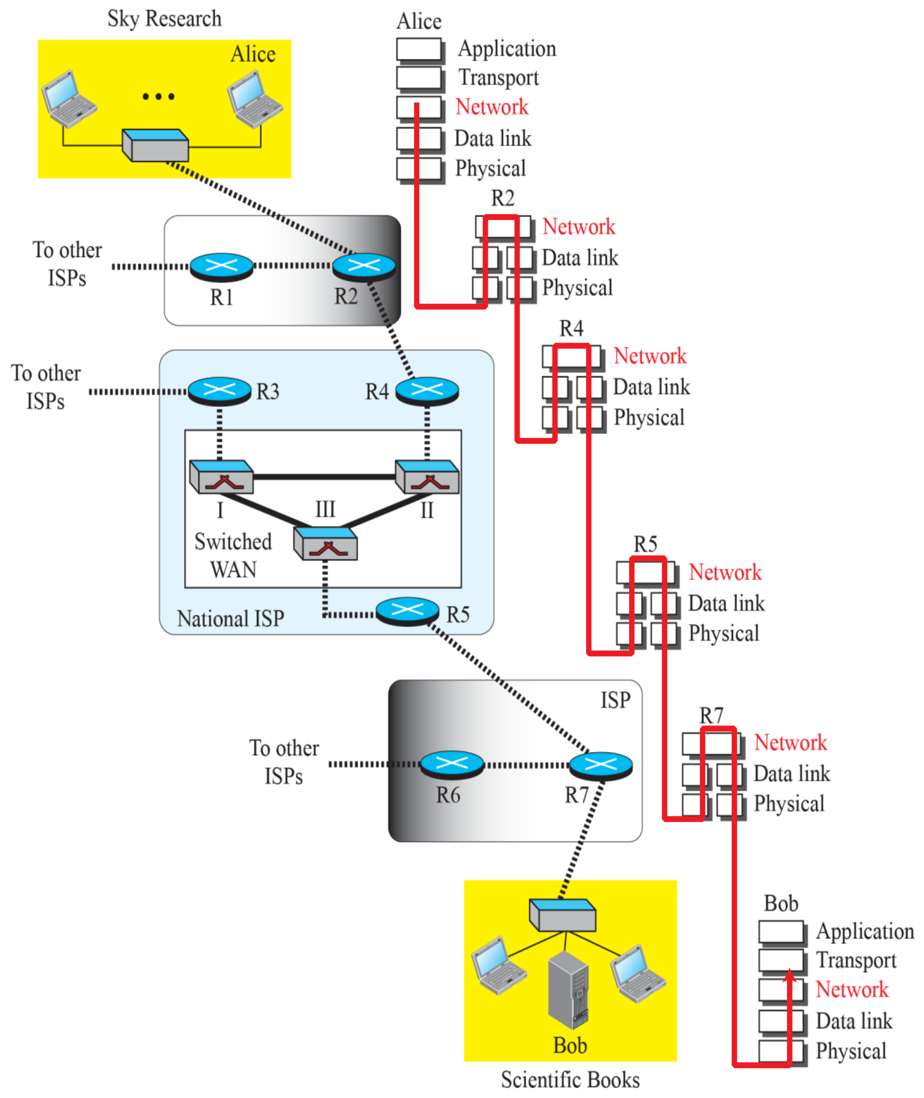
Network Layer and Subnetting

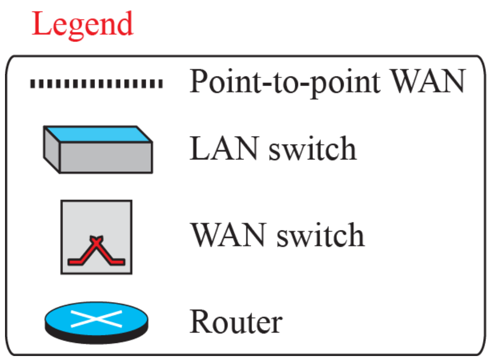
Session Objectives

After going through this session you will learn

- Network Layer Services
- IPv4 Addressing
- Subnetting
- IP Packet Forwarding

Network Layer Routing



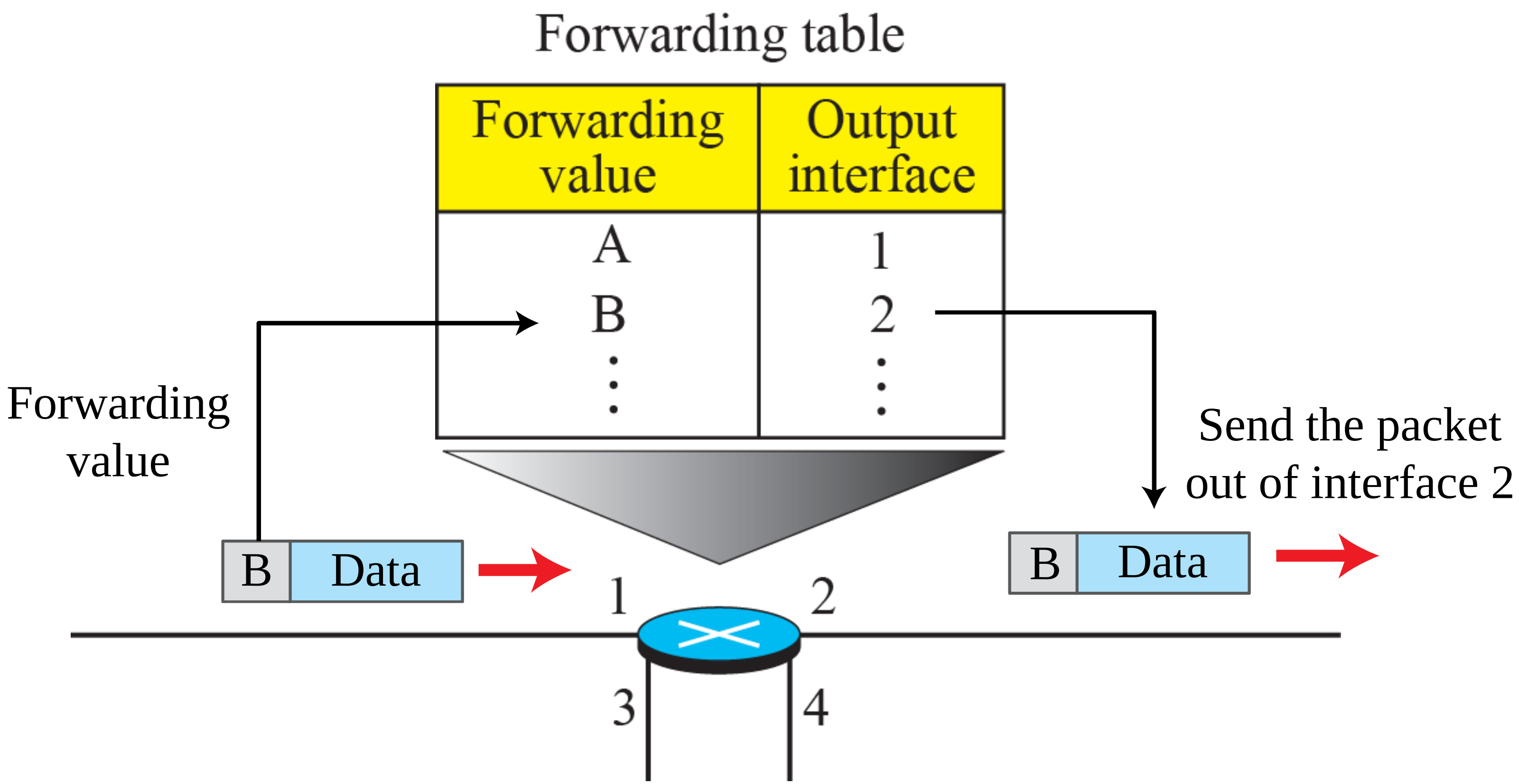


Packetizing and Depacketizing Service

- The network layer does packetizing; *means* encapsulating the payload in a network-layer packet at the source.
- Secondly, it does de-capsulating the payload from the network-layer packet at the destination.
- In other words, one duty of the network layer is to carry a payload from the source to the destination without changing it or using it.
- The network layer is doing the service of a carrier such as the postal office, which is responsible for delivery of packages from a sender to a receiver without changing or using the contents.

