# Chapter 21
# IP: Internet Addressing

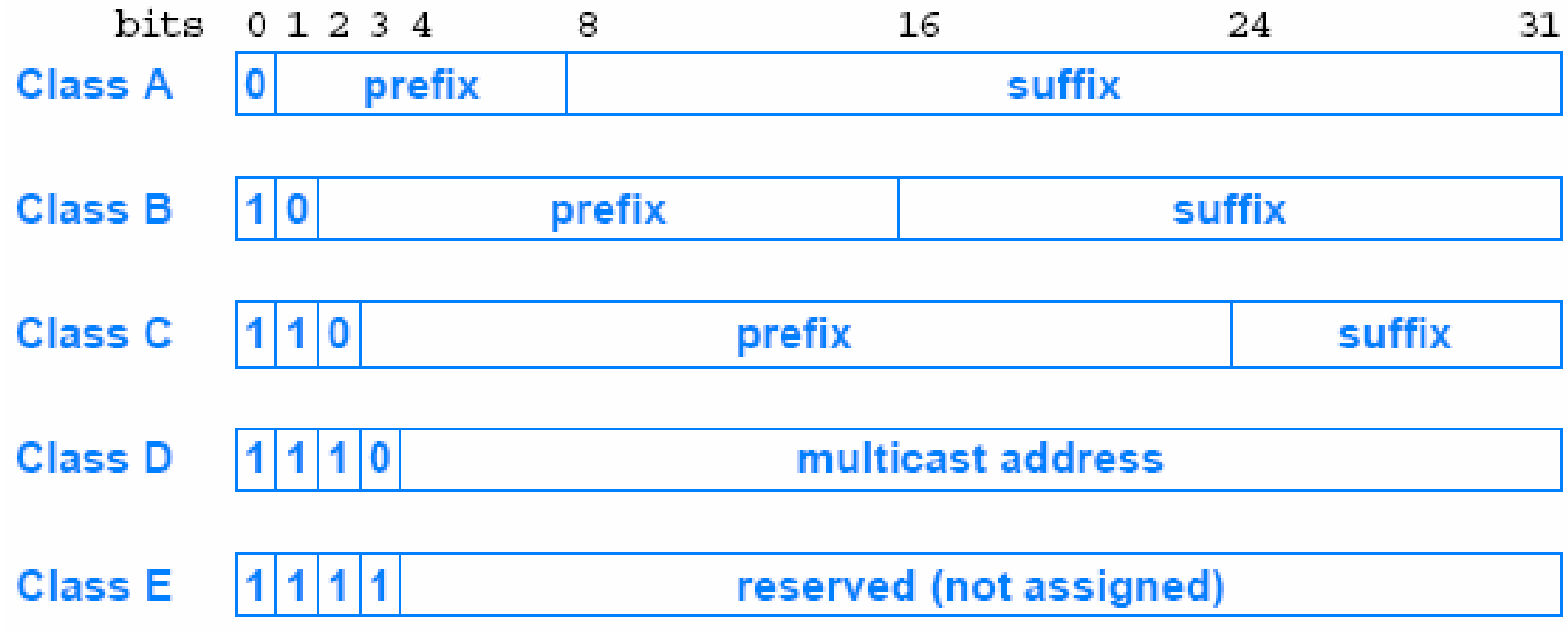
Dr. Natarajan Meghanathan
AssociateProfessor of Computer Science
Jackson State University
E-mail: natarajan.meghanathan@jsums.edu

# IP Address – v4

- Each host connected to the Internet is assigned a 32-bit unique IP address.
- The IP address is hierarchical: comprises of a network part (prefix) and a host part (suffix).
  - Network number (prefix) assignments must be coordinated globally
  - Suffixes are assigned locally (within a network) without global coordination
- How many bits to place in each part of an IP address?
  - The prefix needs sufficient bits to allow a unique network number to be assigned to each physical network in the Internet
  - The suffix needs sufficient bits to permit each computer attached to a network to be assigned a unique suffix
- No simple choice was possible to allocate bits!
  - Choosing a large prefix accommodates many networks; but, limits the size of each network
  - Choosing a large suffix means each physical network can contain many computers; but, limits the total number of networks

# Classes of IP Address

- Internet contains a few large physical networks and many small networks
- The original classful IP addressing divided the IP address space into three (3) primary classes
  - each class has a different size prefix and suffix
- The first four bits of an IP address determined the class to which the address belonged



