

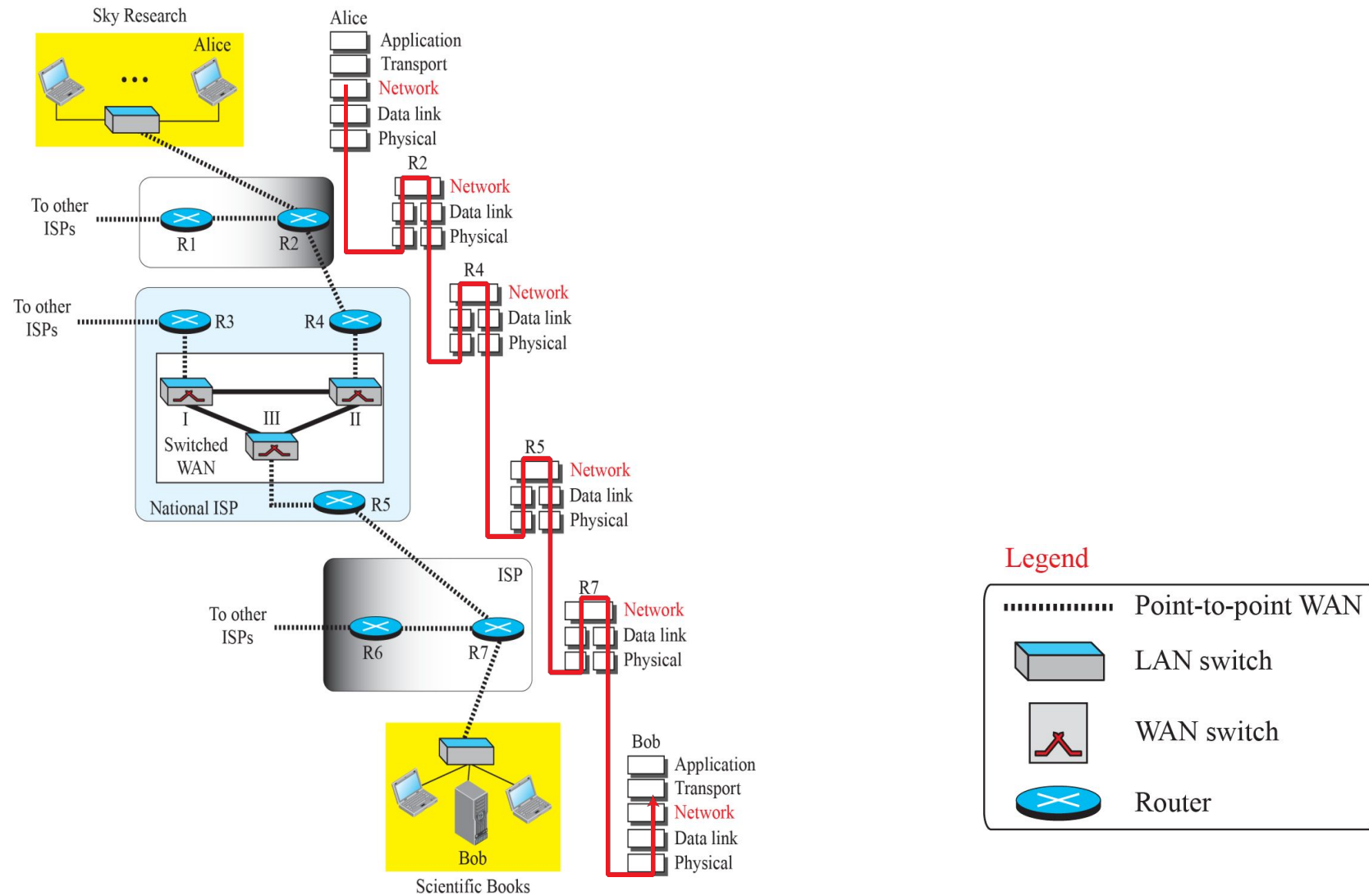
Network Layer and Subnetting

Session Objectives

After going through this session you will learn

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

Network Layer Routing

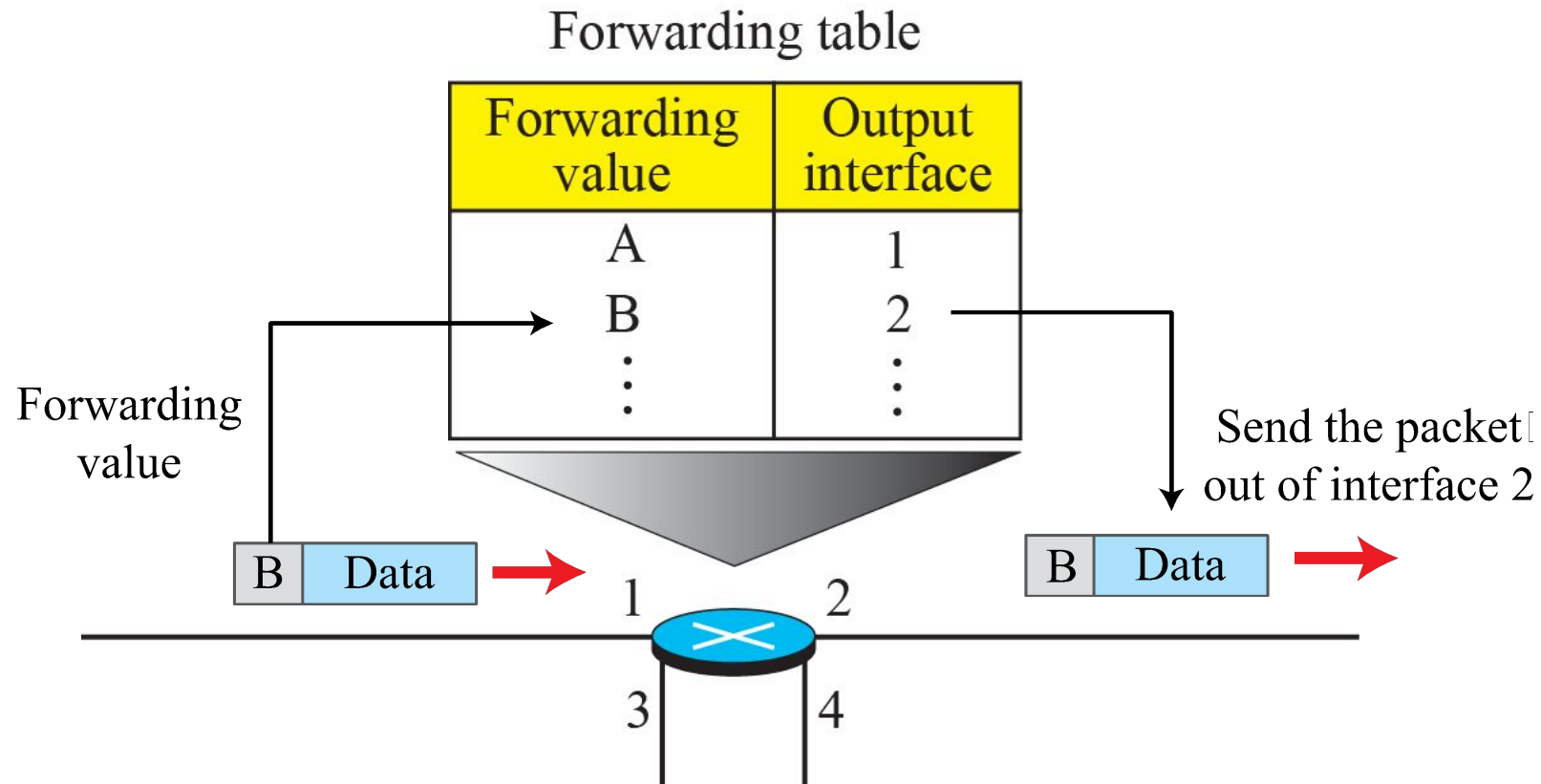


Packetizing and Depacketizing Service

- 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.

