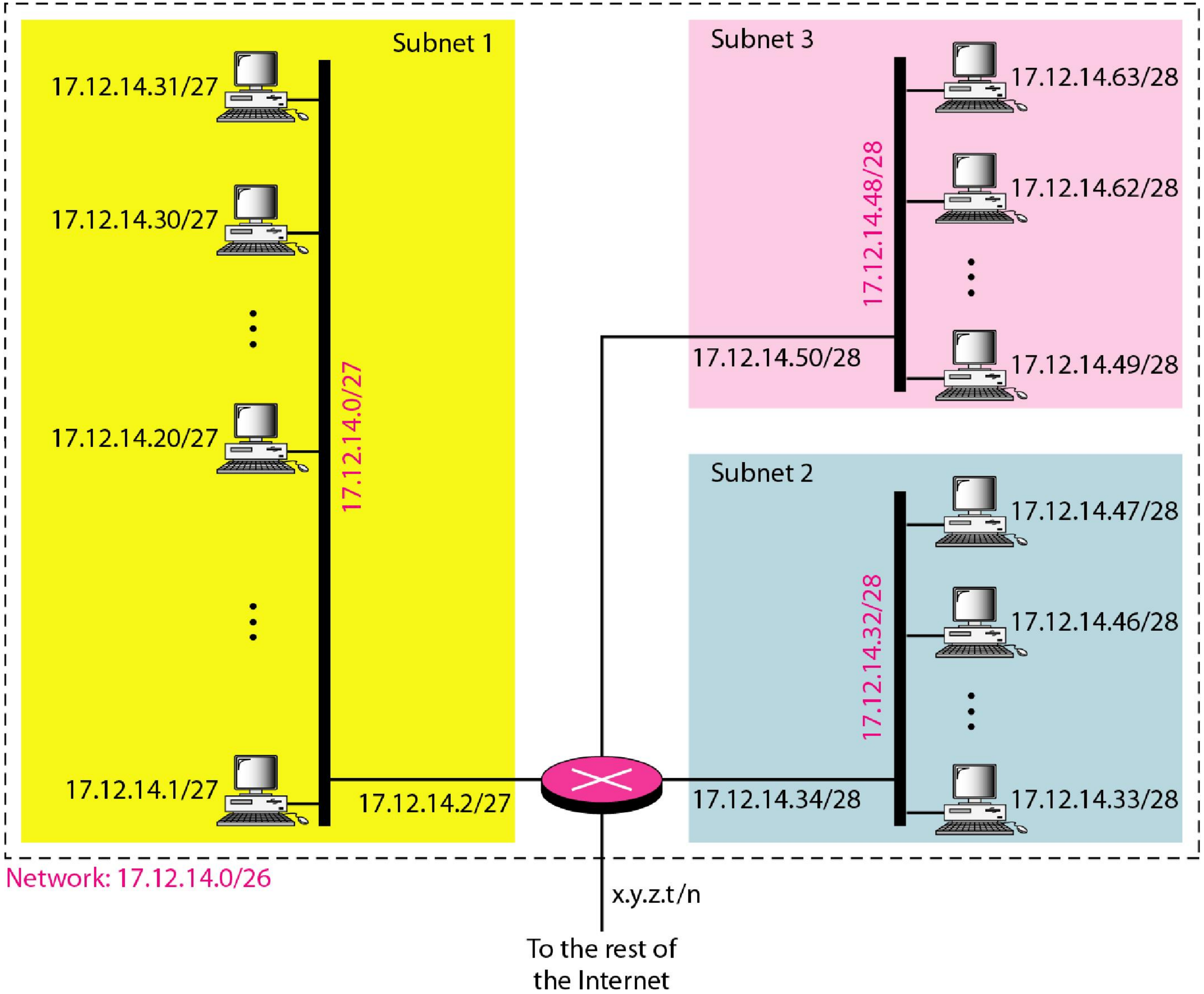
- A subnet mask has 1s for all bits that correspond to the network portion of an IP address within that network
  - The standard does NOT restrict subnet masks to select contiguous bits of the address, however it is recommended that sites use contiguous bits 1

- Bitwise AND of the IP address of a host and subnet mask of the network should give the network number of the network in which the host is

# Use of subnet mask

- To check if two IP addresses belong to the same subnet: the bit-wise AND of the two addresses with the netmask must be the same
- Network mask 255.255.255.240 is applied to a class C network 195.16.100.0
  - Mask = 11111111 11111111 11111111 11110000
  - Address of 1$^{st}$ host on this subnet = 195.16.100.1
  - Address of last host on this network = 195.16.100.14
  - Addresses 195.16.100.3 and 195.16.100.12 are in the same subnet
  - Addresses 195.16.100.3 and 195.16.100.19 are in different subnets

