18.6.2 Key Terms

address aggregation
address space
choke packet
classful addressing
classless addressing
classless interdomain routing (CIDR)
closed-loop congestion control
Dynamic Host Configuration Protocol (DHCP)
longest mask matching
magic cookie
network address
Network Address Translation (NAT)
open-loop congestion control
packetizing

18.6.3 Summary

- The network layer in the Internet provides services to the transport layer and receives services from the network layer.
- The main services provided by the network layer are packetizing and routing the packet from the source to the destination.
- The network layer in the Internet does not seriously address other services such as flow, error, or congestion control.
- One of the main duties of the network layer is to provide packet switching.
- There are two approaches to packet switching: datagram approach and virtual-circuit approach.
- The first is used in a connectionless network; the second, in a connectionoriented network.
- Currently, the network layer is using the first approach, but the tendency is to move to the second.
- Performance of the network layer is measured in terms of delay, throughput, and packet loss.
- Congestion control is a mechanism that can be used to improve the performance.

- Although congestion control is not directly implemented at the network layer, the discussion can help us to understand its indirect implementation and also to understand the congestion control implemented at the transport layer.

- One of the main issues at the network layer is addressing.

- In this chapter, we discussed addressing in IPv4 (the current version).

- We explained the address space of the IPv4 and two address distribution mechanisms: classful and classless addressing.

- Although the first is deprecated, it helps us to understand the second.

- In classful addressing the whole address space is divided into five fixed-size classes.

- In classless addressing, the address space is divided into variable-size blocks based on the demand.

- Some problems of address shortage in the current version can be temporarily alleviated using DHCP and NAT protocols.

- The section on forwarding helps to understand how routers forward packets.

- Two approaches are used for this purpose.

- The first approach, which is used in a connectionless network such as the current Internet, is based on the destination address of the packet.

- The second approach, which can be used if the Internet is changed to a connectionoriented network, uses the labels in the packets.

Q18-1. Why does the network-layer protocol need to provide packetizing service to the transport layer? Why can't the transport layer send out the segments without encapsulating them in datagrams?

Q18-1. The transport layer communication is between two ports; the network layer communication is between two hosts. This means that each layer has a different source/destination address pair; each layer needs a different header to accommodate these pair of addresses. In addition, there are other pieces of information that need to be separately added to the corresponding header.

Q18-2. Why is routing the responsibility of the network layer? In other words, why can't the routing be done at the transport layer or the data-link layer?

The network layer is responsible for routing the packet from its source to the destination. A physical network is a combinationof networks (LANs and WANs) and routers that connect them. This means that there is more than one route from the source to the destination. The network layer is responsible for finding the best one among these possible routes. The network layer needs to have some specific strategies for definingthe best route. In the Internet today, this is done by running some routing protocols to help the routers coordinate their knowledge about the neighborhood and to come up with consistent tables to be used when a packet arrives.

Q18-3. Distinguish between the process of routing a packet from the source to the destination and the process of forwarding a packet at each router.

Q18-3. Forwarding is delivery to the next node. A router uses its forwarding table to send a packet out of one of its interfaces and to make it to reach to the next node. In other words, forwarding is the decision a router makes to send a packet out of one of its interfaces. Routing, on the other hand, is an end-to-end delivery resulting in a path from the source to the destination for each packet. This means a routing process is a series of forwarding processes. To enable each router to perform its forwarding duty, routing protocols need to be running all of the time to provide updated information for forwarding tables. Although forwarding is something we can see in the foreground, in the background, routing provides help to the routers to do forwarding.

Q18-4. What is the piece of information in a packet upon which the forwarding decision is made in each of the following approaches to switching?

a. datagram approach **b.** virtual-circuit approach

• In the datagram approach each source and destination is identified by a unique address, this destination address is provided in the header part of the data packet that is being transferred. While forwarding a packet using datagram approach forwarding decision is based by looking up at the forwarding table and the header part of the packet, based on the destination address in the header part forwarding is done.

• In virtual circuit approach a virtual circuit is established between the source and the destination. Each packet contains a virtual circuit identifier in the packet header a forwarding decision is based on this virtual circuit identifier in the packet header. By referring the virtual circuit table and using the virtual circuit identifier mentioned in the packet header forwarding is done.

Q18-5. If a label in a connection-oriented service is 8 bits, how many virtual circuits can be established at the same time?

Q18-5. The number of virtual circuits is $2^8 = 256$.

Q18-6. List the three phases in the virtual-circuit approach to switching.