Routing and Forwarding Service

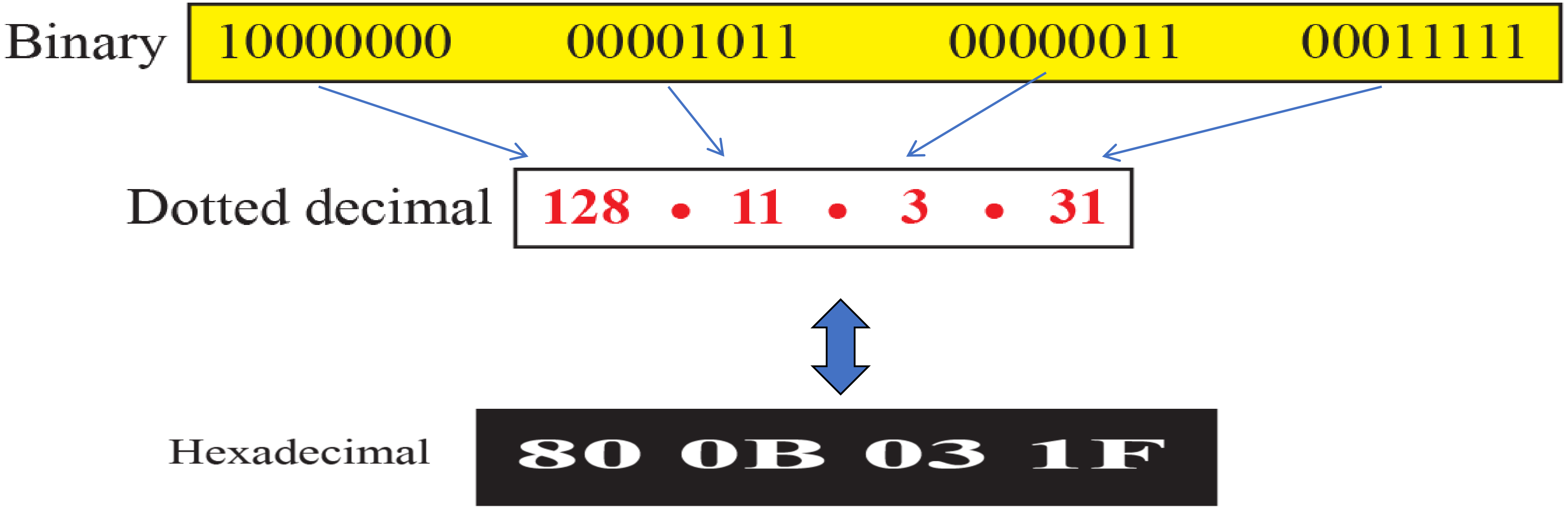
Other duties of the network layer, which are as important as the first, are routing and forwarding, which are directly related to each other.



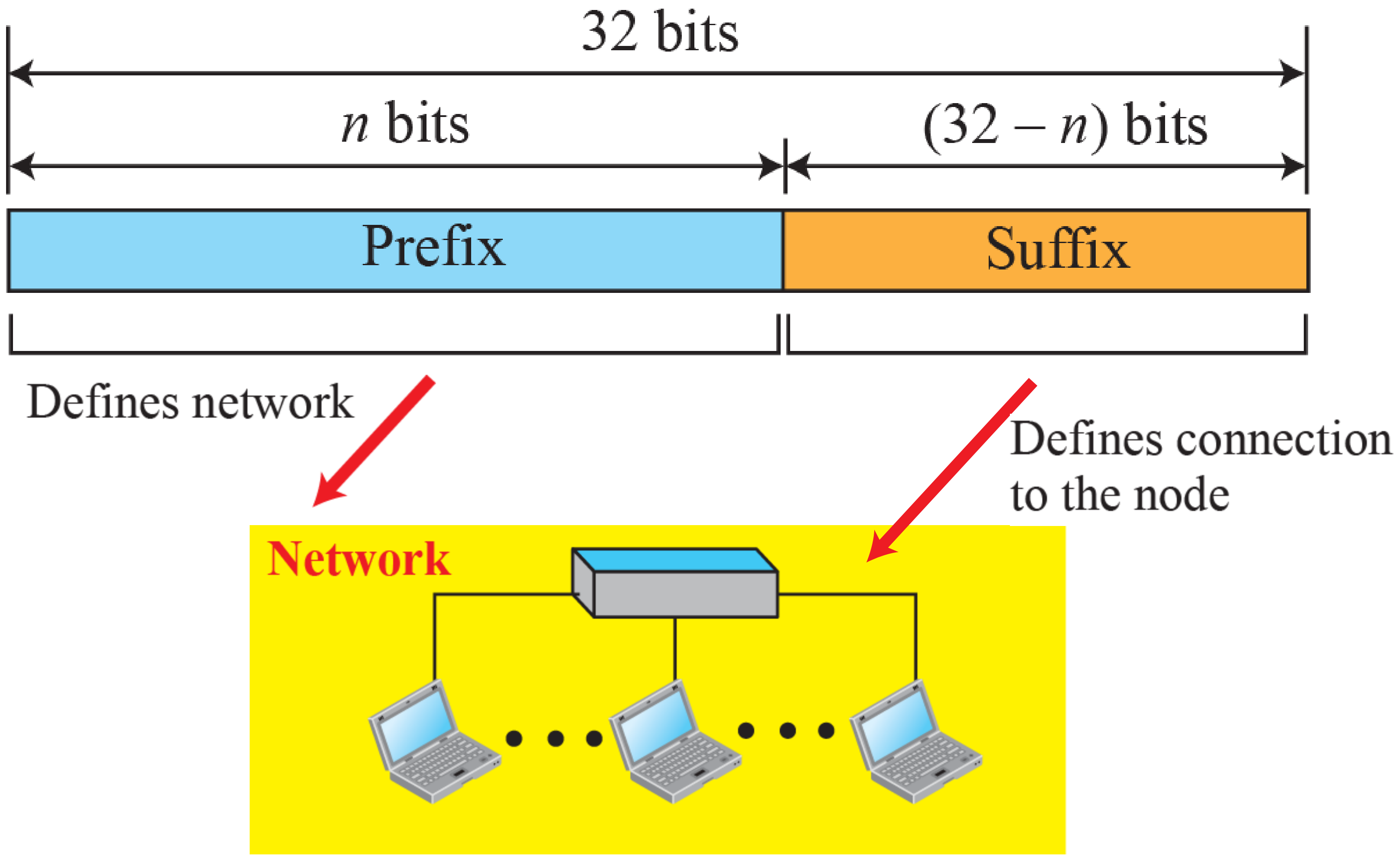
IPv4 Addressing

- The identifier used in the IP layer of the TCP/IP protocol suite to identify the connection of each device to the Internet is called the Internet address or IP address.

- An IPv4 address is a 32-bit address that uniquely and universally defines the connection of a host or a router to the Internet.
- An address space is the total number of addresses used by the protocol.
- IPv4 uses 32-bit addresses, which means that the address space is 4,294,967,296 (more than four billion).

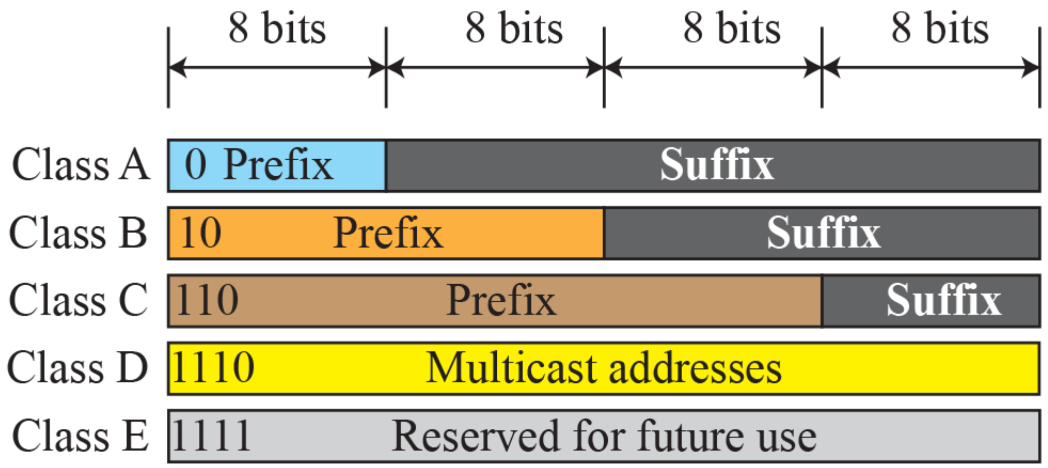


Classful IPv4 Addressing



Classful IPv4 Addressing

- When the Internet started, an IPv4 address was designed with a fixed-length prefix, but to accommodate both small and large networks, three fixed-length prefixes were designed instead of one (n = 8, n = 16, and n = 24).
- The whole address space was divided into five classes (class A, B, C, D, and E), as shown in Figure below. This scheme is referred to as classful addressing.