# Dotted Decimal Notation

- Dotted decimal notation is a syntactic form that IP software uses to express the 32-bit number binary values.
- Each 8-bit section of the 32-bit number is represented as a decimal value and periods are used to separate the sections.
- The first byte of the address in dotted decimal notation can be used to identify the class of an address

| 32-bit Binary Number | Equivalent Dotted Decimal |
|---|---|
| 10000001 00110100 00000110 00000000 | 129 . 52 . 6 . 0 |
| 11000000 00000101 00110000 00000011 | 192 . 5 . 48 . 3 |
| 00001010 00000010 00000000 00100101 | 10 . 2 . 0 . 37 |
| 10000000 00001010 00000010 00000011 | 128 . 10 . 2 . 3 |
| 10000000 10000000 11111111 00000000 | 128 . 128 . 255 . 0 |

# Range of IP Addresses and Network Prefixes for Different Classes

| Class | Range of Integer Values for the 1st 8 bits |
|---|---|
| A | 1 through 126 |
| B | 128 through 191 |
| C | 192 through 223 |
| D | 224 through 239 |
| E | 240 through 255 |

| Address Class | Bits in Network Part | Max. # Networks | Bits in Host Part | Max. # Hosts per Network |
|---|---|---|---|---|
| A | 7 | 126 | 24 | $2^{24} - 2$ |
| B | 14 | $2^{14}$ | 16 | $2^{16} - 2$ |
| C | 21 | $2^{21}$ | 8 | $2^{8} - 2$ |

# Special IP addresses

- IP defines a set of addresses that are reserved and cannot be assigned to hosts.

**Network address**

- Denotes the prefix assigned to a network.
- IP reserves the host suffix containing all 0s for the network address.
- Thus, a network address cannot be used as the destination address of a packet as it does not refer to any host attached to the network.

- Example: The address 128.11.0.0/16 denotes a network with prefix assigned as 128.11.

# Directed Broadcast Address

- **Broadcast** – Sending a copy of a packet to all the hosts on a network.
- If the network hardware has the broadcast capability (configured to a broadcast address) then, a single transmission of the packet with the broadcast address will result in the packet reaching all the hosts on the network.
- If the network hardware does not have the broadcast capability, then separate copies of the packet must be sent to each host on the network.

- **Directed broadcasting** - A single copy of the packet travels across the internet until it reaches the targeted physical network and is then delivered to all hosts on the network.
- Directed broadcast addressing is used to broadcast a packet on a targeted physical network.
- To support, broadcasting to all hosts in a network, the host suffix that contains all 1s is reserved and cannot be used as part of a host IP address.

# Limited Broadcast/ This Computer Address

- Limited broadcast – the broadcast done on the local physical network.
- IP reserves the address consisting of all 1 bits to be used as the limited broadcast address.
- Limited broadcast is used during system startup when a computer does not know its network number.

- **This computer address** – used during boot up.
- The computer does not know its IP address but needs to communicate with a server machine that assigns the IP address. The communication protocol uses IP that needs each packet to have the address of the source and the destination.
- To overcome the above requirement of address specification, the computer can supply a dummy value of an address containing all 0s to mean “this computer”. Consequently, an IP address containing all 0s is reserved.

# Loopback Address

- Loopback address – used to test and debug network application programs.
- Consider two application programs that are developed to communicate over the network. To test these programs without running them on two different hosts, it is possible to run the two application programs on the same host and use the loopback address to communicate.
- When data from one application program travels down the protocol stack and reaches the IP software, the packet is forwarded back up through the protocol stack to the second application program.

- The advantage of loopback testing is that no packets leave the computer.
- Note that the loopback address never appears on a packet traveling in a network.