There are three phases in a virtual circuit approach to switching:

1) Setup phase: during the setup phase a connection is established between the source and the destination systems. The source system which wants to communicate with the destination sends a Request packet containing the source and destination addresses. An acknowledgement packet is sent by the destination and all the entries are entered into the switching tables of the routers.

2) Data Transfer phase: this is the data transfer phase where using the forwarding table information of the routers data is transferred between the source and destination.

3) Teardown Phase: once the data transfer is completed, the source sends a special packet called teardown packet to disconnect the connection established. The destination also sends a confirmation packet to disconnect the connection and deletes all the switching table entries.

Q18-7. Do we have any of the following services at the network layer of TCP/IP? If not, why?

a. flow control **b.** error control **c.** congestion control

Q18-7. None of these services are implemented for the IP protocol in order to make it simple.

Q18-8. List four types of delays in a packet-switched network.

• **Processing delay**: this is the amount of processing time taken by a router it is the time between when a router receives a packet and when the packet is forwarded towards the output interface.

• A router after receiving the packet identifies the destination, does error checking and identifies which route to be taken to move towards the destination all this processing accounts to the processing delay.

• **Queuing delay:** this is the amount of time spent by the packet waiting in a queue for transmission by the router. When a router receives more number of packets that are to be transmitted towards the destination packets are placed in queue and are transmitted on first come first serve basis.

• **Transmission delay:** this is the amount of time taken by a router to transmit or put a packet on the output link towards the destination.

• **Propagation delay:** this is the amount of time taken by a packet to move from one end of the output interface link to the other end of the link or to the next link.

Q18-9. In Figure 18.10, assume that the link between R1 and R2 is upgraded to 170 kbps and the link between the source host and R1 is now downgraded to 140 kbps. What is the throughput between the source and destination after these changes? Which link is the bottleneck now?

Q18-9. The throughput is the smallest transmission rate, or 140 Kbps. The bottleneck is now the link between the source host and R1.

Q18-10. In classless addressing, we know the first and the last address in the block. Can we find the prefix length? If the answer is yes, show the process.

Classless addressing:

• Larger address spaces needed as a long-term solution because Internet rapidly growing.

• Larger address space means that increment in IP addresses, such as Internet Protocol version 6 (IPv6), there is changed in size of IP packets.

• For a short-term solution, still uses Internet Protocol version 4 (IPv4) and it is called classless addressing.

Consider the following details:

If the user knows both first address and last address, that means block is completely defined.

Use this relation to calculate total number of address (N):

$$N = 2^{32-n}$$

Use this relation to calculate length of the prefix (n):

$$n = 32 - \log_2 N$$

Example:

First address: 18.23.13.64

Last address: 18.23.13.72

Then the total number of address (N) is 8.

Calculate length of the prefix (n):

$$\begin{aligned} n &= 32 - \log_2 N \\ &= 32 - \log_2 8 \\ &= 32 - \log_2 2^3 \\ &= 32 - 3 \end{aligned}$$

$$= 29$$

Yes, the user can find the length of prefix, for this example length of prefix is $\boxed{29}$ bits.

Q18-11. In classless addressing, we know the first address and the number of addresses in the block. Can we find the prefix length? If the answer is yes, show the process.

Q18-11. Yes. We can find the prefix length using only the block size. The prefix length is directly related to the block size as shown below:

$$n = 32 - \log_2 N$$

Q18-12. In classless addressing, can two different blocks have the same prefix length? Explain.

- Yes, in classless addressing two blocks can have same prefix.
- Prefix length usually indicates the number of addresses in a block. Therefore more than two blocks have same number of addresses indicating same prefix length. Same number of addresses with different addresses in each block.

18.7.3 Problems

P18-1. What is the size of the address space in each of the following systems?

a. A system in which each address is only 16 bits.

b. A system in which each address is made of six hexadecimal digits.

c. A system in which each address is made of four octal digits.

P18-1. The size of the address in each case is the base to the power of the number of digits:

a. The size of the address space is $2^{16} = 65{,}536$.

b. The size of the address space is $16^6 = 16{,}777{,}216$.

c. The size of the address space is $8^4 = 4096$.

P18-2. Rewrite the following IP addresses using binary notation:

a. 110.11.5.88 **b.** 12.74.16.18 **c.** 201.24.44.32

a) Given IP address is 110.11.5.88

• Convert each byte into binary, the binary notation of 110 is 01101110

• The binary notation of 11 is 00001011.

• The binary notation of 5 is 00000101.

• The binary notation of 88 is 01011000.

Therefore the binary notation of the IP address is 01101110 00001011 00000101 01011000.

b) Given IP address is 12.74.16.18

• The binary notation of 12 is 00001100.