# Configuration and addresses in a subnetted network



# Natural Masks & Special IP addresses

- Class A, B, C addresses each have natural masks
  - Class A : natural mask is 255.0.0.0
  - Class B : natural mask is 255.255.0.0
  - Class C : natural mask is 255.255.255.0

- Classful addresses are self-identifying, but use of subnets make this property invalid
  - Routing algorithms become more complex

# Routing in the presence of subnets

- A conventional routing table contains entries like
  - `<network address, next hop address>`
  - First 3 bits of an IP address informs address class
- In presence of subnets
  - Not possible to know which bits corresponds to the network portion, from the address alone
  - Routing table entries of the form

`<Network-address, Subnet-mask, Next-hop-address>`

# Forwarding example with subnet masks

Consider the following routing table:

| SubnetNumber | SubnetMask | NextHop |
|---|---|---|
| 128.96.170.0 | 255.255.254.0 | Interface 0 |
| 128.96.168.0 | 255.255.254.0 | Interface 1 |
| 128.96.166.0 | 255.255.254.0 | R2 |
| 128.96.164.0 | 255.255.252.0 | R3 |
| Default | | R4 |

Packets with the following destination IP addresses will be sent to which interfaces ?

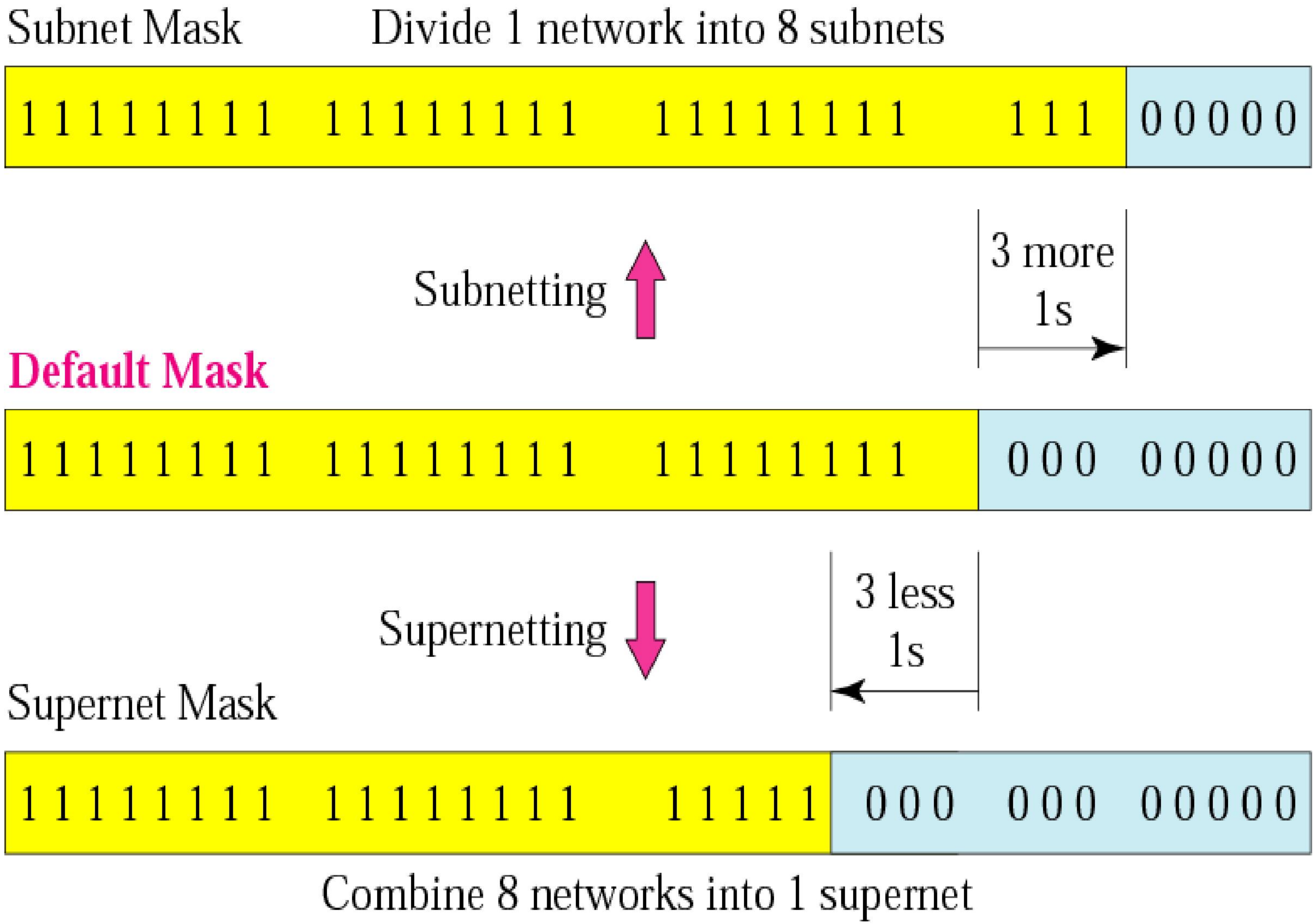
*a.* 128.96.171.92
*b.* 128.96.167.151
*c.* 128.96.163.151
*d.* 252.5.15.111