- IP reserves the network prefix 127/8 for use with loopback.
- Commonly used loopback address: 127.0.0.1/8

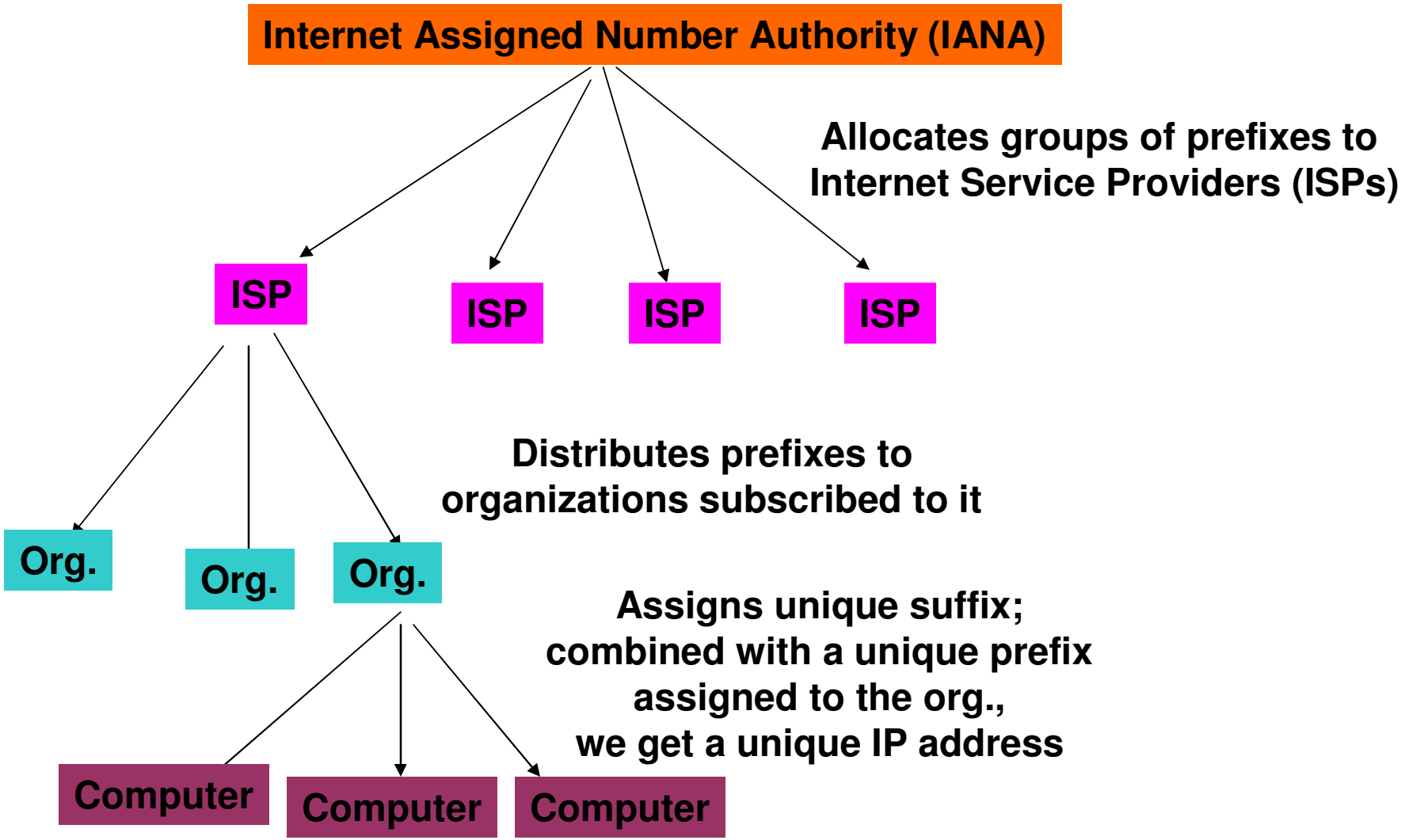
# Summary of Special IP Address Forms

| Prefix | Suffix | Type Of Address | Purpose |
|---|---|---|---|
| all-0s | all-0s | this computer | used during bootstrap |
| network | all-0s | network | identifies a network |
| network | all-1s | directed broadcast | broadcast on specified net |
| all-1s | all-1s | limited broadcast | broadcast on local net |
| 127 | any | loopback | testing |

# Sample Question: IP Addresses

- Identify whether the following is a network address, broadcast IP address, unicast IP address, multicast IP address or a private IP address:
  - a) 143.132.10.1 – unicast IP address for a class B network
  - b) 229.0.1.2 – multicast IP address
  - c) 16.1.255.255 – broadcast IP address for a class A network
  - d) 10.1.1.1 – private IP address
  - e) 172.18.12.34 – private IP address
  - f) 202.14.12.255 – broadcast IP address for a class C network
  - g) 156.25.32.0 – unicast IP address for a class B network
  - h) 202.45.69.0 – network address for a class C network