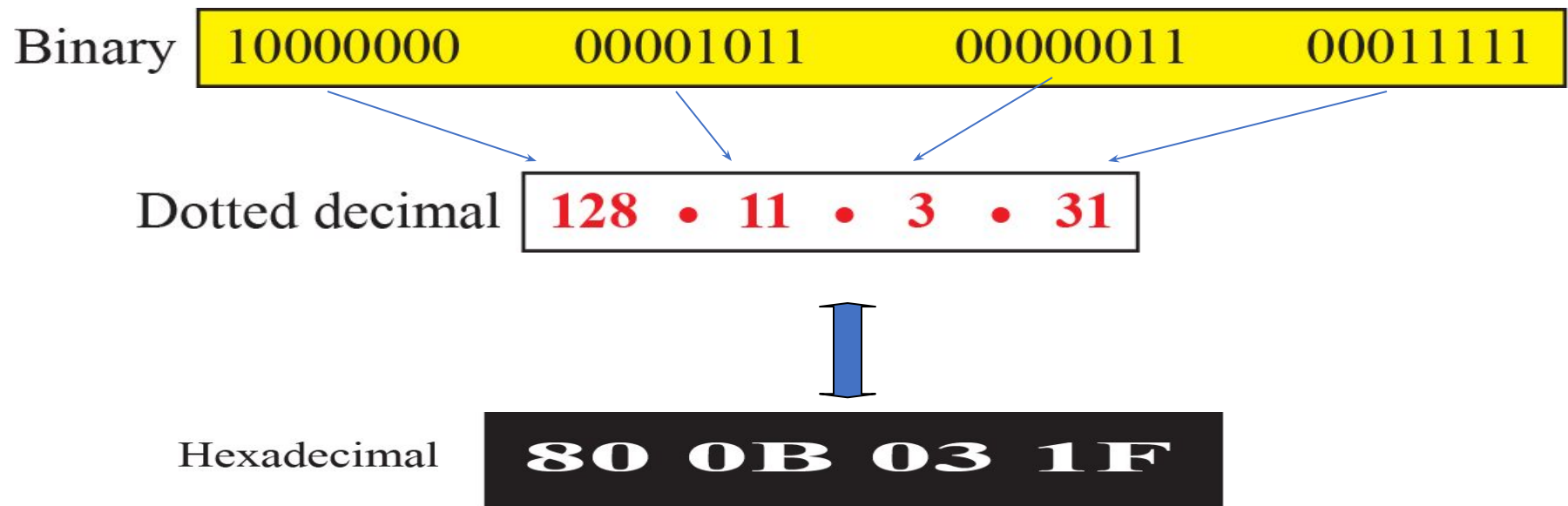
Routing and Forwarding Service

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

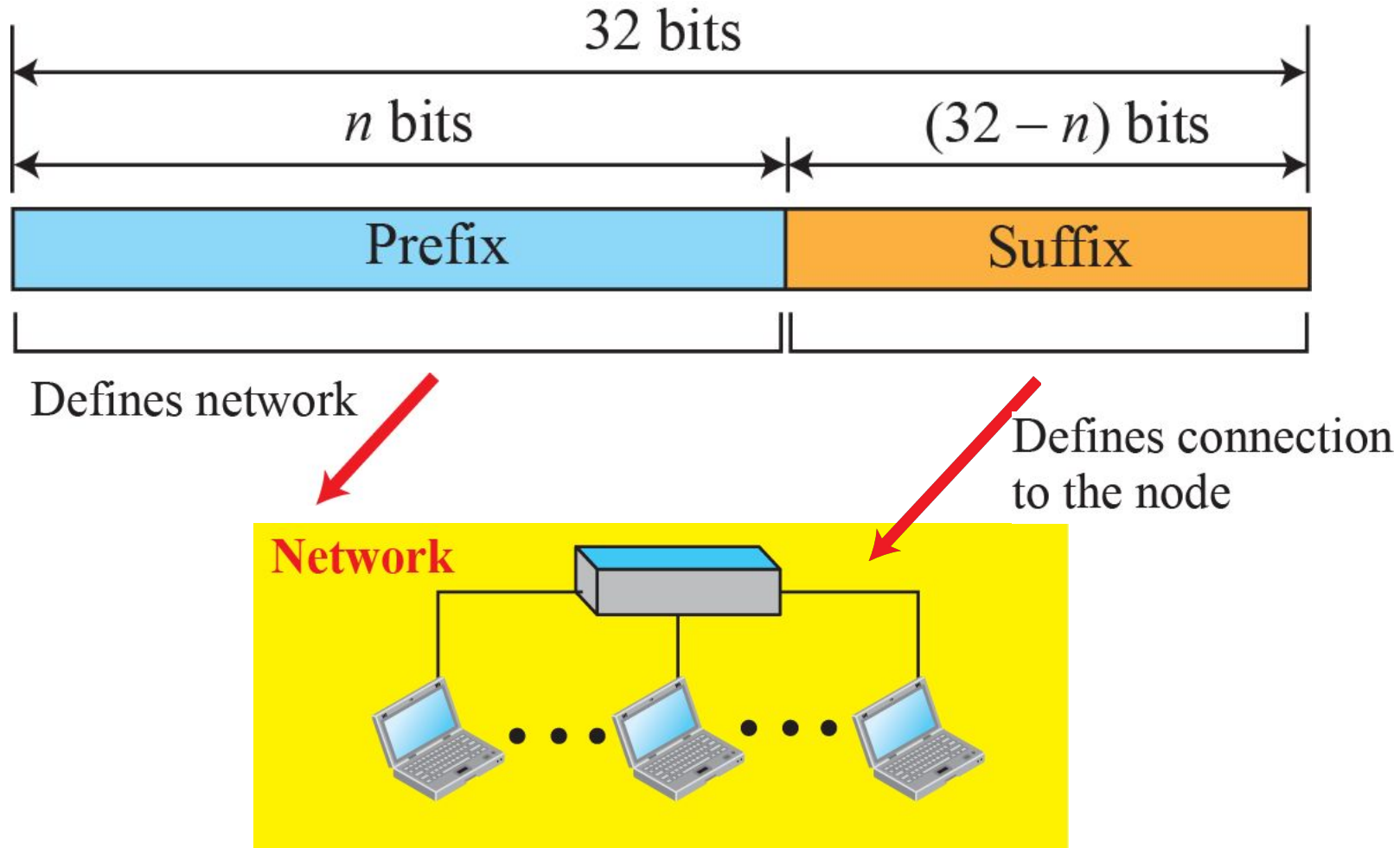


IPv4 Addressing