• The binary notation of 74 is 01001010.

• The binary notation of 16 is 00010000.

• The binary notation of 18 is 00010010.

Therefore the binary notation of the IP address is 00001100 01001010 00010000 00010010

c) Given IP address is 201.24.44.32

• The binary notation of 201 is 11001001

• The binary notation of 24 is 00011000

• The binary notation of 44 is 00101100

• The binary notation of 32 is 00100000

Therefore the binary notation of the IP address is 11001001 00011000 00101100 00100000

P18-3. Rewrite the following IP addresses using dotted-decimal notation:

a. `01011110 10110000 01110101 00010101`

b. `10001001 10001110 11010000 00110001`

c. `01010111 10000100 00110111 00001111`

P18-3. We change each 8-bit section to the corresponding decimal value and insert dots between the bytes.

a. 94.176.117.21

b. 137.142.208.49

c. 87.132.55.15

P18-4. Find the class of the following classful IP addresses:

a. 130.34.54.12 b. 200.34.2.1 c. 245.34.2.8

The class of an IP address can be identified by observing the first 8 bits or first byte of the address.

a) Given IP address is 130.34.54.12 the first byte is 130

• If the IP address of the first byte is in between 128-191 then the IP address belongs to Class B.

b) Given IP address is 200.34.2.1 the first byte is 200

• If the IP address of the first byte is in between 192-223 then the IP address belongs to Class C.

c) Given IP address is 245.34.2.8 the first byte is 245

• If the IP address of the first byte is in between 240-254 then the IP address belongs to Class E.

P18-5. Find the class of the following classful IP addresses:

a. `01110111 11110011 10000111 11011101`

b. `11101111 11000000 11110000 00011101`

c. `11011111 10110000 00011111 01011101`

P18-5. The class can be defined by checking the first few bits (see figure 4.31). We need to stop checking if we find a 0 bit or four bits have already been checked.

a. Since the first bit is 0, the Class is A.

b. Since the first four bits are 1110, the class is D.

c. Since the first three bits are 110, the class is C.

P18-6. In classless addressing, show the whole address space as a single block using the CIDR notation.

- To show the whole address space as a single block using CIDR notation, the address space should consists of 2^{32} addresses.
- When the address space has 2^{32} addresses then the prefix value is '0' as $N=2^{32-n}$, where N is the number of addresses of the block or size of the block and n is the prefix length.
- This indicates that the entire address space can be identified by 0.0.0.0.
- Therefore the whole address block can be represented by 0.0.0.0/0 and the first address of the block is 0.0.0.0.

P18-7. In classless addressing, what is the size of the block (N) if the value of the prefix length (n) is one of the following?

a. $n = 0$ b. $n = 14$ c. $n = 32$

P18-7. We can use the formula $N = 2^{32-n}$

a. $N = 2^{32-0} = 4{,}294{,}967{,}296$

b. $N = 2^{32-14} = 262{,}144$

c. $N = 2^{32-32} = 1$

P18-8. In classless addressing, what is the value of the prefix length (n) if the size of the block (N) is one of the following?

a. $N = 1$ **b.** $N = 1024$ **c.** $N = 2^{32}$

- Size of a block is represented by N, $N=2^{32-n}$, where n is the length of the prefix.
- Therefore prefix length can be calculated by $n= 32-\log_2 N$.

a) When N=1, then $n= 32-\log_2 1= 32$.

- Therefore prefix length is 32.

b) When N=1024, then $n=32- \log_2 1024 = 32-10=22$.

- Therefore prefix length is 22.

c) When $N= 2^{32}$, then $n= 32-\log_2 2^{32} = 32-32= 0$

- Therefore prefix length is 0.

P18-9. Change each of the following prefix lengths to a mask in dotted-decimal notation:

a. $n = 0$ **b.** $n = 14$ **c.** $n = 30$

P18-9. We can first write the prefix in binary and then change each 8-bit chunk to decimal:

a. 00000000 00000000 00000000 00000000 **mask:** 0.0.0.0

b. 11111111 11111100 00000000 00000000 **mask:** 255.252.0.0

c. 11111111 11111111 11111111 11111100 **mask:** 255.252.255.252

P18-10. Change each of the following masks to a prefix length:

a. 255.224.0.0 **b.** 255.240.0.0 **c.** 255.255.255.128

a) Firstly represent 255.224.0.0 in binary notation:

- Binary notation is 11111111 11100000 00000000 00000000
- Prefix length is the number of digits set to ‘1’ in a given subnet mask.
- The number of 1’s in the given mask 255.224.0.0 is 11.
- Therefore the prefix length is 11.

b) Represent 255.240.0.0 in binary notation.