# Authority for Addresses



# Private IP Addresses

- IANA reserves certain blocks of IP addresses (called private IP address) for use by the private internets. The **private ip address blocks are:**

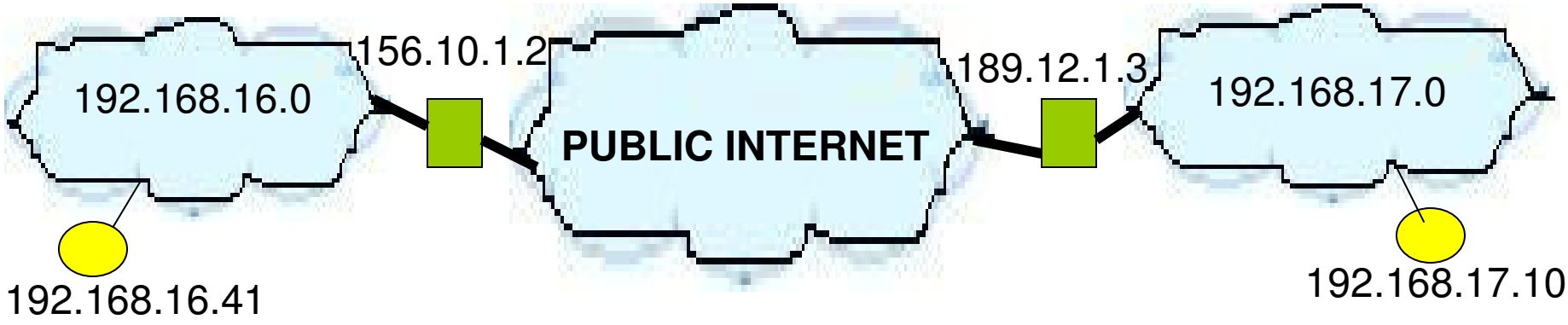
  **10.0.0.0 - 10.255.255.255**
  **172.16.0.0 - 172.31.255.255**
  **192.168.0.0 - 192.168.255.255**

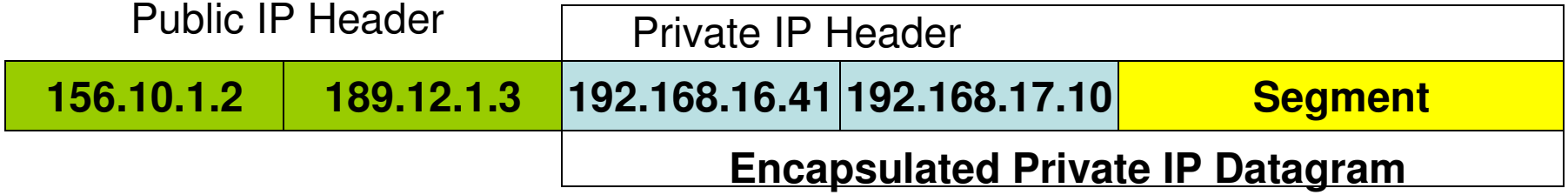
- The same set of private IP addresses can be used at different organizations (i.e., a private IP address has to be only locally unique); where as a public IP address has to be globally unique.
- Private IP addressing is one of the solutions to reduce the exhaustion of IP address space.
- The private ip addresses are not routable in the public internet (i.e., packets bearing private ip addresses are not forwarded by routers in the Internet).
  - Because if more than one host (located in the networks of two different organizations/domains) has the same IP address, then to which host do the routers forward a packet? – Not possible to resolve.

# Virtual Private Network (VPN)

- Organizations setup network sites at different locations, have each of them assigned a private IP address space that is unique among the hosts within the entire organization.
- Hosts at the different sites communicate with each through a VPN setup across the public Internet.
- This is accomplished through IP-in-IP encapsulation. There will be a public gateway (that has a public IP address) setup at each of these sites.
- The private datagram (containing the IP header with the source and destination private IP addresses plus the segment) is encapsulated inside a public IP header containing the public IP addresses of the gateways at the two sites as the source and destination IP addresses.
- Routers across the Internet will transfer the datagram based on the public IP addresses. For security reasons, the inner private IP datagram may be even encrypted by the end-gateways so that the contents of the inner encapsulated datagram are not seen by anyone in the public Internet.