- 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).

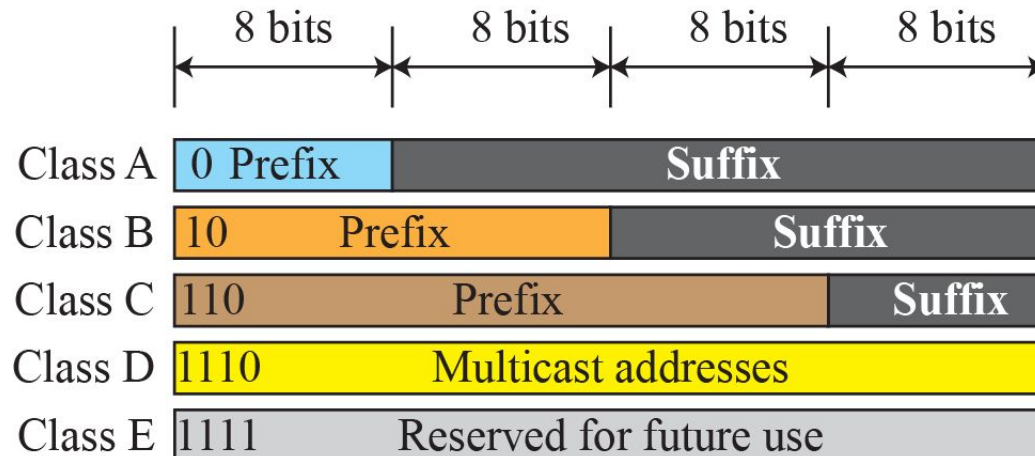


Classful IPv4 Addressing



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.



