Data Communication and Computer Network

Network Layer - Addressing

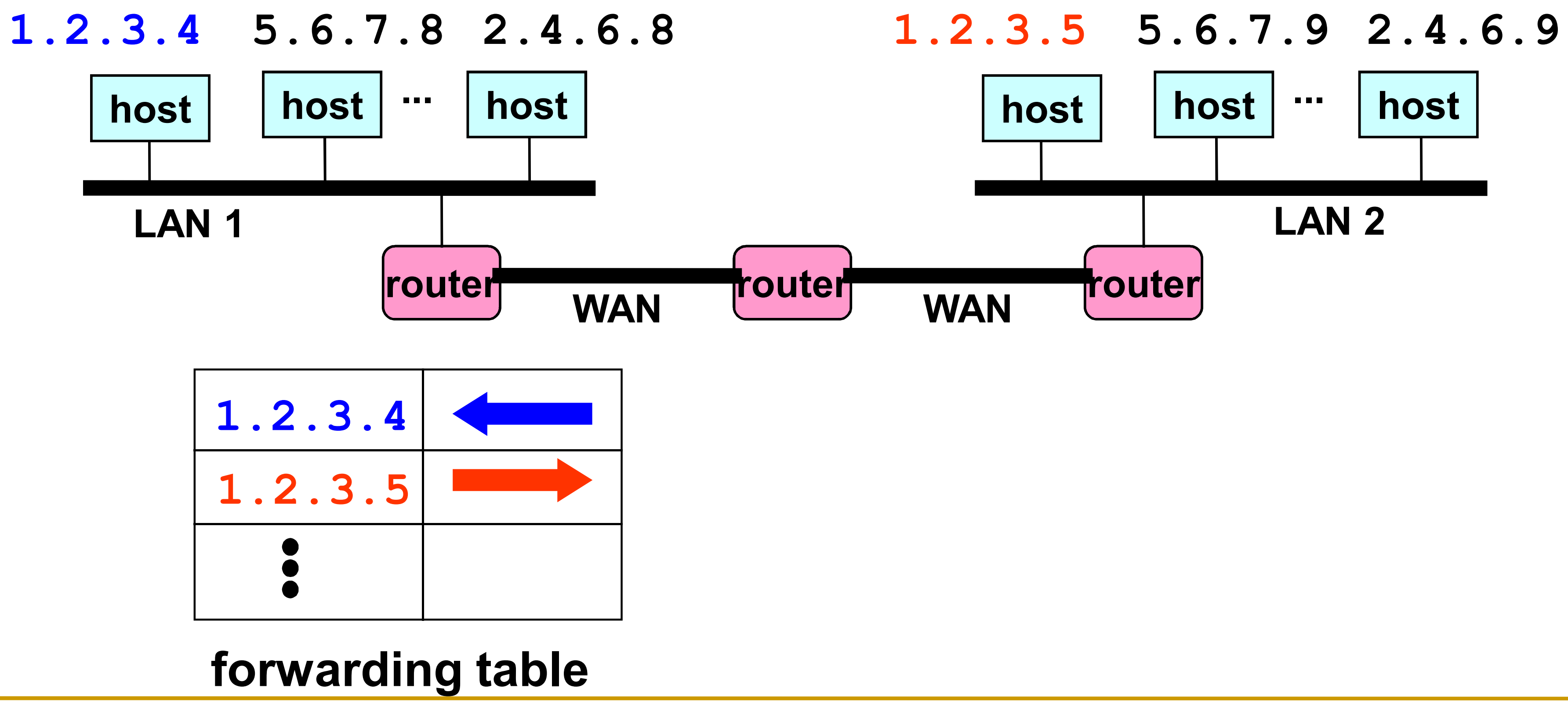
IP Address (IPv4)