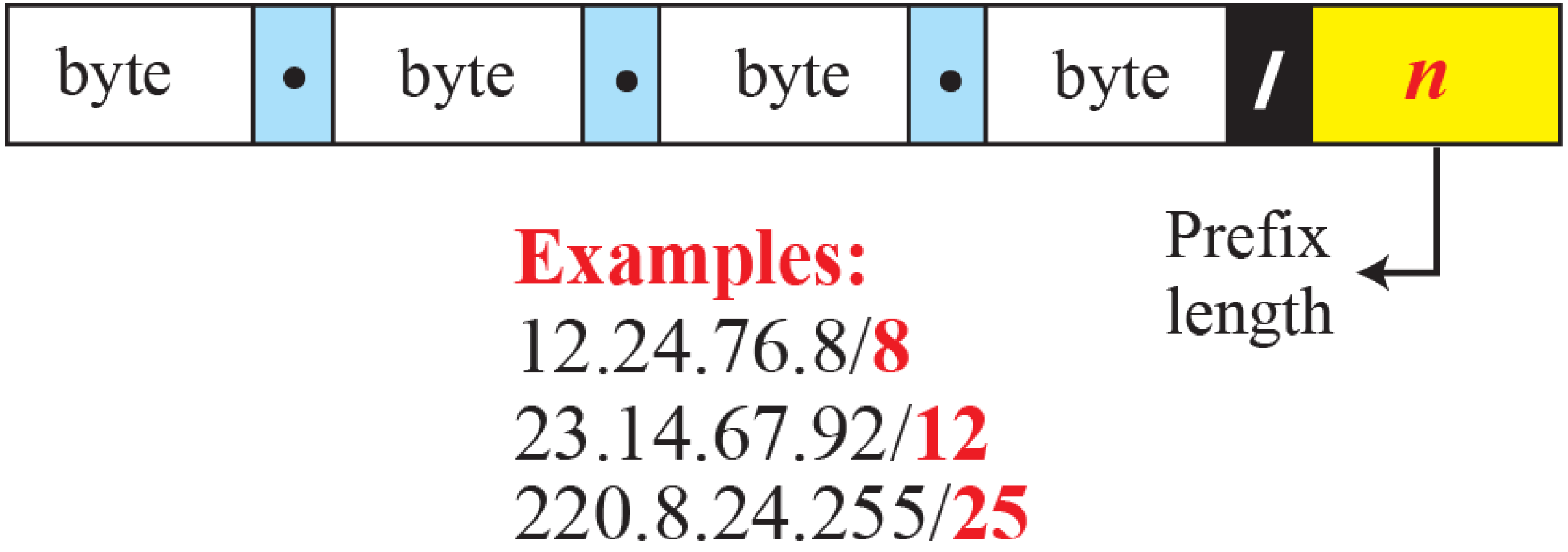


Class	Prefixes	First byte
A	$n = 8$ bits	0 to 127
B	$n = 16$ bits	128 to 191
C	$n = 24$ bits	192 to 223
D	Not applicable	224 to 239
E	Not applicable	240 to 255

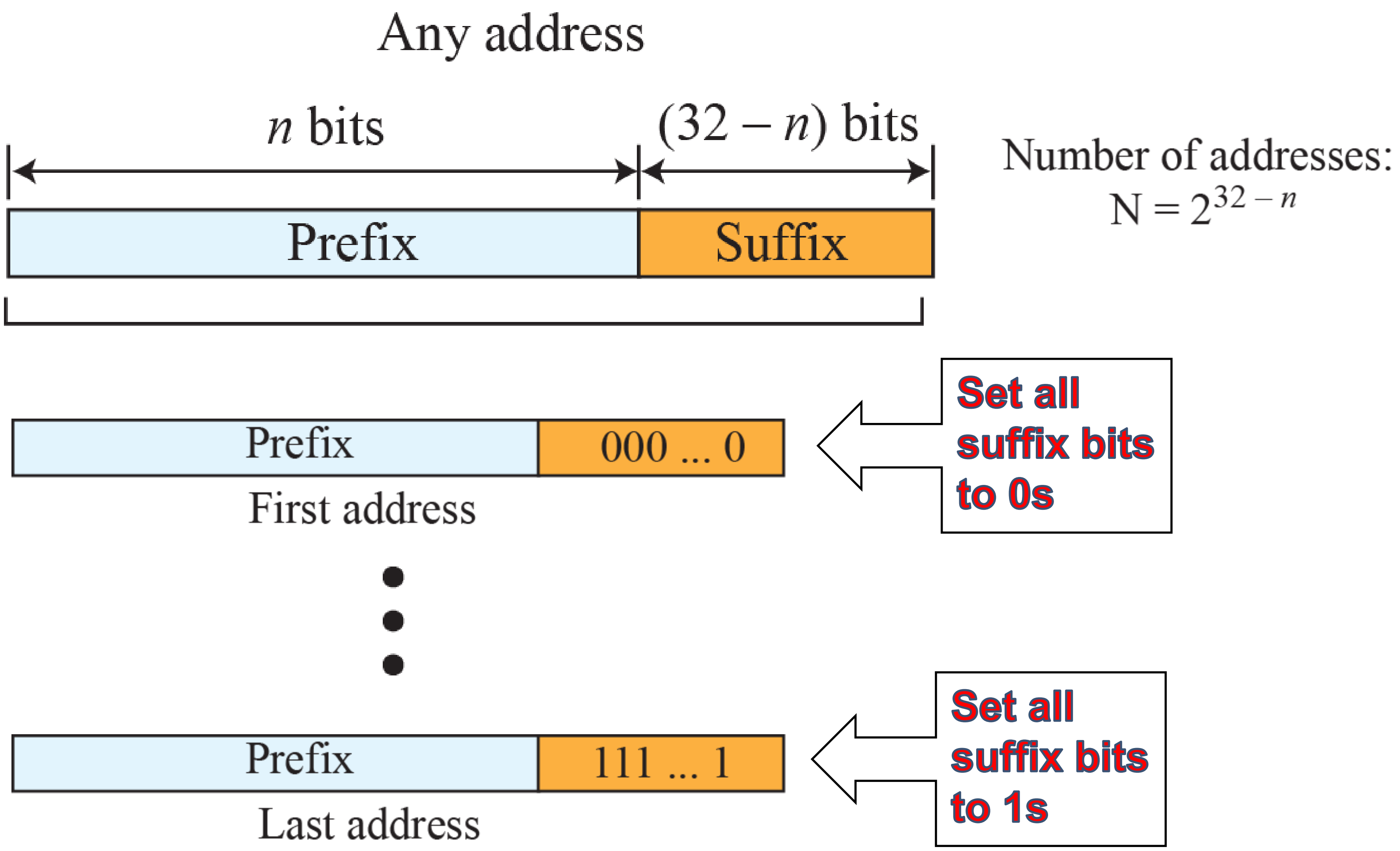
Class	Leading bits	Size of network number bit field	Size of rest bit field	Number of networks	Addresses per network	Total addresses in class	Start address	End address	Default subnet mask in dot-decimal notation	CIDR notation
Class A	0	8	24	128 (2^7)	16,777,216 (2^{24})	2,147,483,648 (2^{31})	0.0.0.0	127.255.255.255	255.0.0.0	/8
Class B	10	16	16	16,384 (2^{14})	65,536 (2^{16})	1,073,741,824 (2^{30})	128.0.0.0	191.255.255.255	255.255.0.0	/16
Class C	110	24	8	2,097,152 (2^{21})	256 (2^8)	536,870,912 (2^{29})	192.0.0.0	223.255.255.255	255.255.255.0	/24
Class D (multicast)	1110	not defined	not defined	not defined	not defined	268,435,456 (2^{28})	224.0.0.0	239.255.255.255	not defined	not defined
Class E (reserved)	1111	not defined	not defined	not defined	not defined	268,435,456 (2^{28})	240.0.0.0	255.255.255.255	not defined	

Classless IPv4 Addressing

- With the growth of the Internet, it was clear that a larger address space was needed as a long-term solution.
- The larger address space, however, requires that the length of IP addresses also 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, a short-term solution was also devised to use the same address space but to change the distribution of addresses to provide a fair share to each organization.
- The short-term solution still uses IPv4 addresses, but it is called classless addressing.