- Binary notation is 11111111 11110000 00000000 00000000.
- Prefix length is the number of ‘1’ in a given subnet mask.
- The number of 1’s in the given mask 255.240.0.0 is 12.
- Therefore the prefix length is 12.

c) Represent 255.255.255.128 in binary notation:

- Binary notation is 11111111 11111111 11111111 10000000.
- Prefix length is the number of ‘1’ in a given subnet mask.
- The number of 1’s in the given mask 255.255.255.128 is 25.
- Therefore the prefix length is 25.

P18-11. Which of the following cannot be a mask in CIDR?

a. 255.225.0.0 **b.** 255.192.0.0 **c.** 255.255.255.6

P18-11. We first write each potential mask in binary notation and then check if it has a contiguous number of 1s from the left followed by 0s.

a. `11111111 11100001 00000000 00000000` Not a mask

b. `11111111 11000000 00000000 00000000` A mask

c. `11111111 11111111 11111111 00000110` Not a mask

P18-12. Each of the following addresses belongs to a block. Find the first and the last address in each block.

a. 14.12.72.8/24 **b.** 200.107.16.17/18 **c.** 70.110.19.17/16

The first address in a block can be identified by performing an AND operation between the given address and the subnet mask.

• A subnet mask can be calculated using the prefix length. prefix length indicates the number of 1's in an address.

• The last address in a block can be identified by performing an OR operation between the given address and the compliment of the subnet mask

a) Representing the given address in binary format 14.12.72.8

• 00001110 00001100 01001000 00001000 is the binary representation of the above address.

• The prefix length is 24, therefore assume the subnet mask as

11111111 11111111 11111111 00000000

• Perform AND operation between address and the subnet mask.

00001110 00001100 01001000 00001000

AND 11111111 11111111 11111111 00000000

Result 00001110 00001100 01001000 00000000—first address

• The compliment of the subnet mask is 00000000 00000000 00000000 11111111

• Perform OR operation between the address and the compliment to identify the last address

00001110 00001100 01001000 00001000

OR 00000000 00000000 00000000 11111111

Result 00001110 00001100 01001000 11111111 – last address.

• Therefore the first address in binary format is 00001110 00001100 01001000 00000000 and in decimal format is 14.12.72.0

• The last address in binary format is 00001110 00001100 01001000 11111111 and in decimal format is 14.12.72.255

b) Representing the given address in binary format 200.107.16.17

• 11001000 01101011 00010000 00010001 is the binary representation of the above address.

• The prefix length is 18, therefore assume the subnet mask as

11111111 11111111 11000000 00000000

• Perform AND operation between address and the subnet mask.

11001000 01101011 00010000 00010001

AND 11111111 11111111 11000000 00000000

Result 11001000 01101011 00000000 00000000—first address

• The compliment of the subnet mask is 00000000 00000000 00111111 11111111

• Perform OR operation between the address and the compliment to identify the last address

11001000 01101011 00010000 00010001

OR 00000000 00000000 00111111 11111111

Result 11001000 01101011 00111111 11111111 – last address.

• Therefore the first address in binary format is 11001000 01101011 00000000 00000000 and in decimal format is 200.107.0.0

• The last address in binary format is 11001000 01101011 00111111 11111111 and in decimal format is 200.107.63.255

c) Representing the given address in binary format 70.110.19.17

• 01000110 01101110 00010011 00010001 is the binary representation of the above address.

• The prefix length is 16, therefore assume the subnet mask as

11111111 11111111 00000000 00000000

• Perform AND operation between address and the subnet mask.

01000110 01101110 00010011 00010001

AND 11111111 11111111 00000000 00000000

Result 01000110 01101110 00000000 00000000—first address

• The compliment of the subnet mask is 00000000 00000000 11111111 11111111

• Perform OR operation between the address and the compliment to identify the last address

01000110 01101110 00010011 00010001

OR 00000000 00000000 11111111 11111111

Result 01000110 01101110 11111111 11111111 – last address.

• Therefore the first address in binary format is 01000110 01101110 00000000 00000000 and in decimal format is 70.110.0.0

• The last address in binary format is 01000110 01101110 11111111 11111111 and in decimal format is 70.110.255.255

P18-13. Show the n leftmost bits of the following network-addresses/masks that can be used in a forwarding table.

a. 170.40.11.0/24 **b.** 110.40.240.0/22 **c.** 70.14.0.0./18

P18-13. We write the address in binary and then keep only the leftmost n bits.

a. `10101010 00101000 00001011`

b. `01101110 00101000 111100`

c. `01000110 00001110 00`

P18-14. Explain how DHCP can be used when the size of the block assigned to an organization is less than the number of hosts in the organization.