- 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

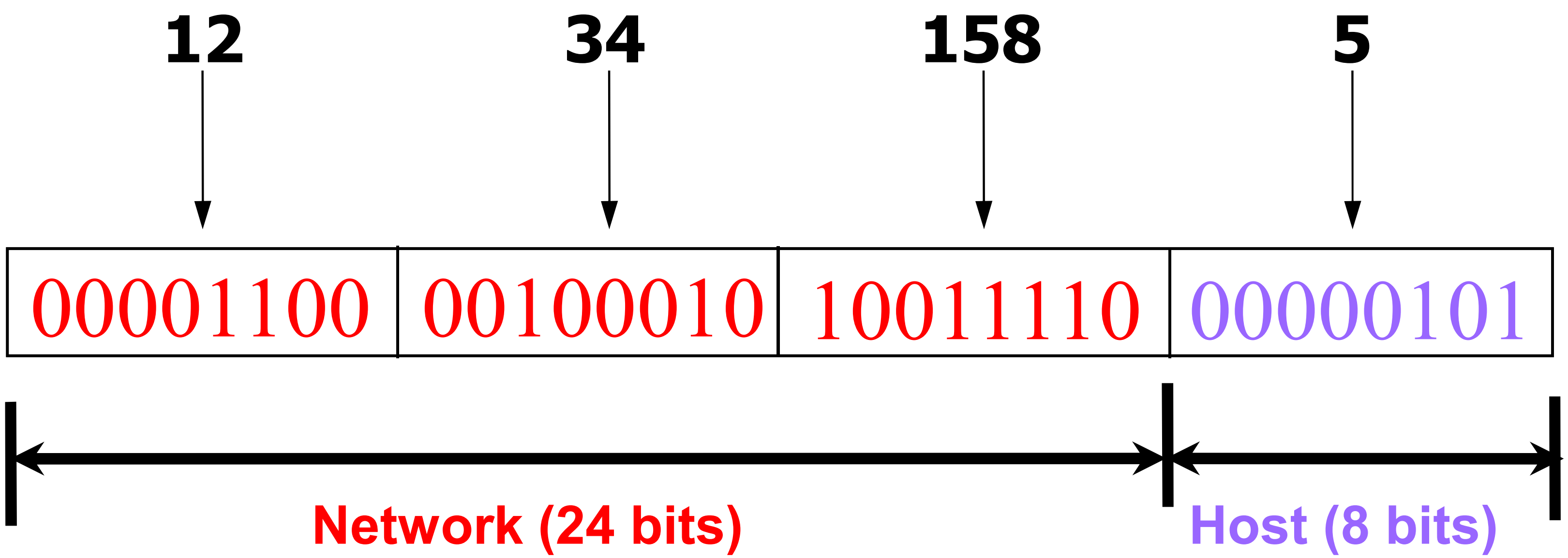
Scalability Challenge

- 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



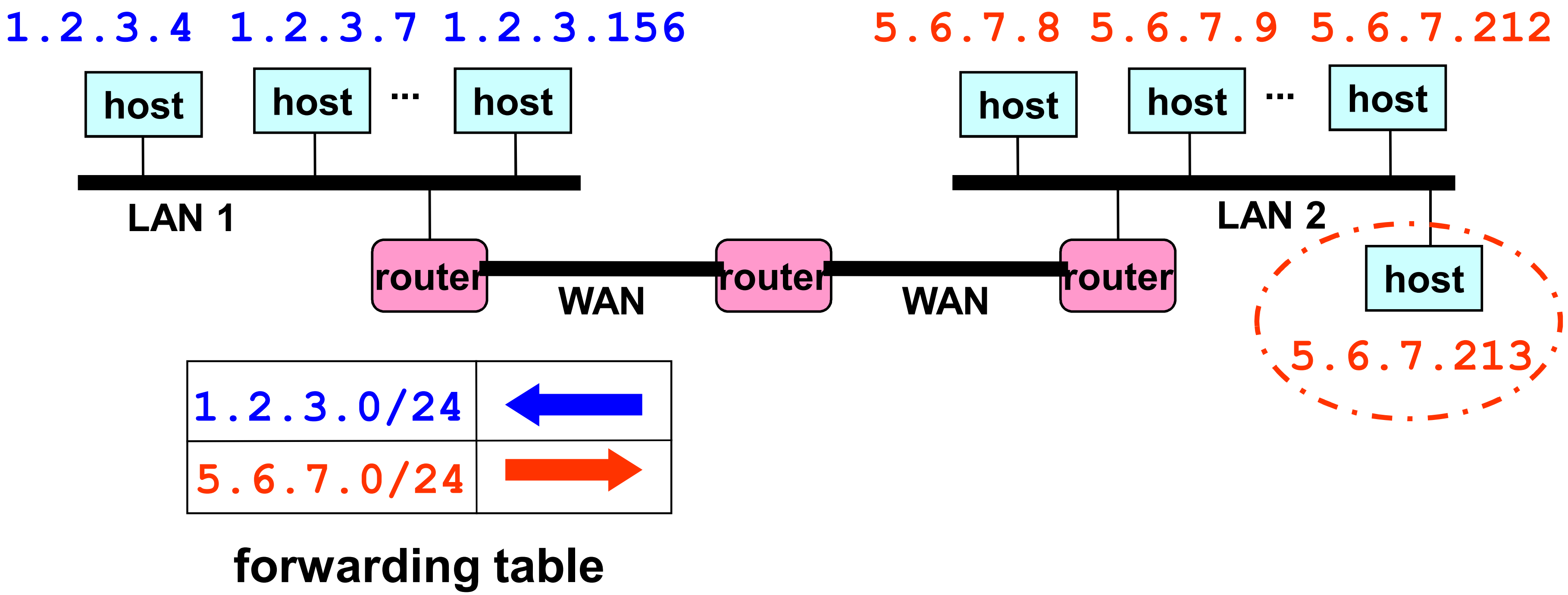
Hierarchical Addressing: IP Prefixes