Information Extraction in Classless Addressing



Example 1

A classless address is given as 167.199.170.82/27. Find the **total host address space, first address and last address.**

The number of addresses (N) 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	01011111
Last address: 167.199.170.95/**27**	10100111	11000111	10101010	01011111

Example 2: Applying Mask to find the same information

- We repeat Example 1 using the mask.
- The mask in dotted-decimal notation is 256.256.256.224
- The AND, OR, and NOT operations can be applied to individual bytes.

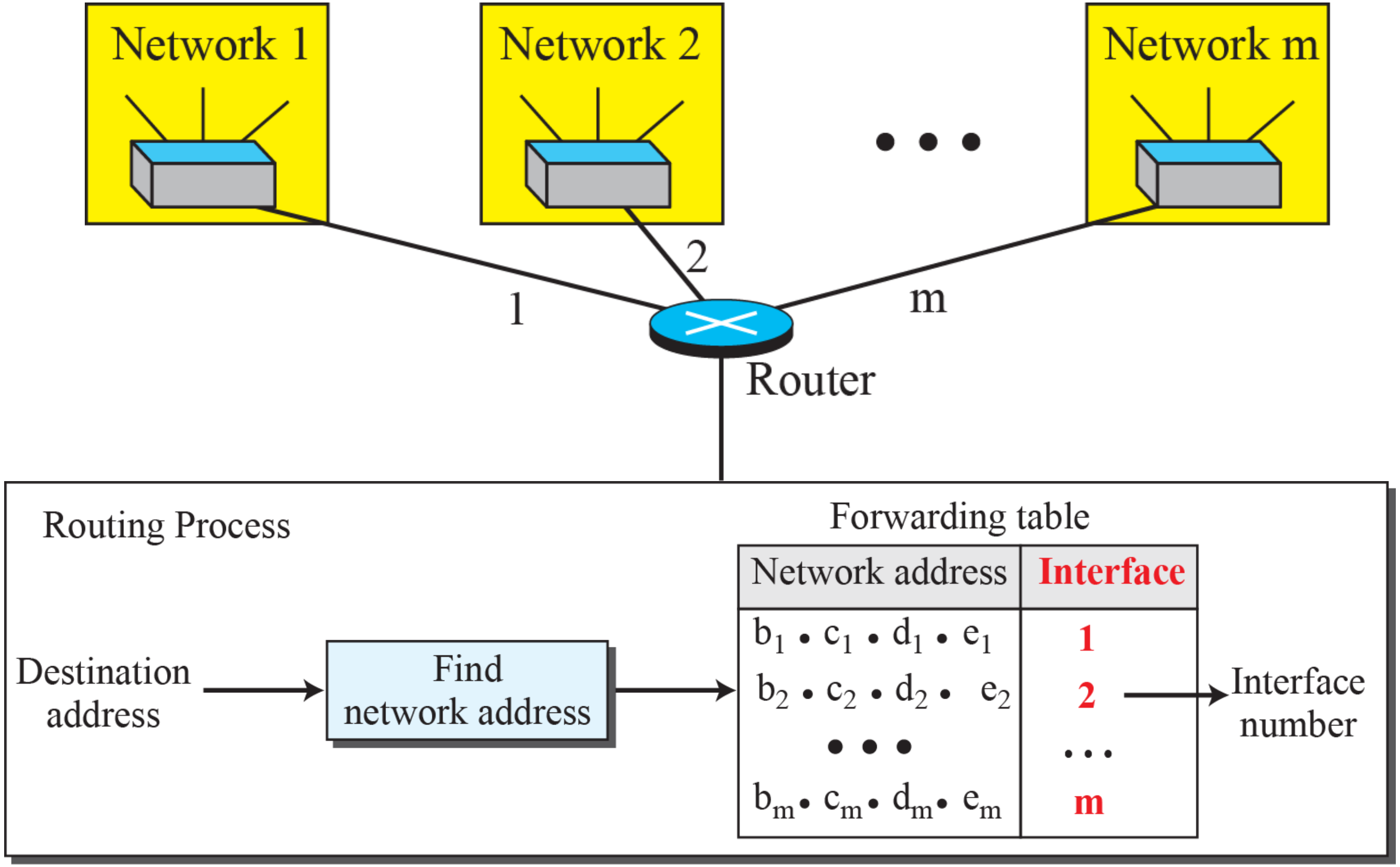
Number of addresses in the block:	N = **NOT** (mask) + 1= 0.0.0.31 + 1 = 32 addresses
First address:	First = (address) **AND** (mask) = 167.199.170. 64
Last address:	Last = (address) **OR** (**NOT** mask) = 167.199.170. 95

Example 3: Classless Addressing Block

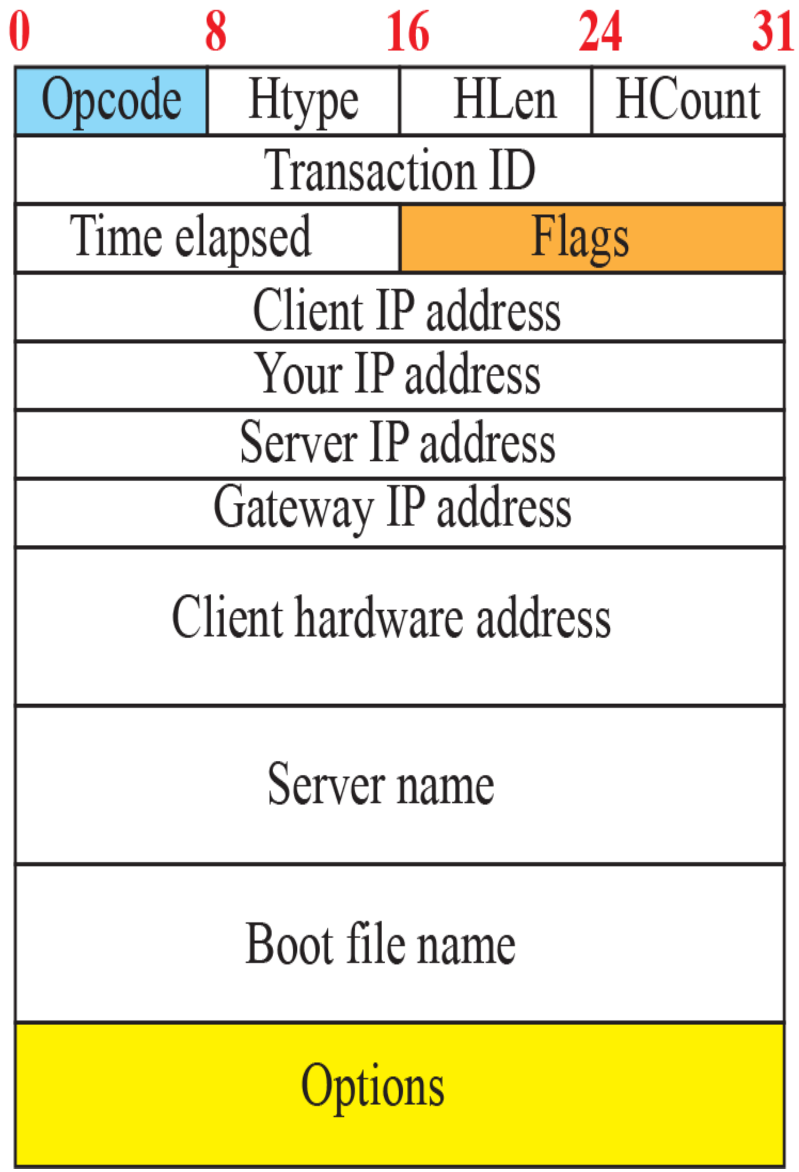
- In classless addressing, an address cannot define the block the address belongs to.
- For example, the address 230.8.24.56 can belong to many blocks. Some of them are shown below with the value of the prefix associated with that block.