# Virtual Private Network (VPN)




IP-in-IP Encapsulation

# Subnet/ Classless Addressing

- As the Internet grows rapidly, the IP address space gets exhausted quickly.
- Also, since there are only three distinct possible choices for the maximum number of hosts per network, most of the allocated addresses are unused.

- Example: Consider a network that contains 9 hosts.
- If we have to use classful addressing, we might end up choosing a class C address with 8 bits for the suffix, making it possible to support 254 hosts while we need a network that can support only 9 hosts.
- It would be enough to assign 4 bits of host suffix to represent all possible host values.
- With classless addressing, it is possible to subdivide a single class C address into 16 addresses such that each have a 28-bit prefix and a 4-bit suffix. Thus, it is possible to create 16 networks such that each can support a maximum of 14 hosts.

- **Generalization:** Instead of having three distinct classes, the division between prefix and suffix must be allowed to be made on an arbitrary bit boundary.

# Address Masks

- To specify the exact boundary between the prefix and suffix, IP address are supplemented with a 32-bit binary value called the subnet mask or address mask.
- A sequence of 1 bits in the subnet mask represent the network portion and is followed by a sequence of 0 bits representing the host portion.
- Given an IP address, D and its address mask M, a bitwise AND operation applied over D and M, yields the network prefix portion of the address D. The rest of the bits in D then represent the host portion of the address.
- Example: D = 128.10.2.3 and M = 255.255.0.0

  D 1000000 00001010 00000010 00000011

  M 1111111 11111111 00000000 00000000

  D&M 1000000 00001010 00000000 00000000

  D&M=128.10.0.0, the network prefix for D.

# Sample Question 1: Subnetting

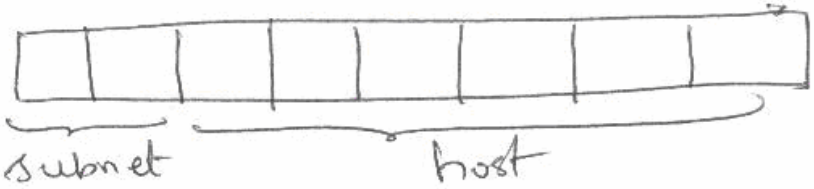
- Assume there are three Departments P, Q and R in an organization XYZ. Each of the department needs a separate subnet. The number of computers in Departments P, Q and R are 30, 10 and 47 respectively. Assume organization XYZ got a class C network prefix 212.46.98.0. Derive the following for each of the Departments P, Q and R:
  - i) The subnet prefix
  - ii) The subnet mask
  - iii) The directed broadcast IP address for each subnet
  - iv) The valid range of IP addresses for each subnet

# Solution for Question 1

**<u>Step 1:</u> Identifying the number of bits for the subnet and host part**

| | | Max. # bits. |
|---|---|---|
| P | 30 | 5 |
| Q | 10 | 4 |
| R | 47 | 6 |

212.46.98.




6 bits are needed for the host part and 2 bits are needed for the subnet part.

Subnet Mask for all the three subnets is 11111...1111 000000
(26 1s, 6 0s)

255.255.255.192

# Solution for Question 1 (continued…)

Subnet P

212.46.98. 


Subnet prefix/ subnet address. 212.46.98.0/26.

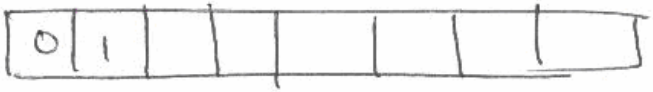
212.46.98. 0 0 0 0 0 0 0 0

Directed broadcast IP address 212.46.98. 0 0 1 1 1 1 1 1

212.46.98.63/26.

Valid range of IP addresses for this subnet is 212.46.98.1/26 to 212.46.98.62/26.

Subnet Q

212.46.98. 