- 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



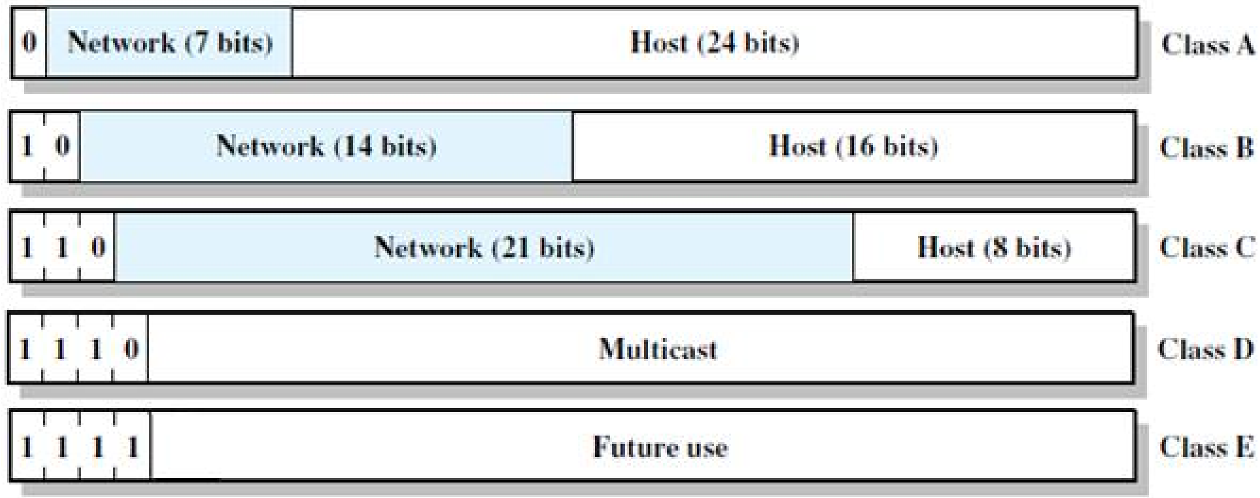
Classful addressing

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

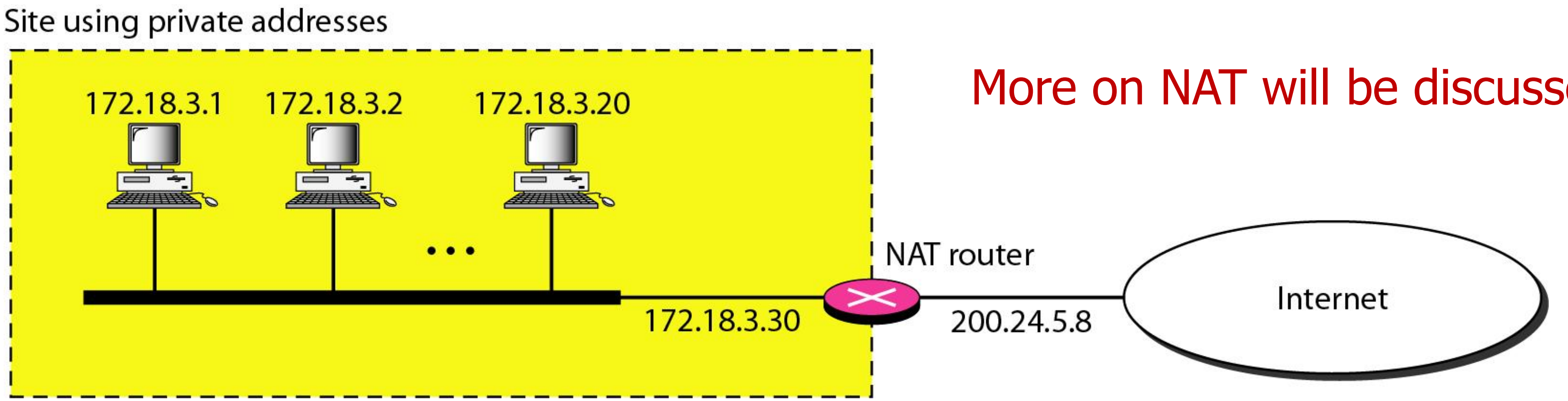
Limited and Directed Broadcast addresses