Prefix length:16	→	Block:	230.8.0.0	to	230.8.255.255
Prefix length:20	→	Block:	230.8.16.0	to	230.8.31.255
Prefix length:26	→	Block:	230.8.24.0	to	230.8.24.63
Prefix length:27	→	Block:	230.8.24.32	to	230.8.24.63
Prefix length:29	→	Block:	230.8.24.56	to	230.8.24.63
Prefix length:31	→	Block:	230.8.24.56	to	230.8.24.57

Network Address based Routing Process

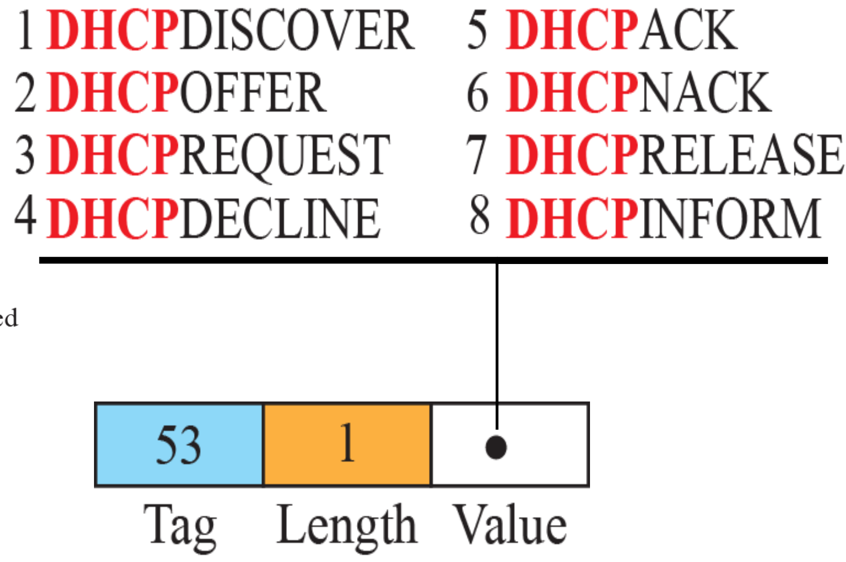


Dynamic Host Configuration Protocols (DHCP)

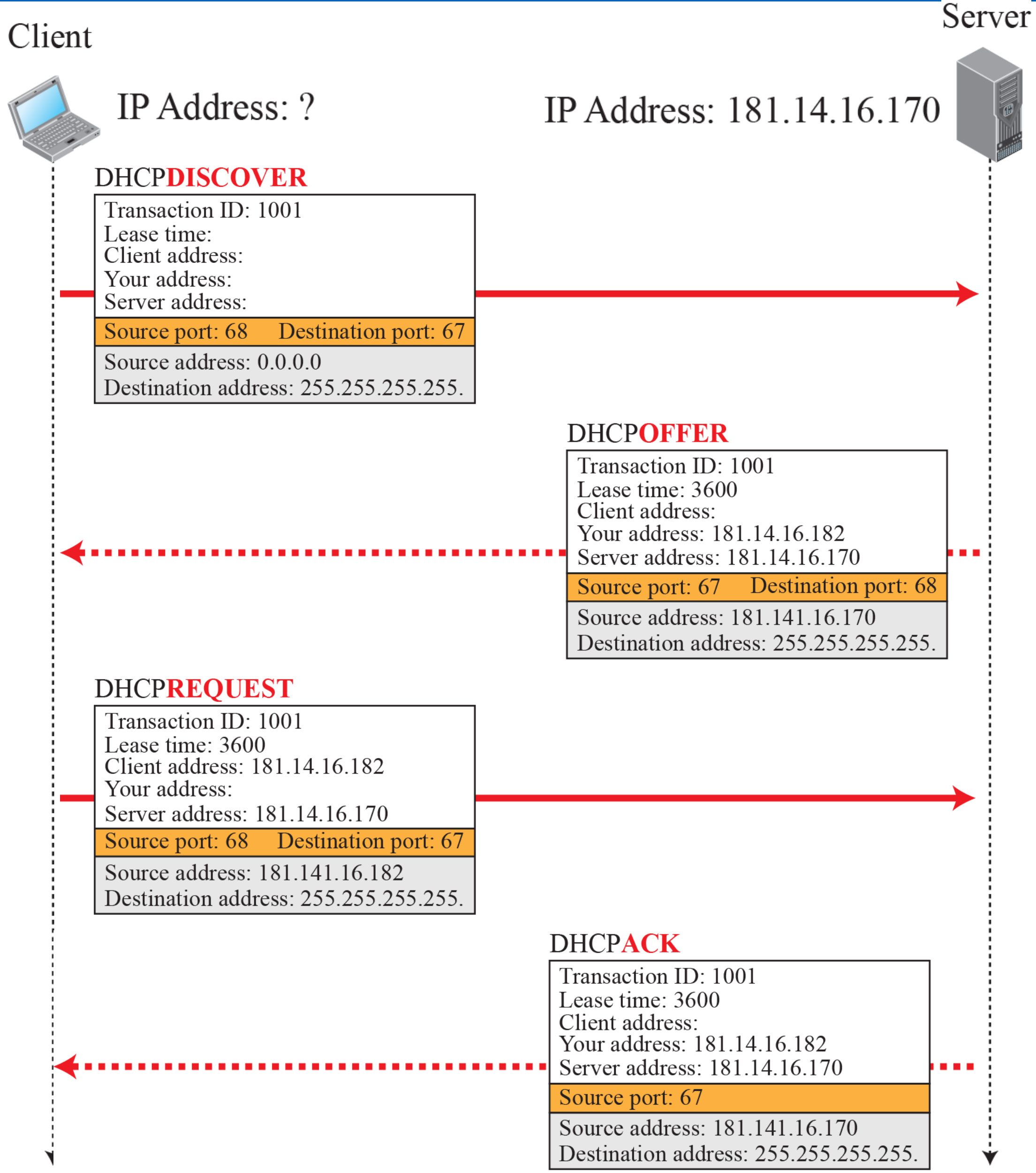


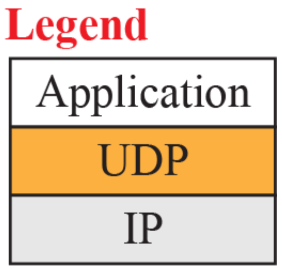
- After a block of addresses are assigned to an organization, the network administration can manually assign addresses to the individual hosts or routers.
- However, address assignment in an organization can be done automatically using the Dynamic Host Configuration Protocol (DHCP).
- DHCP is an application-layer program, using the client-server paradigm, that actually helps TCP/IP at the network layer.