• DHCP dynamic host configuration protocol is client server protocol, this protocol improves the efficiency by utilizing the IP addresses in an efficient manner.

• DHCP has a feature where it assigns IP address to a host or a computer when it demands for one, this allocation can be done in different methods.

• DHCP dynamically assigns addresses to the clients upon receiving a request. It assumes that only one fourth of the hosts are working at a given moment and assigns addresses for hosts.

• Therefore when an organization is assigned a block of addresses which are less than the number of hosts, DHCP dynamically assigns addresses to the hosts which require an IP address, after the completion of the host task, it assigns the address to other hosts which request for an IP address. Therefore every time a host when wants to access the internet gets a new IP address.

• Thus assigning addresses only to hosts which are running DHCP manages with less number of addresses.

P18-15. Compare NAT and DHCP. Both can solve the problem of a shortage of addresses in an organization, but by using different strategies.

P18-15. Both NAT and DHCP can be used for this purpose. DHCP dynamically assigns one of the assigned addresses when a host needs to access the Internet; NAT permanently assigns a set of private addresses to the host, but maps the private address to the global address when a host needs to use the Internet.

P18-16. Assume we have an internet with an 8-bit address space. The addresses are equally divided between four networks (N_0 to N_3). The internetwork communication is done through a router with four interfaces (m_0 to m_3). Show the internet outline and the forwarding table (with two columns: prefix in binary and the interface number) for the only router that connects the networks. Assign a network address to each network.

• Given that the address space is 8 bit, therefore 2^8=256 addresses are present in the internet.

• 256 addresses when divided between four networks, N_0, N_1, N_2, N_3, each network has 64 addresses.

• Therefore Block N_0 has addresses from 0 to 63.

N_1 has addresses from 64 to 127.

N_2 has addresses from 128 to 191.

N_3 has addresses from 192 to 255.

• Prefix can be calculated by n= 8- $\log_2 64$= 8-6 = 2.

• The leftmost 2 bits in an address belonging to a network identify the interface through which the router forwards the data packets.

• For network N_0 the starting address is 00000000 to 00111111 prefix is 00, the network address is 0.0.0.0/2

• For network N_1 the starting address is 01000000 to 01111111 prefix is 01, the network address is 0.0.0.64/2

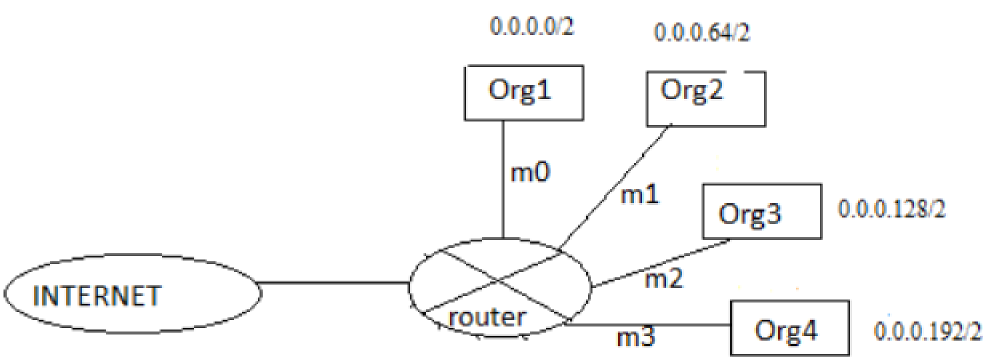
• For network N_2 the starting address is 10000000 to 10111111 prefix is 10, the network address is 0.0.0.128/2

• For network N3 the starting address is 11000000 to 11111111 prefix is 11, the network address is 0.0.0.192/2

• Therefore the forwarding table is:

Prefix	Interface Number
00	M_0
01	M_1
10	M_2
11	M_3

• The diagrammatic representation of the networks and the interfaces connecting to the router:



P18-17. Assume we have an internet with a 12-bit address space. The addresses are equally divided between eight networks (N_0 to N_7). The internetwork communication is done through a router with eight interfaces (m_0 to m_7). Show the internet outline and the forwarding table (with two columns: prefix in binary and the interface number) for the only router that connects the networks. Assign a network address to each network.