Examples:

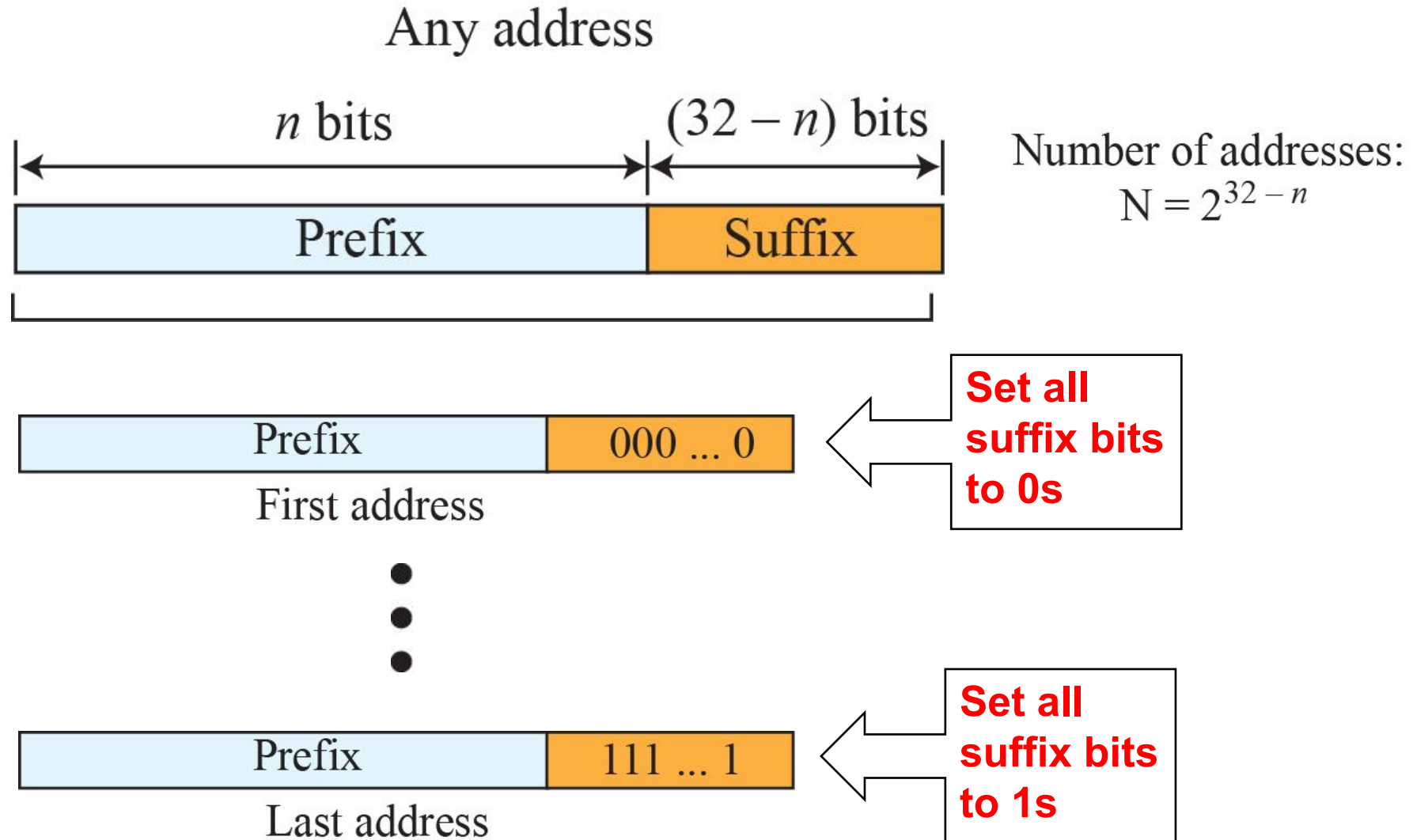
12.24.76.8/**8**

23.14.67.92/**12**

220.8.24.255/**25**

Prefix
length ←

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: $N = \text{NOT}(\text{mask}) + 1 = 0.0.0.31 + 1 = 32$ addresses