Fields:
Opcode: Operation code, request (1) or reply (2)
Htype: Hardware type (Ethernet, ...)
HLen: Lengh of hardware address
HCount: Maximum number of hops the packet can travel
Transaction ID: An integer set by client and repeated by the server
Time elapsed: The number of seconds since the client started to boot
Flags: First bit defines unicast (0) or multicast (1); other 15 bits not used
Client IP address: Set to 0 if the client does not know it
Your IP address: The client IP address sent by the server
Server IP address: A broadcast IP address if client does not know it
Gateway IP address: The address of default router
Server name: A 64-byte domain name of the server
Boot file name: A 128-byte file name holding extra information
Options: A 64-byte field with dual purpose described in text



DHCP Operation

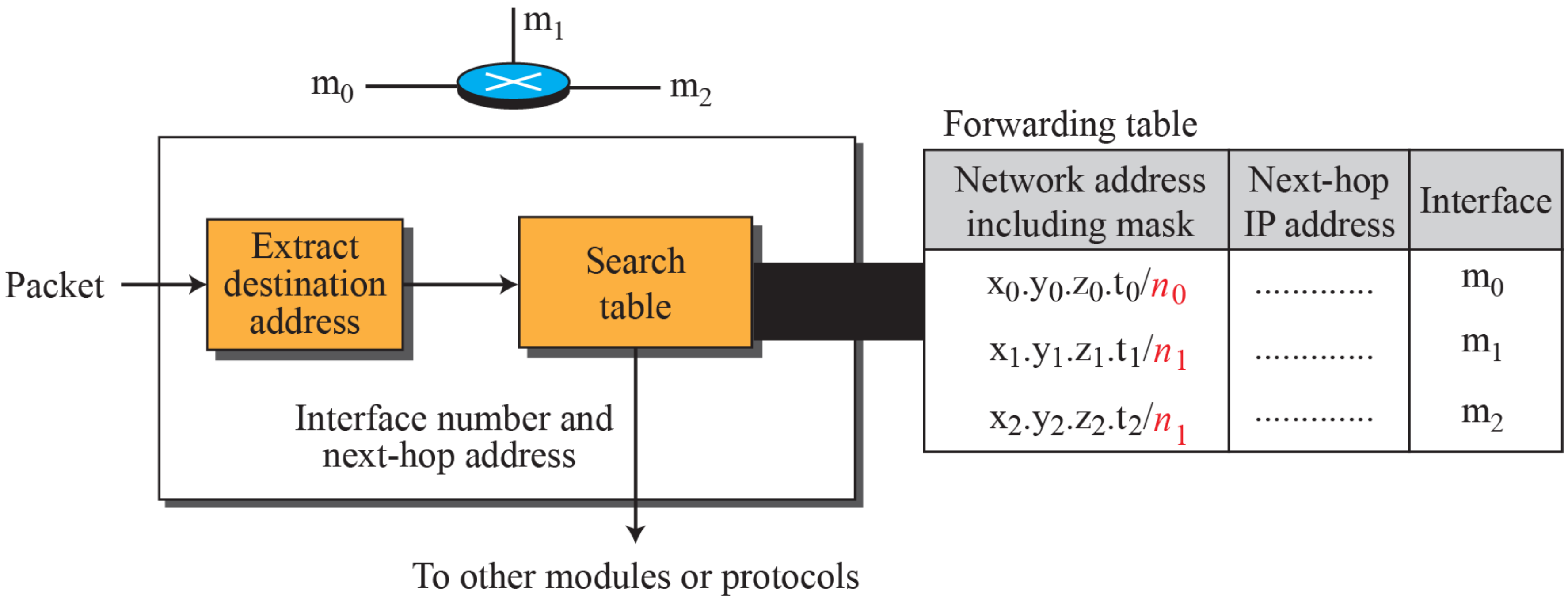




Note:
Only partial information is given.

Forwarding based on Destination Address

- Here we will discuss forwarding based on the destination address. This is a traditional approach, which is prevalent today.
- In this case, forwarding requires a host or a router to have a forwarding table.
- When a host has a packet to send or when a router has received a packet to be forwarded, it looks at this table to find the next hop to deliver the packet to.



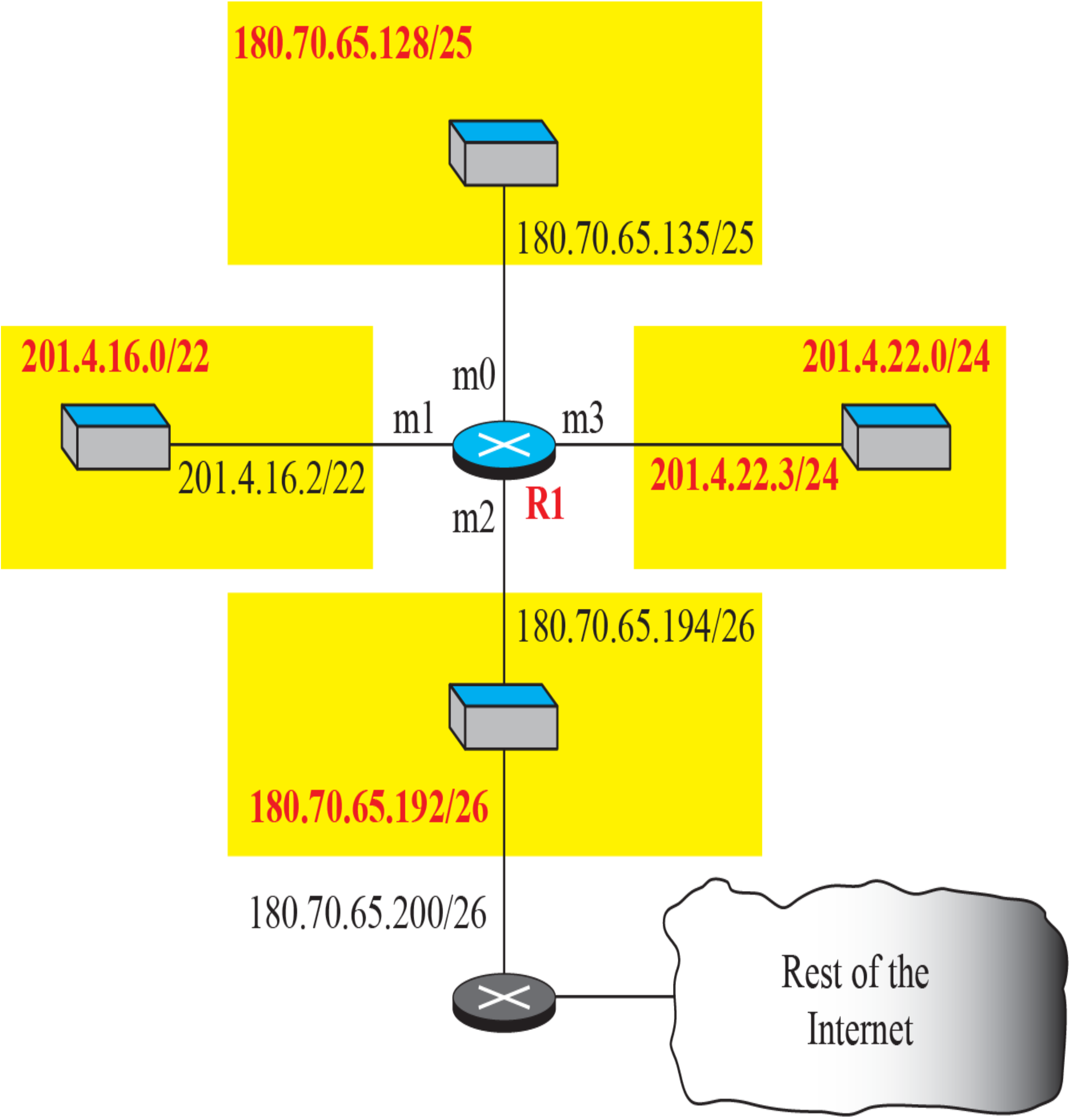
Example 6.1: Creating Forwarding Table

Make a forwarding table for router R1 using the configuration in adjacent Figure.

Solution

Forwarding table for router R1.

Network address/mask	*Next hop*	*Interface*
180.70.65.192/**26**	—	m2
180.70.65.128/**25**	—	m0
201.4.22.0/**24**	—	m3
201.4.16.0/**22**	—	m1
Default	180.70.65.200	m2



Example 6.2: Forwarding Process using Table

Show the forwarding process if a packet arrives at R1 in previous Figure with the destination address 180.70.65.140.

Solution

The router performs the following steps:

1. The first mask (**/26**) is applied to the destination address. The result is 180.70.65.128, which does not match the corresponding network address.
2. The second mask (**/25**) is applied to the destination address. The result is 180.70.65.128, which matches the corresponding network address. The next-hop address and the interface number m0 are extracted for forwarding the packet.