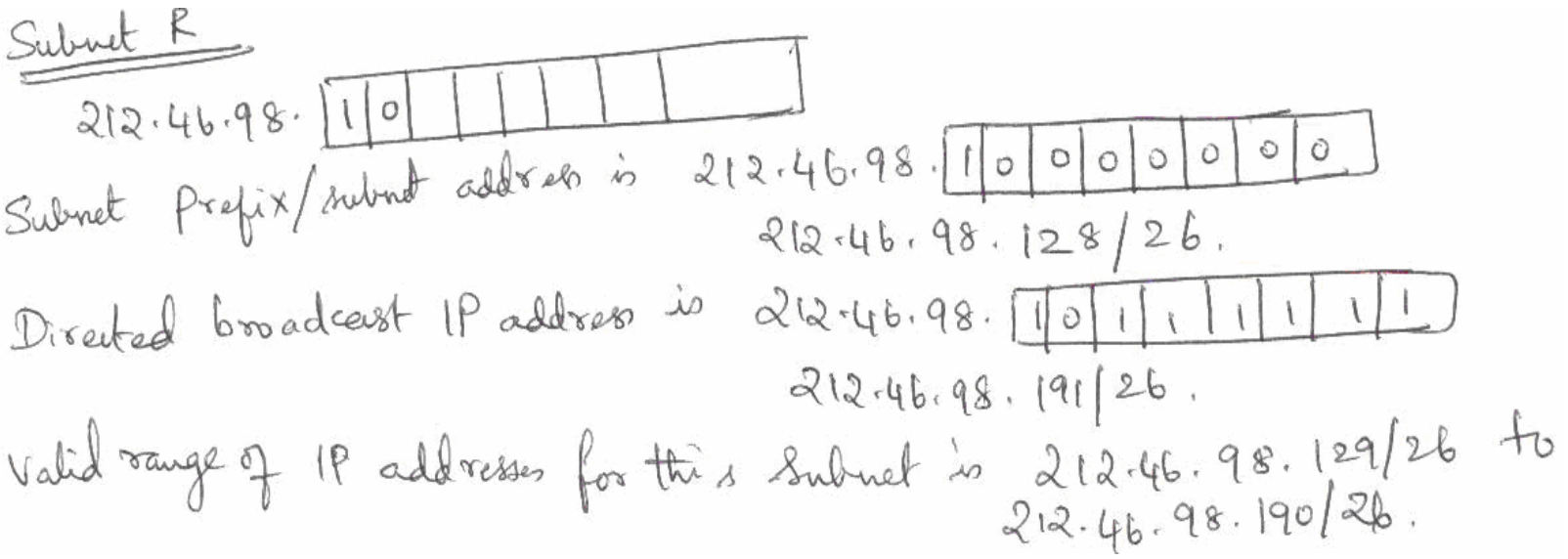

Subnet prefix/ subnet address is 212.46.98. 0 1 0 0 0 0 0 0

212.46.98. 64/26.

Directed broadcast IP address is 212.46.98.127/26. 212.46.98. 0 1 1 1 1 1 1

Valid range of IP addresses for this subnet is 212.46.98.65/26 to 212.46.98.126/26.

# Solution for Question 1 (continued…)



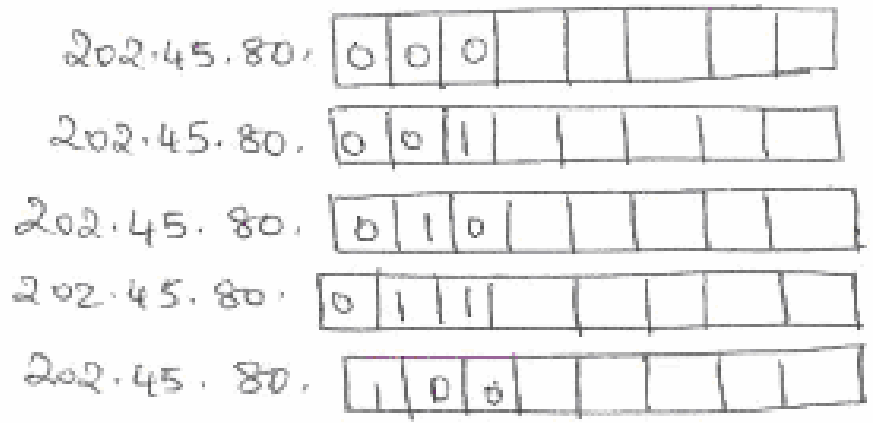

| Subnet | Subnet Mask | Subnet Prefix (Subnet Address) | Broadcast IP Address | Range of Valid IP Addresses |
|---|---|---|---|---|
| P | 255.255.255.192 | 212.46.98.0 / 26 | 212.46.98.63 / 26 | 212.46.98.1 / 26 to 212.46.98.62 / 26 |
| Q | 255.255.255.192 | 212.46.98.64 / 26 | 212.46.98.127 / 26 | 212.46.98.65 / 26 to 212.46.98.126 / 26 |
| R | 255.255.255.192 | 212.46.98.128 / 26 | 212.46.98.191 / 26 | 212.46.98.129 / 26 to 212.46.98.190 / 26 |