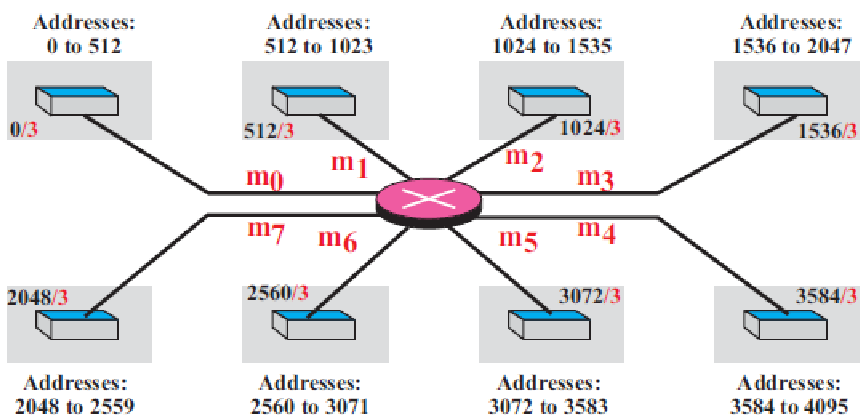
P18-17. The total number of addresses is 2^{12} = 4096. This means that there are 512 addresses for each network. We can divide the whole address space into eight blocks (block 0 to block7), each of 512 addresses. The addresses in each block are allocated as (0 to 511), (512 to 1023), (1024 to 1535), (1536 to 2047), …, (3584 to 4095). It can be checked that each block is allocated according to the two restrictions needed for the proper operation of CIDR. First, the number of addresses in each block is a power of 2. Second, the first address is divisible by the number of addresses as shown below:

Block 0: 0 / 512 = 0 **Block 1**: 512 / 512 = 1 **Block 2**: 1024 / 512 = 2 …

The prefix length for each group is $n_i = 12 - \log_2 512 = 3$. We can then write the ranges in binary to find the prefix for each block.

Block	Range	Range in binary	*n*	Prefix
0	0 to 511	000000000000 to 000111111111	3	000
1	512 to 1023	001000000000 to 001111111111	3	001
2	1024 to 1535	010000000000 to 010111111111	3	010
3	1536 to 2047	011000000000 to 011111111111	3	011
4	2048 to 2559	100000000000 to 100111111111	3	100
5	2560 to 3071	101000000000 to 101111111111	3	101
6	3072 to 3583	110000000000 to 110111111111	3	110
7	3584 to 4095	111000000000 to 111110000000	3	111

The following figure shows the outline and the forwarding table. Note that each interface can use one of the addresses in the corresponding block. The addresses are written in decimal (not dotted-decimal) because of the address space size.



Forwarding table

Prefix	Interface
000	m_0
001	m_1
010	m_2
011	m_3
000	m_4
000	m_5
000	m_6
000	m_7

P18-18. Assume we have an internet with a 9-bit address space. The addresses are divided between three networks (N_0 to N_2), with 64, 192, and 256 addresses respectively. The internetwork communication is done through a router with three interfaces (m_0 to m_2). Show the internet outline and the forwarding table (with two columns: prefix in binary and the interface number) for the only router that connects the networks. Assign a network address to each network.

- Given that the internet has 9-bit address space. Therefore N=9
- Therefore the number of addresses in the ISP is 2^9= 512 addresses.
- Given the addresses are divided into 3 networks, N_0, N_1, N_2 and the number of addresses in each network are 64, 192, 256.
- That is the address range in N_0 is 0 to 63.
- The address range in N_1 is 64 to 255.
- The address range in N_2 is 256 to 511.
- According CIDR rule, the number of addresses in a block or network should be a power of 2. All the networks except N_1 do not satisfy this rule.
- In order to assign addresses to N_1, network N_1 is divided into two sub networks they are N_{11} with range from 64 to 127 and N_{12} with range from 128 to 255.
- Therefore the networks and their address ranges are:

Network N_0: the number of addresses is 64. Range is 0 to 63

- The prefix n= N- $\log_2 64$= 9-$\log_2 64$ = 9-6 = 3
- The first address is 0 00000000
- The last address is 0 00111111
- The subnet mask or prefix is 000 or 3.

Network N_1: the number of addresses is 192. It is divided into two sub networks:

a) **Network N_{11}**: the number addresses are 64. Range is 64 to 127

• The prefix n = N- $\log_2 64$= 9-$\log_2 64$ = 9-6 = 3

• The first address is 0 01000000

• The last address is 0 01111111

• The subnet mask or prefix is 001 or 3.

b) **Network N_{12}**: the number of addresses is 128. Range is 128 to 255

• The prefix n = N- $\log_2 128$= 9-$\log_2 128$ = 9-7 = 2

• The first address is 0 10000000

• The last address is 0 11111111

• The subnet mask or prefix is 01 or 2.