First address: First = (address) **AND** (mask) = 167.199.170. **64**

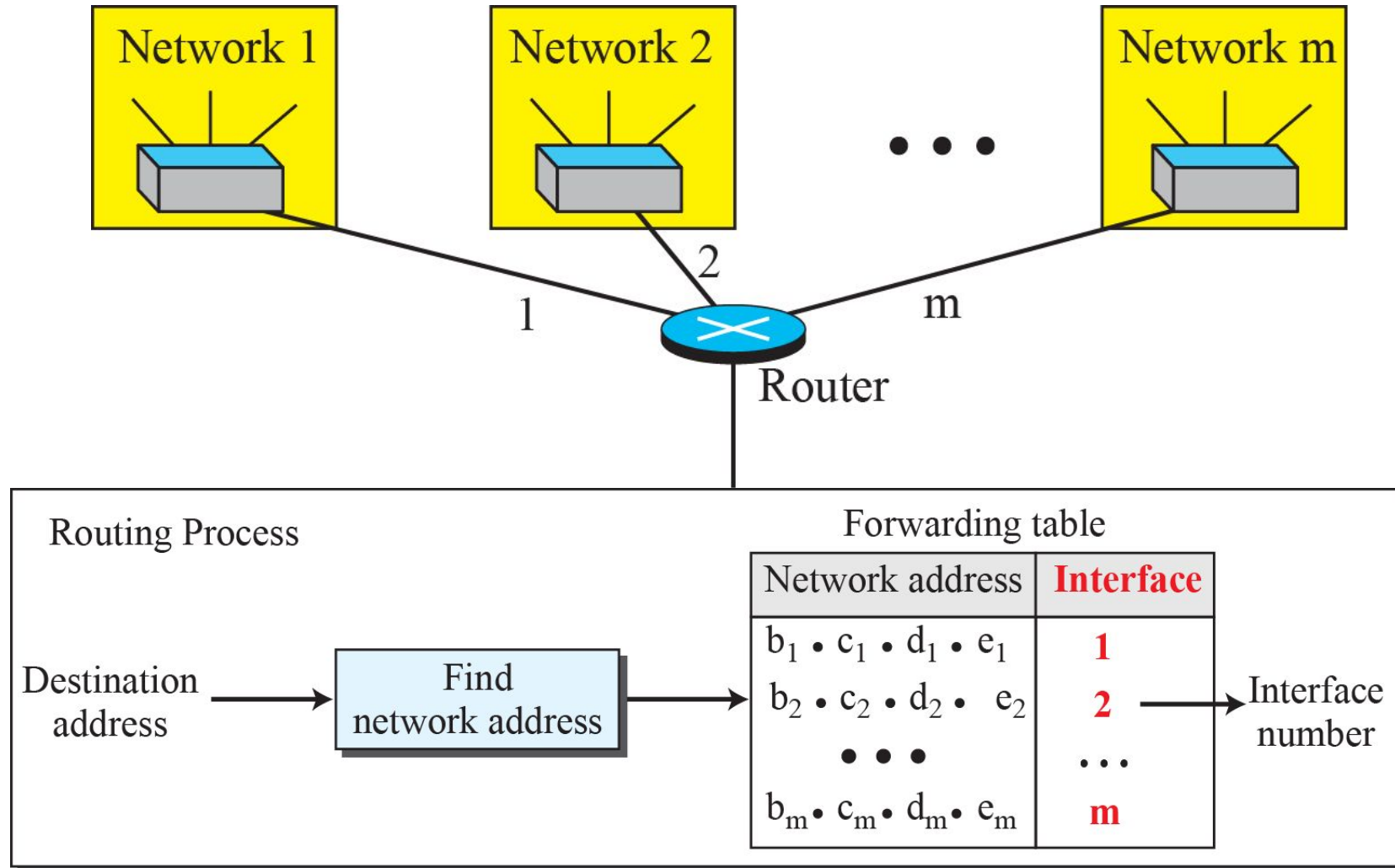
Last address: Last = (address) **OR** (**NOT** mask) = 167.199.170. **95**

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



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.