# Sample Question 2: Subnetting

- Assume there are five units A, B, C, D and E in an organization. Each of the units needs a separate subnet. The number of computers in units A, B, C, D and E are 10, 15, 20, 25 and 30 respectively. Assume the organization got a class B network prefix 202.45.80.0. Derive the following for each of the units A, B, C, D and E:
  - The subnet prefix
  - The subnet mask
  - The directed broadcast IP address for each subnet.
  - The valid range of IP addresses for each subnet

# Solution for Question 2

| | | |
|---|---|---|
| A | 10 | 4 |
| B | 15 | 5 |
| C | 20 | 5 |
| D | 25 | 5 |
| E | 30 | 5 |




3 bits for the subnet part and 5 bits for the host part

Subnet mask is 11111...111|00000 (27 1's, 5 0's) 255.255.255.224

# Solution for Question 2 (continued…)

**Subnet Addresses**

A 202.45.80.0/27
B 202.45.80.32/27
C 202.45.80.64/27
D 202.45.80.96/27
E 202.45.80.128/27

**Broadcast addresses**

A 202.45.80.31/27
B 202.45.80.63/27
C 202.45.80.95/27
D 202.45.80.127/27
E 202.45.80.159/27

**Valid Range of IP addresses**

A 202.45.80.1/27 to 202.45.80.30/27
B 202.45.80.33/27 to 202.45.80.62/27
C 202.45.80.65/27 to 202.45.80.94/27
D 202.45.80.97/27 to 202.45.80.126/27
E 202.45.80.129/27 to 202.45.80.158/27

# Classless Interdomain Routing (CIDR)

- With class A, B and C addresses, we are forced to hand out network address space in fixed-sized chunks of three very different sizes.
- Even though subnetting helps us to assign addresses carefully, it does not get around the fact that any autonomous system with more than 255 hosts, wants a class B address.
- Unless any AS shows a need for something close to 64K addresses, we should not assign them a class B address and instead assign an appropriate number of class C addresses to cover the expected number of hosts. The drawback with this approach would be that we will require more entries in the routing tables to handle the multiple class C network addresses.
- CIDR tries to balance the desire to minimize the number of routes that a router needs to know against the need to assign addresses efficiently. CIDR does this by aggregating routes.

# Classless Interdomain Routing (CIDR)

- Suppose we need 16 class C network numbers for an AS. Instead of assigning 16 random network numbers, we can assign the class C network numbers from 192.4.16 to 192.4.31.
- The first 20 bits of all the addresses in the above range would be the same.
- Subnetting is used to share one address among multiple physical networks, CIDR aims to collapse the multiple addresses that would be assigned to a single AS onto one address.

# Sample Question: CIDR

Consider the use of the Classless Interdomain Routing (CIDR). Let there be a network PQR that requires the support of 700 hosts and we assign three contiguous class C network address space 212.45.16.0, 212.45.17.0 and 212.45.18.0. Compute the following for network PQR:

- (1) Subnet mask
- (2) Network address
- (3) Broadcast address
- (4) Range of valid IP addresses

# Solution for CIDR

212.45. 0 0 0 1 0 0 0 0. 0

212.45. 0 0 0 1 0 0 0 1. 0

212.45. 0 0 0 1 0 0 1 0. 0

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212.45. 0 0 0 1 0 0 0 0 . 0 / 22 ← Network Prefix/ Network Address

212.45.0 0 0 1 0 0 0 0 .0
212.45.16.0 / 22

212.45.0 0 0 1 0 0 11 .255
212.45.19.255/ 22 ← Broadcast IP Address

255.255.11111100.00000000
255.255.252.0 ← Subnet Mask

212.45.16.1/22 to
212.45.19.254/22 ← Range of Valid IP Addresses

**Note: With the above assignment, we can support 255 + 256 + 256 + 255 = 1022 unique IP addresses.**