Network N $_2$: the number of addresses is 256. Range is 256 to 511

• The prefix n= N- $\log_2 256$= 9-$\log_2 256$ = 9-8 = 1

• The first address is 1 00000000

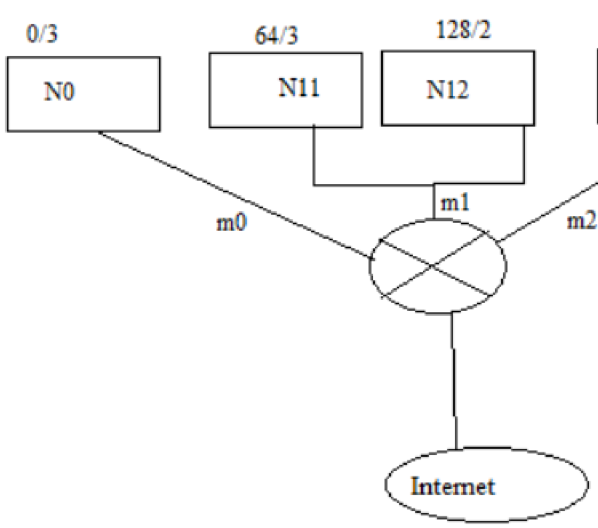
• The last address is 1 11111111

• The subnet mask or prefix is 1.

• The forwarding table for the above network is:

Prefix	**Interface number**
000	m0
001	m1
01	m1
1	m2

• The diagrammatic representation of the interfaces and its connection to the internet is:



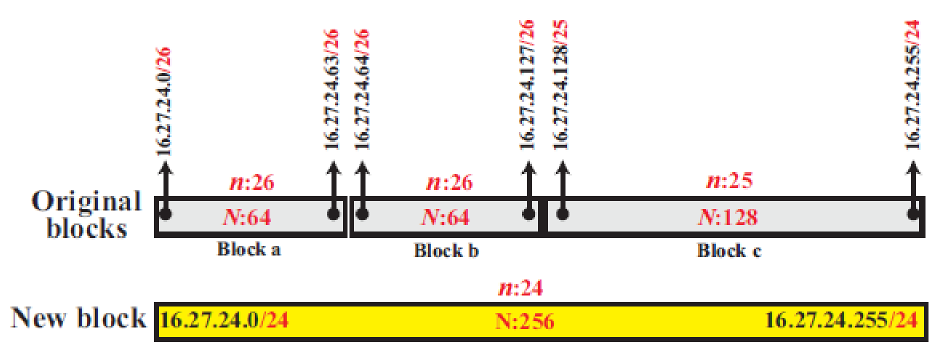
P18-19. Combine the following three blocks of addresses into a single block:

a. 16.27.24.0/**26** **b.** 16.27.24.64/**26** **c.** 16.27.24.128/**25**

P18-19. One way to do this is to first find the size of each block. We can then add the size to the first address in the block to find the last address. Next, we can put the blocks together to find whether they can be combined into a larger block.

Block	Size	First address		Last address
a	$N = 2^{32-26} = 64$	16.27.24.0/26	→	16.27.24.63/26
b	$N = 2^{32-26} = 64$	16.27.24.64/26	→	16.27.24.127/26
c	$N = 2^{32-25} = 128$	16.27.24.128/25	→	16.27.24.255/26

Since the blocks are contiguous, we can combine the three blocks into a larger one. The new block has 256 addresses and $n = 32 - \log_2 256 = 24$.



P18-20. A large organization with a large block address (12.44.184.0/21) is split into one medium-size company using the block address (12.44.184.0/22) and two small organizations. If the first small company uses the block (12.44.188.0/23), what is the remaining block that can be used by the second small company? Explain how the datagrams destined for the two small companies can be correctly routed to these companies if their address blocks still are part of the original company.

Consider the given data:

The block address of a large organization = 12.44.184.0/21.

This organization is divided into one medium organization and two small organizations.

The block address of the medium organization = 12.44.184.0/22.

Each block address of two small organizations = 12.44.188.0/23.

The required calculations are given below:

The number of address bits of the large organization(prefix) is n = 21 bits.

The number of addresses of the large organization is,

$$\begin{aligned} N &= 2^{32-n} \\ &= 2^{32-21} \\ &= 2^{11} = 2048 \end{aligned}$$

The number of addresses of the large organization is 2048 addresses.

The number of address bits of the medium organization(prefix) is n = 22 bits.

The number of addresses of the medium organization is,

$$\begin{aligned} N &= 2^{32-n} \\ &= 2^{32-22} \\ &= 2^{10} = 1024 \end{aligned}$$

The number of addresses of the medium organization is 1028 addresses.