Available Class A Networks

Mask	Prefix	Subnets	Hosts
255.0.0.0	(/8)	1 network	with 16,777,214 hosts
255.128.0.0	(/9)	2 subnets	with 8,388,606 hosts each
255.192.0.0	(/10)	4 subnets	with 4,194,302 hosts each
255.224.0.0	(/11)	8 subnets	with 2,097,150 hosts each
255.240.0.0	(/12)	16 subnets	with 1,048,574 hosts each
255.248.0.0	(/13)	32 subnets	with 524,286 hosts each
255.252.0.0	(/14)	64 subnets	with 262,142 hosts each
255.254.0.0	(/15)	128 subnets	with 131,070 hosts each
255.255.0.0	(/16)	256 subnets	with 65,534 hosts each
255.255.128.0	(/17)	512 subnets	with 32,766 hosts each
255.255.192.0	(/18)	1,024 subnets	with 16,384 hosts each
255.255.224.0	(/19)	2,048 subnets	with 8,190 hosts each
255.255.240.0	(/20)	4,096 subnets	with 4,094 hosts each
255.255.248.0	(/21)	8,192 subnets	with 2,046 hosts each
255.255.252.0	(/22)	16,384 subnets	with 1,022 hosts each
255.255.254.0	(/23)	32,768 subnets	with 510 hosts each
255.255.255.0	(/24)	65,536 subnets	with 254 hosts each
255.255.255.128	(/25)	131,072 subnets	with 126 hosts each
255.255.255.192	(/26)	262,144 subnets	with 62 hosts each
255.255.255.224	(/27)	524,288 subnets	with 30 hosts each
255.255.255.240	(/28)	1,048,576 subnets	with 14 hosts each
255.255.255.248	(/29)	2,097,152 subnets	with 6 hosts each
255.255.255.252	(/30)	4,194,304 subnets	with 2 hosts each

Summary

In this section we have discussed the following:

- ✓Network Layer
- ✓IPv4 addressing
- ✓Classful Addressing with A, B, C Classes.
- ✓Classless Subnetting.
- ✓IP based routing in network

Netid and Hostid

- An IP address in class A, B, or C is divided into netid and hostid.
- In class A, one byte defines the netid and three bytes define the hostid.
- In class B, two bytes define the netid and two bytes define the hostid.
- In class C, three bytes define the netid and one byte defines the 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

Default masks for classful addressing

Subnetting

- During the era of classful addressing, subnetting was introduced.
- If an organization was granted a large block in class A or B, it could divide the addresses into several contiguous groups and assign each group to smaller networks (called subnets).
- Subnets masks are 32 bit addresses like IP Addresses.
- Subnet Masks are used with IP Addresses. .
- The 1’s represents the network parts, and 0’s represents the host parts.
- Subnetting increases the number of 1’s in the mask.

Mask

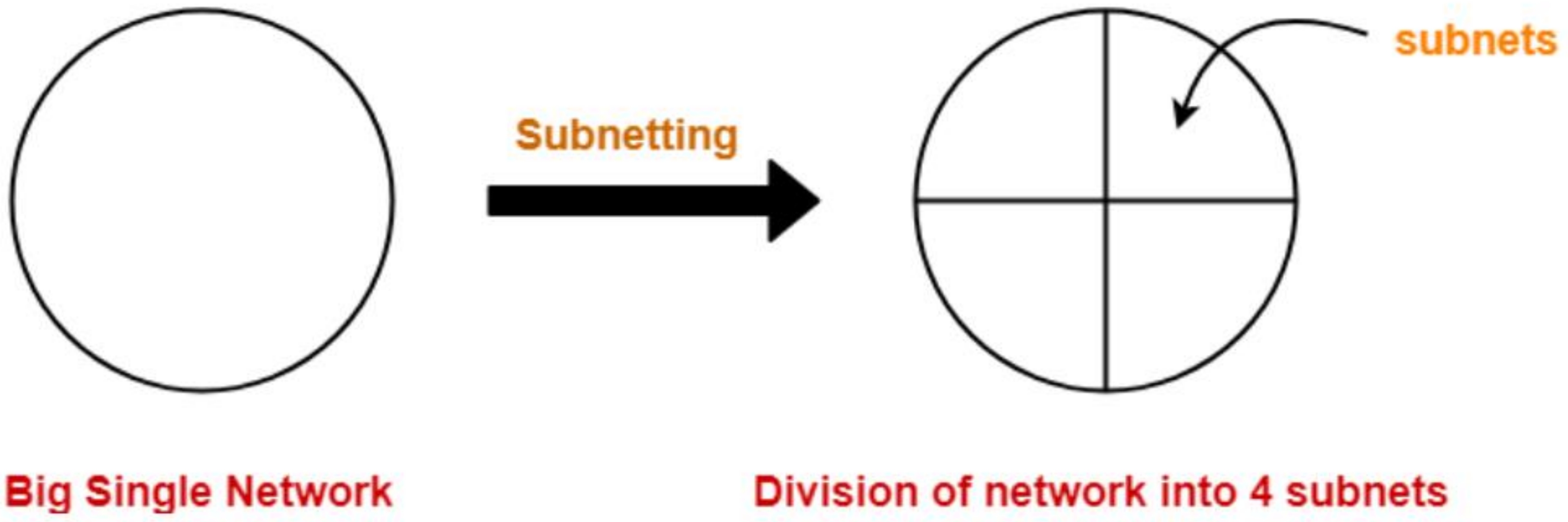
- A way to define a block of addresses is to select any address in the block and the mask.
- A mask is a 32-bit number in which the “n” leftmost bits are 1’s and the (32 – n) rightmost bits are 0’s.
- Example: A block of addresses is granted to a small organization. We know that one of the addresses is 205.16.37.39/28. What is the first address in the block?
  - Class-C address with first 24 bits for netid and last 8 bits for hostid.
  - Binary representation of given address is 11001101 00010000 00100101 00100111.
  - If we Set 32 - 28 rightmost bits to 0, we get 11001101 00010000100101 0010000 or **205.16.37.32**

Mask

- 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 last address in the block?
- Binary representation of the given address is 11001101 00010000000100101001 00111.
- If we set 32 - 28 rightmost bits to 1, we get 11001101 00010000 001001010010 1111 or 205.16.37.47.

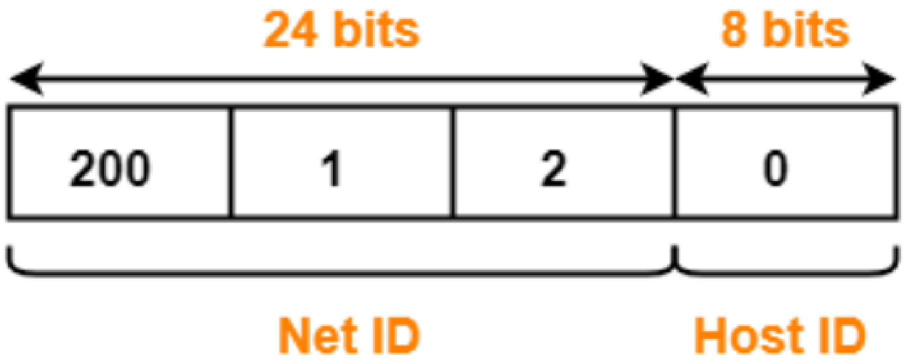
Example: Subnetting

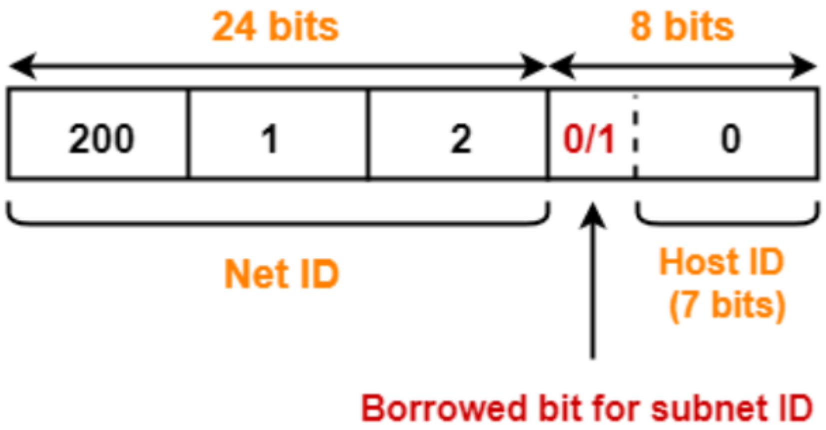
- It improves the security.
- The maintenance and administration of subnets is easy.