- 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
- Classful addressing, which is almost obsolete, is replaced with **classless addressing.**

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

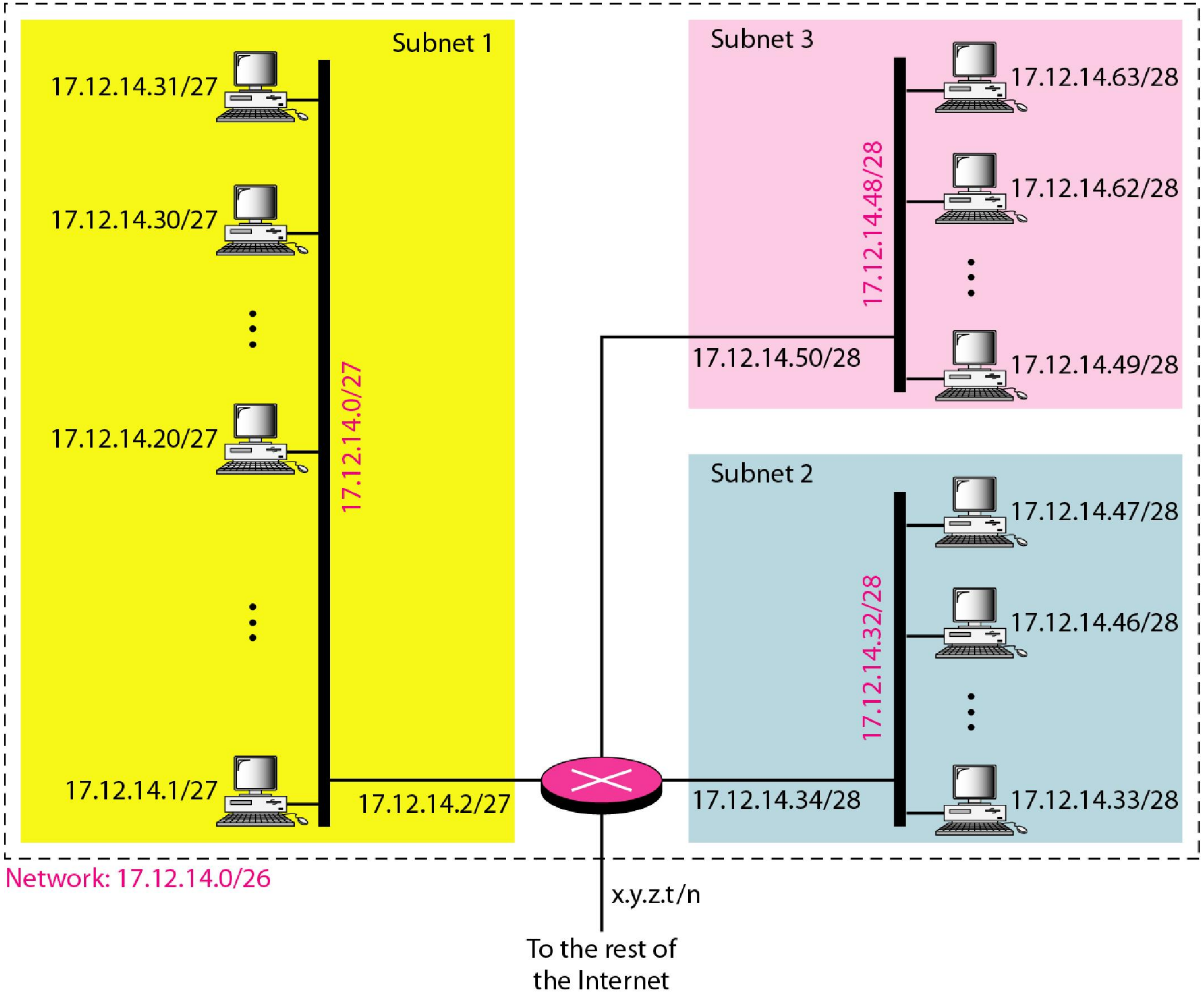
- A subnet mask has 1s for all bits that correspond to the network portion of an IP address within that network
  - The standard does NOT restrict subnet masks to select contiguous bits of the address, however it is recommended that sites use contiguous bits 1