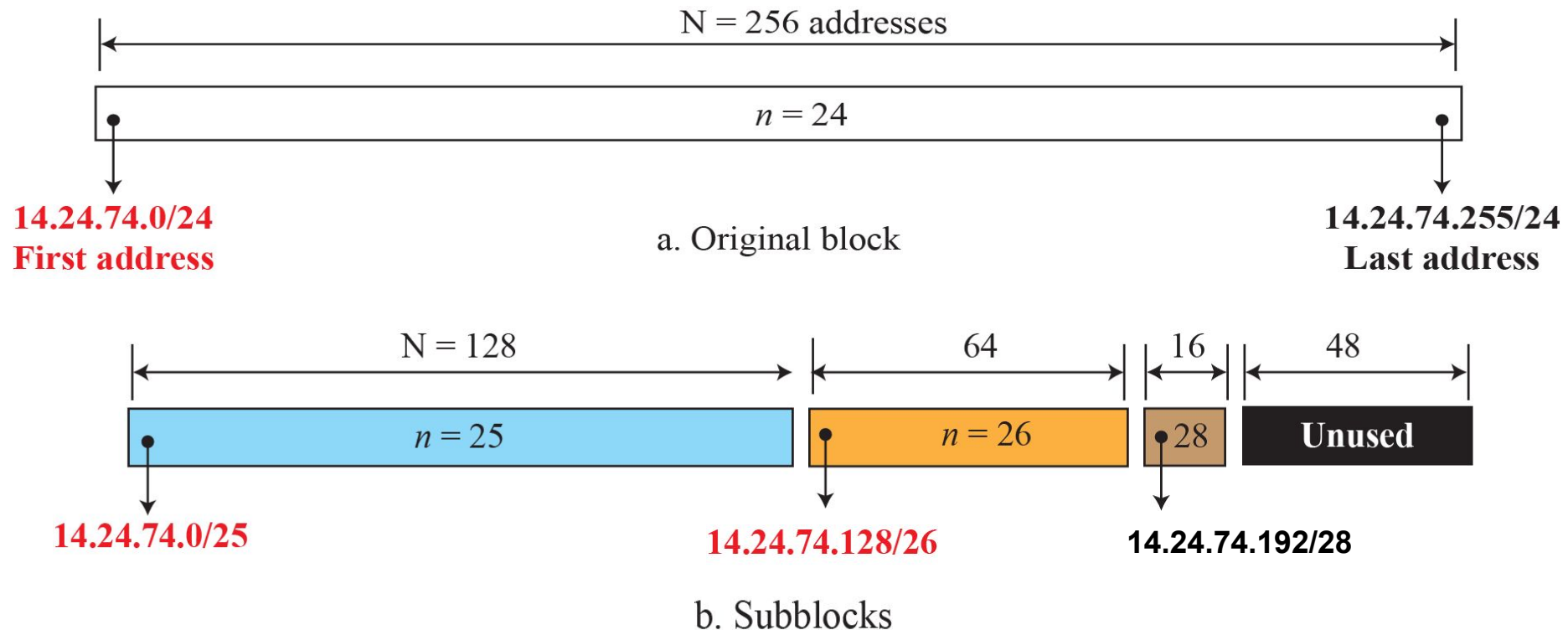
Solution

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.



Dynamic Host Configuration Protocols (DHCP)

0	8	16	24	31
Opcode	Htype	HLen	HCount	
Transaction ID				
Time elapsed		Flags		
Client IP address				
Your IP address				
Server IP address				
Gateway IP address				
Client hardware address				
Server name				
Boot file name				
Options				

Fields:

Opcode: Operation code, request (1) or reply (2)

Htype: Hardware type (Ethernet, ...)

HLen: Length 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

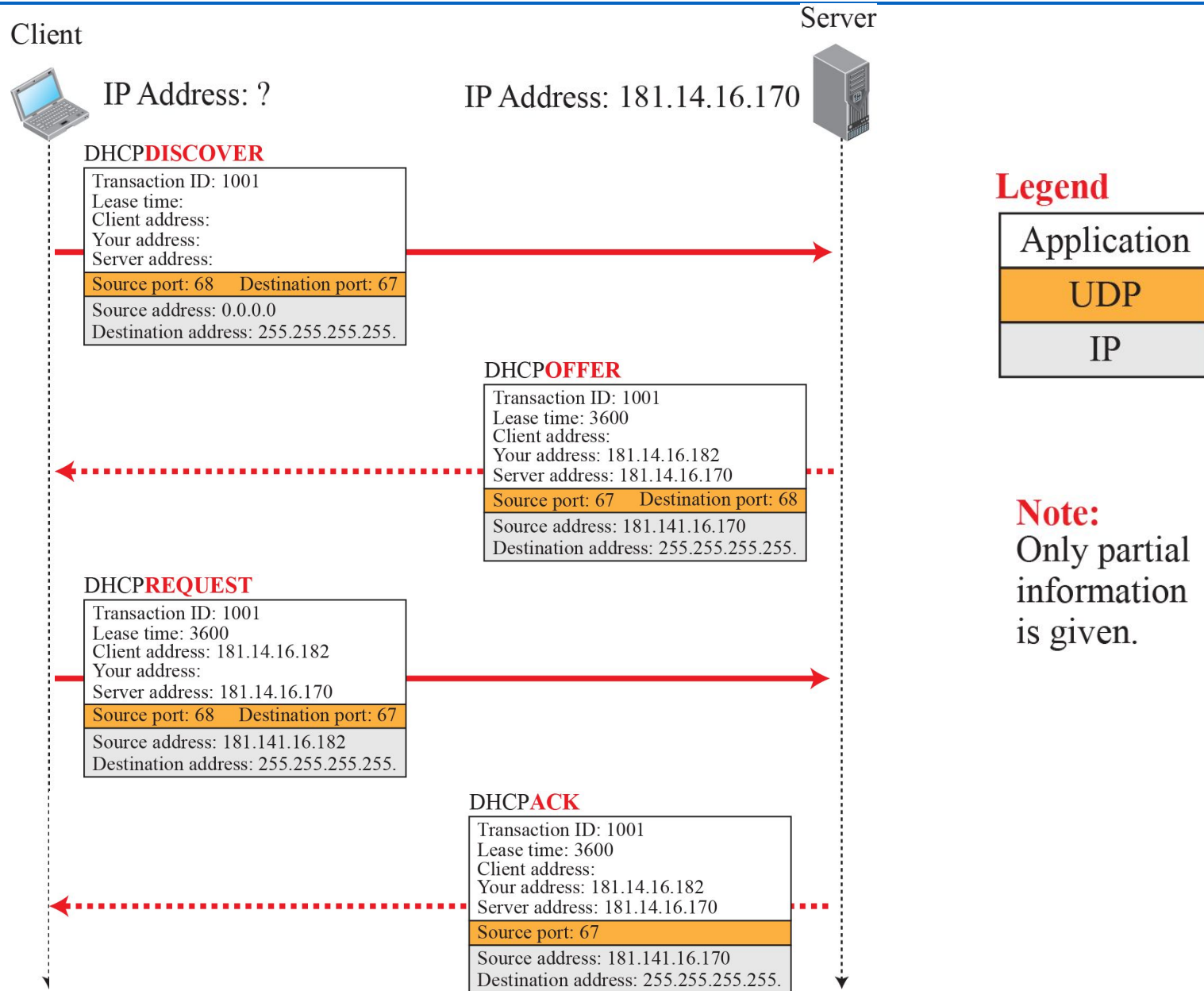
Options: A 64-byte field with dual purpose described in text