Example

- Consider- We have a big single network having IP Address 200.1.2.0. We want to do subnetting and divide this network into 2 subnets.
- The given network belongs to class C.

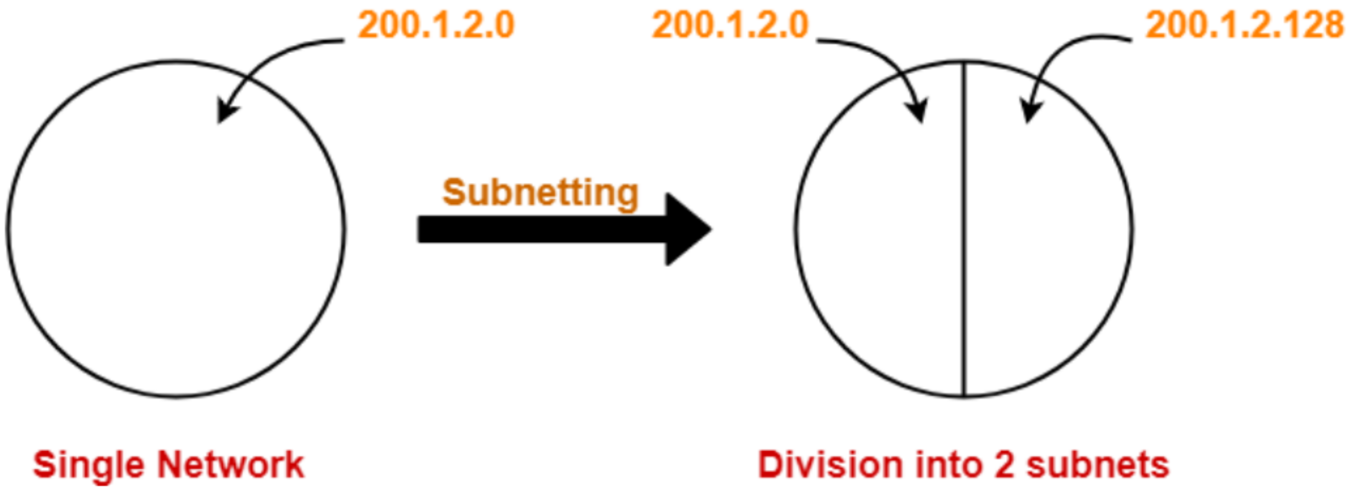




- We borrow one bit from the Host ID part.

Example

- IP Address of the two subnets are-
  - 200.1.2.**0**0000000 (Binary) = 200.1.2.0
  - 200.1.2.**1**0000000 (Binary) = 200.1.2.128



Note: *Red color shows binary digits

Example

- For 1st Subnet-
- IP Address of the subnet = 200.1.2.0
- Total number of IP Addresses = 2^7 = 128
- Total number of hosts that can be configured = 128 – 2 = 126
- Range of IP Addresses = [200.1.2.00000000, 200.1.2.01111111] = [200.1.2.0, 200.1.2.127]
- Broadcast Address = 200.1.2.01111111 = 200.1.2.127

Note: *Red color shows binary digits

Example

- For 2nd Subnet-
- IP Address of the subnet = 200.1.2.128
- Total number of IP Addresses = 2^7 = 128
- Total number of hosts that can be configured = 128 – 2 = 126
- Range of IP Addresses = [200.1.2.10000000, 200.1.2.11111111] = [200.1.2.128, 200.1.2.255]
- Direct Broadcast Address = 200.1.2.11111111 = 200.1.2.255

Note: *Red color shows binary digits

Example 4: Sub netting a Network

An organization is granted a block of addresses with the beginning address 14.24.74.0**/24**. The organization needs to have 3 subblocks of addresses to use in its three subnets: one subblock of 10 addresses, one subblock of 60 addresses, and one subblock of 120 addresses. Design the subblocks.

Solution

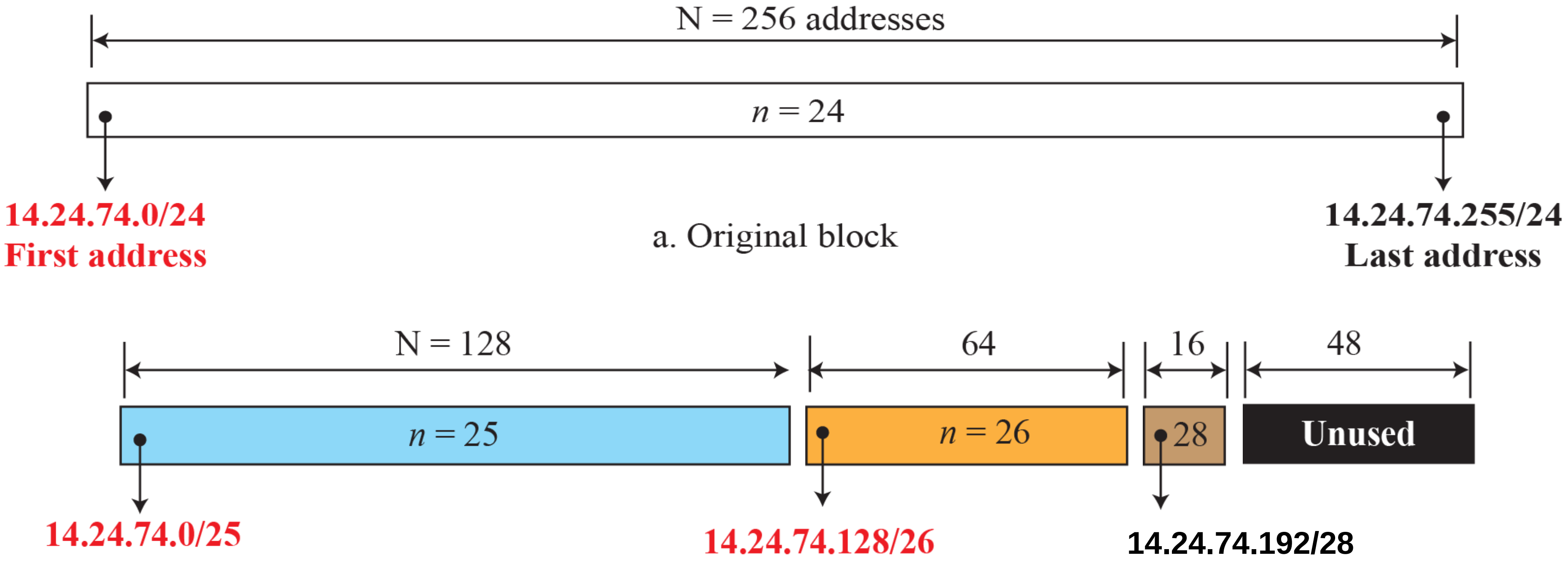
There are $2^{32-24} = 256$ addresses in this block. The first address is 14.24.74.0**/24**; the last address is 14.24.74.255**/24**. To satisfy the third requirement, we assign addresses to subblocks, starting with the largest and ending with the smallest one.

a. The number of addresses in the largest subblock, which requires 120 addresses, is not a power of 2. We allocate 128 addresses. The subnet mask for this subnet can be found as $n_1 = 32 - \log_2 128 = 25$. The first address in this block is 14.24.74.0**/25**; the last address is 14.24.74.127**/25**.

b. The number of addresses in the second largest subblock, which requires 60 addresses, is not a power of 2 either. We allocate 64 addresses. The subnet mask for this subnet can be found as $n_2 = 32 - \log_2 64 = 26$. The first address in this block is 14.24.74.128**/26**; the last address is 14.24.74.191**/26**.

c. The number of addresses in the smallest subblock, which requires 10 addresses, is not a power of 2. We allocate 16 addresses. The subnet mask for this subnet can be found as $n_1 = 32 - \log_2 16 = 28$. The first address in this block is 14.24.74.192/**28**; the last address is 14.24.74.207/**28**.

If we add all addresses in the previous subblocks, the result is 208 addresses, which means 48 addresses are left in reserve. The first address in this range is 14.24.74.208. The last address is 14.24.74.255. We don't know about the prefix length yet. Figure below shows the configuration of blocks. We have shown the first address in each block.



b. Subblocks