*a. Interface 0*
*b. R2*
*c. R4*
*d. R4*

# Supernetting

- Motivation
  - By 1993, apparent that subnetting (used since 1980s) was not enough to prevent exhaustion of addresses
  - Class B addresses were getting exhausted very quickly
- Supernetting: complementary to subnetting
  - Subnetting aims to use a single IP network prefix for multiple physical networks at a given organization
  - Supernetting allows the addresses assigned to a single organization to span multiple classed prefixes
- Example: If an organization wants a class B address, assign it a block of 256 class C addresses instead of a single class B address

# Subnet mask vs supernet mask



# Effect of subnets and supernets on routing

- Subnetting and supernetting help to conserve address space, but increases the amount of information that routers need to store and exchange

- Classless Inter-Domain Routing (CIDR) allows more efficient use of address space as well as solves this problem

# Classless Inter-Domain Routing

# CIDR

# Number of addresses in a block

- Using CIDR, there is only one condition on the number of addresses in a block:
  - it must be a power of 2 (2, 4, 8, . . .)

- Number of IP addresses allocated must be as close to the requirement as possible

# Classless Inter-Domain Routing (CIDR)

**Use two 32-bit numbers to represent a network.**
**Network number = IP address + Mask**

**IP Address : 12.4.0.0 IP Mask: 255.254.0.0**

| | | | | |
|---|---|---|---|---|
| **Address** | 00001100 | 00000100 | 00000000 | 00000000 |
| **Mask** | 11111111 | 11111110 | 00000000 | 00000000 |

**← Network Prefix →** **← for hosts →**

**Written as 12.4.0.0/15**

# Combine contiguous networks – an example

- Contiguous networks combined into a larger address block for the purpose of reducing routing table size
- Suppose Company A needs IP for 1000 machines
- Assign 4 *contiguous* Class C address blocks 192.60.128.0, 192.60.129.0, 192.60.130.0, 192.60.131.0 (last 8 bits 0 indicates a network)
- A single supernet defined: 192.60.128.0 / 22
  - Address : 192.60.128.0
  - Netmask: 255.255.252.0 (last 10 bits 0)

# Combine contiguous networks – example (contd.)

- Routing table at all higher level routers:
  - Need only 1 entry for the four class C networks: 192.60.128.0/22
- Routing table at RA distinguishes among nets:
  - 192.60.128.0/24 –> send to router of first net
  - 192.60.129.0/24 –> send to router of second net
  - 192.60.130.0/24 –> send to router of third net
  - 192.60.131.0/24 –> send to router of fourth net
- Possible due to contiguous allocation of IP addr

# Allocation of IP addresses (contd.)

- Allocation of contiguous blocks of IP addresses to geographically close networks preferred
  - Enables maximal use of super-nets to reduce number of entries at higher level routing tables
  - If class C address 192.60.128.0 assigned to a network in India, and 192.60.129.0 assigned to a network in Brazil, no chance of super-netting, routers at all levels need two different entries
  - If contiguous address blocks allocated to networks in India, all routers (at higher levels) upto some router in India can have just 1 entry

# But…problems with CIDR too

- CIDR allows efficient use of the limited address space but makes packet forwarding much harder

- Forwarding table may have many matches
  - E.g., routing table entries for 201.10.0.0/21 and 201.10.6.0/23
  - The destination IP address 201.10.6.17 would match *both* entries

- Routers always do longest prefix match. If multiple entries match, longest match taken
  - 201.10.6.0/23 used even though both match

# CIDR blocks reserved for private networks

- A set of network prefixes reserved for use in private networks
- These reserved prefixes will never be assigned to networks in the global Internet
- Known as private addresses or non-routable addresses

- Example: 10/8, 192.168/16

# References


- *Data Communications & Networking, 5th Edition, Behrouz A. Forouzan*
- *Computer Networks, Andrew S. Tanenbaum and David J. Wetherall*
- *Wikipedia*