- 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.

1 DHCP DISCOVER	5 DHCP ACK
2 DHCP OFFER	6 DHCP NACK
3 DHCP REQUEST	7 DHCP RELEASE
4 DHCP DECLINE	8 DHCP INFORM

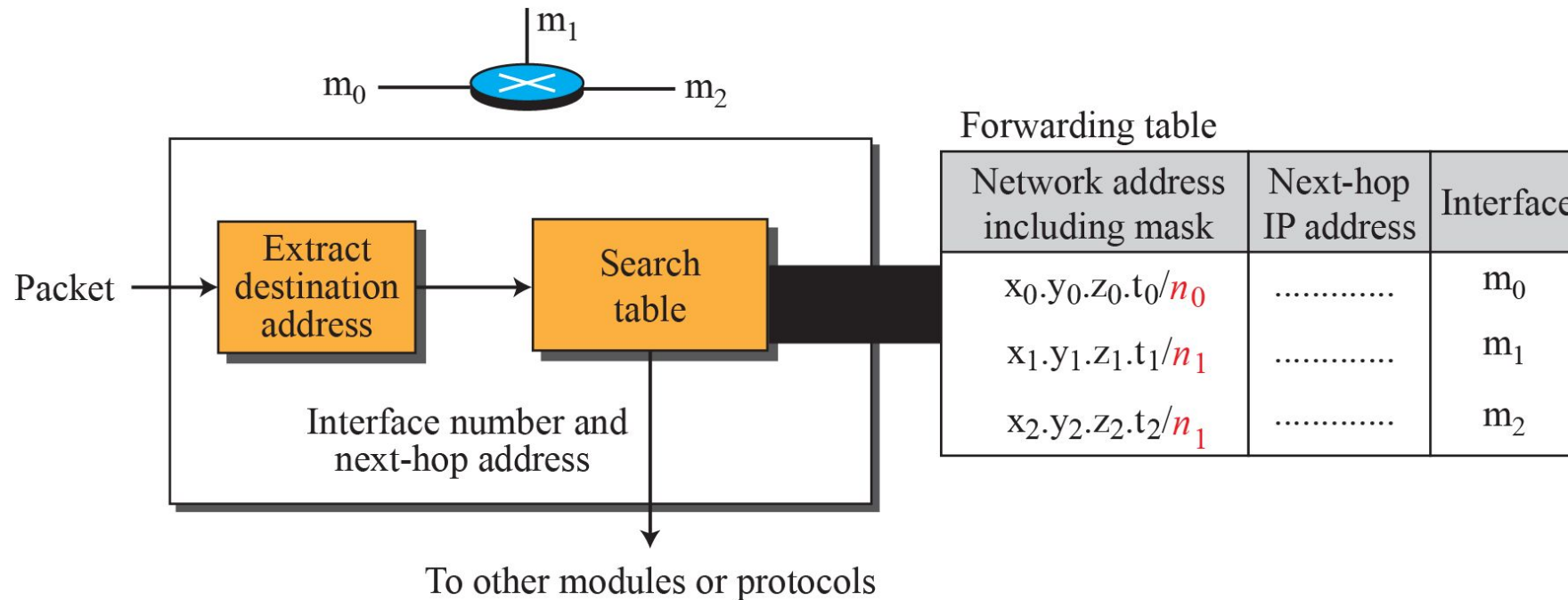
53	1	•
Tag	Length	Value

DHCP Operation



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.