- 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 1st 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



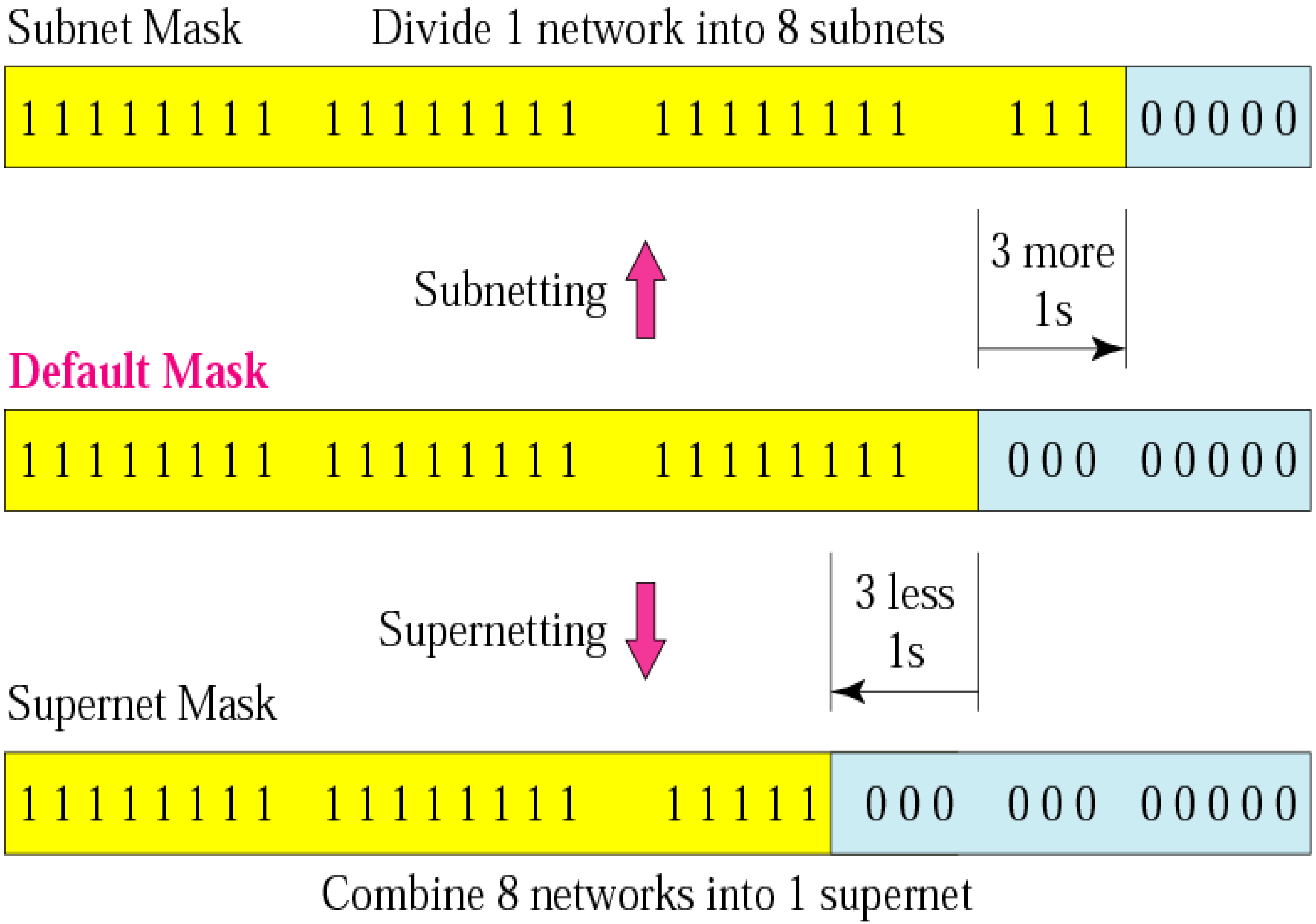
Natural Masks & Special IP addresses

- 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

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*