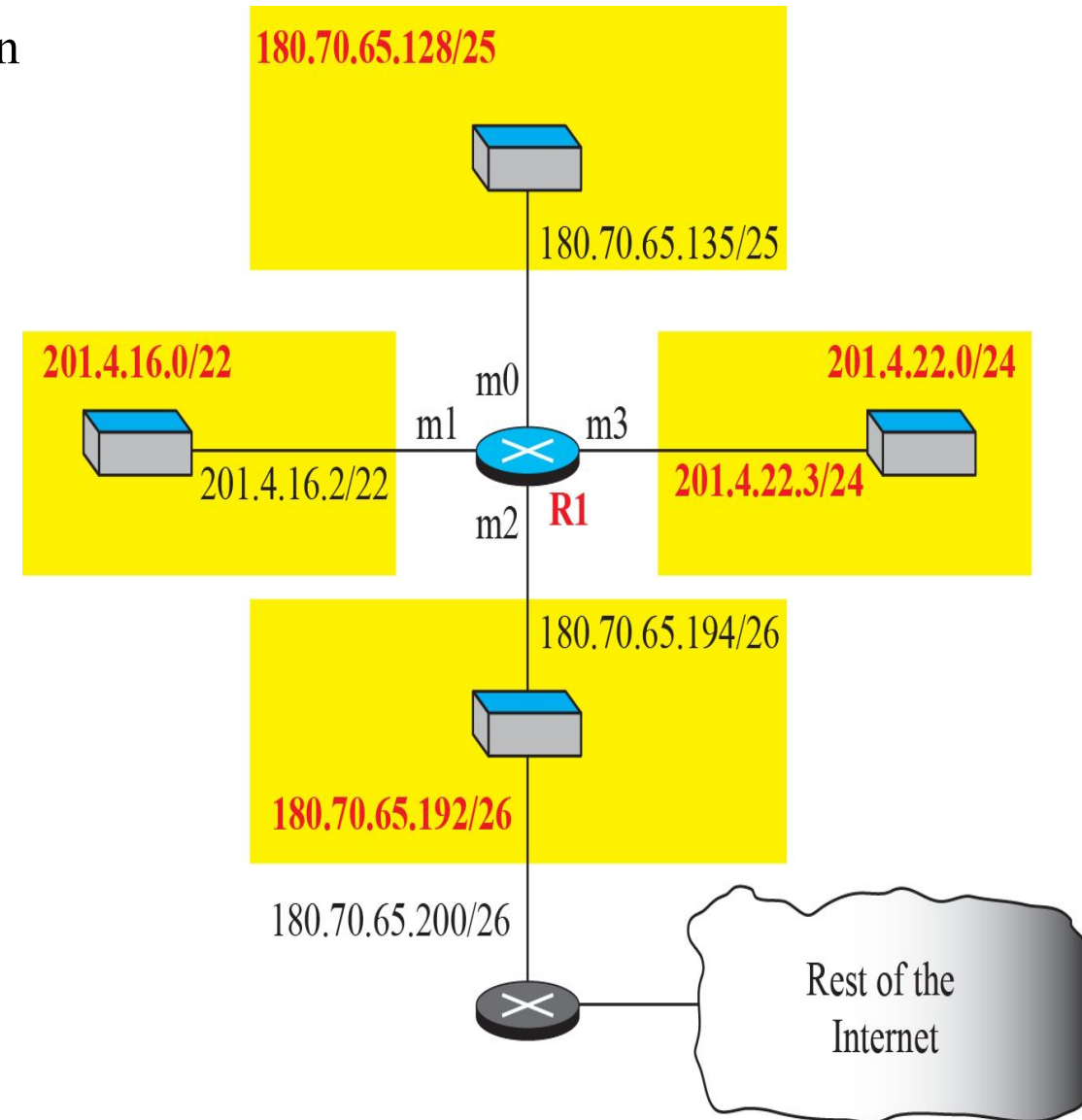
Example 6.1: Creating Forwarding Table

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

Subnetting Practice Questions

- . An organization is granted the block 16.0.0.0/8. The administrator wants to create 500 fixed-length subnets.
 - a. Find the subnet mask.
 - b. Find the number of addresses in each subnet.
 - c. Find the first and last addresses in subnet 1.
 - d. Find the first and last addresses in subnet 500.

Solution

d. Subnet 500:

Note that the subnet 500 is not the last possible subnet; it is the last subnet used by the organization. To find the first address in subnet 500, we need to add 16,351,232 (499×32678) in base 256 (0. 249.128.0) to the first address in subnet 1. We have $16.0.0.0 + 0.249.128.0 = \mathbf{16.249.128.0}$. Now we can calculate the last address in subnet 500.

First address in subnet 500:	16	.	249	.	128	.	0
Number of addresses:	0	.	0	.	127	.	255
Last address in subnet 500:	16	.	249	.	255	.	255

Subnetting Practice Questions

23. An organization is granted the block 211.17.180.0/24. The administrator wants to create 32 subnets.
- a. Find the subnet mask.
 - b. Find the number of addresses in each subnet.
 - c. Find the first and last addresses in subnet 1.
 - d. Find the first and last addresses in subnet 32.

Solution

a. $\log_2 32 = 5$ Extra 1s = **5** Possible subnets: **32** Mask: **/29** (24 + 5)

b. $2^{32-29} = \mathbf{8}$ Addresses per subnet

c. **Subnet 1:**

The first address is the beginning address of the block or **211.17.180.0**. To find the last address, we need to write 7 (one less than the number of addresses in each subnet) in base 256 (0.0.0.7) and add it to the first address (in base 256).

First address in subnet 1:	211	.	17	.	180	.	0
Number of addresses:	0	.	0	.	0	.	7
Last address in subnet 1:	211	.	17	.	180	.	7

In 32 block

First add: 211.17.180.240

Last add: 211.17.180.247

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

*Thank
you!*