The number of address bits of the first small organization(prefix) is n = 23 bits.

The number of addresses of the first small organization is,

$$\begin{aligned} N &= 2^{32-n} \\ &= 2^{32-23} \\ &= 2^{9} = 512 \end{aligned}$$

The number of addresses of the first small organization is 512 addresses.

Now, calculate the number of addresses of the second small organization using the below formula.

The number of addresses of the second small organization = Total addresses of the large organization – (total addresses of the medium organization + total addresses of the first small organization).

The number of addresses of the second small organization is,

$$= 2048 - (1024 + 512)$$
$$= 2048 - 1536$$
$$= 512$$

Therefore, the number of addresses of the second small organization is $\boxed{512}$ addresses.

The block address of the large organization = 12.44.184.0/21.

The number of address bits(prefix) of the large organization = 21 bits.

Convert the block address of the large organization into binary form as below:

00001100 00101100 10111000 00000000

The subnet mask is given by converting the first 21 bits of the address of the large organization into 1's and remaining bits remains constant. Then, the subnet mask is 11111111. 11111111.11111000. 00000000 (in binary). The decimal representation for this is 255.255.248.0.

The first address of the large organization can be identified by performing an AND operation between the network address and the subnet mask.

Perform the AND operation between the 12.44.184.0 and 255.255.248.0

The result of the AND operation is 12.44.184.0/21.

Therefore, the first address block of the large organization is 12.44.184.0/21.

The last address of the large organization can be identified by performing an OR operation between the network address and the subnet mask.

The subnet mask to get the last address is given as make last (32-n) bits as 1's and remaining all bits are 0's. Then, the subnet mask is 00000000 00000000 00000111 11111111 (in binary). The decimal representation for this is 0.0.7.255.

Perform the OR operation between the 12.44.184.0 and 0.0.7.255

The result of the OR operation is 12.44.191.255

Therefore, the last address block of the large organization is 12.44.191.255 /21.

Similarly, for the medium organization and the first small organization.

Now, calculate the block address used by the second small organization.

From the above calculation, the number of addresses of the second small organization is 512 bits.

The prefix of the block address of the second small organization is given using the below formula:

$$N = 2^{32-n}$$
$$512 = 2^{32-n}$$
$$2^9 = 2^{32-n}$$
$$9 = 32 - n$$
$$n = 23$$

The prefix of the block address of the second small organization is 23.

Therefore, the block address 12.44.190.0/23 is used by the second small organization.

The below diagram represents the address blocks of the medium organization, the first small organization, and the second small organization:

Network address	First address	Last address	Number of addresses in the block
12.44.184.0/22	12.44.184.0/22	12.44.187.255/22	1024
12.44.188.0/23	12.44.188.0/23	12.44.189.255/23	512
12.44.190.0/23	12.44.190.0/23	12.44.191.255/23	512

To forward the datagram packets, the router constructs a forwarding table and the forwarding table consists of the subnet mask and the interface through which the packets are forwarded.

Prefix or subnet mask	Interface name
00001100 00101100 101110	M0 (interface leading to medium size organization)
00001100 00101100 1011110	M1 (interface leading to first small size organization)
00001100 00101100 1011111	M2 (interface leading to second small size organization)

• Therefore, when a router receives a data packet with a destination address, the router extracts the first 23 bits of the address.

• These 23 bits are compared with the small size organization subnet masks in the forwarding table. If a match is found the packet is forwarded through that interface.

• When the 23 bits do not match with the small size organization subnet masks in the forwarding table, then the router extracts the first 22 bits of the destination address and it is compared with the medium size organization subnet mask. If it matches, then the data packet is forwarded through that interface.

For example: A router receives a data packet with address 12.44.190.70 binary format of the address is 00001100 00101100 10111110 01001000.

The router extracts the first 23 bits of the address (00001100 00101100 1011111). These bits when compared to the forwarding table. The third subnet mask matches with these bits.

Therefore, the packet is forwarded using interface M2(interface leading to second small size organization).

P18-21. An ISP is granted the block 16.12.64.0/20. The ISP needs to allocate addresses for 8 organizations, each with 256 addresses.

a. Find the number and range of addresses in the ISP block.

b. Find the range of addresses for each organization and the range of unallocated addresses.

c. Show the outline of the address distribution and the forwarding table.

P18-21.

a. The number of addresses in the ISP block is $N = 2^{32-20} = 4096$. We can add 4095 (which is $N - 1$) to the first address to find the last one (note that the addition can be done in base 256, as described in Appendix B. In base 256, 4095 is (15.255). We have

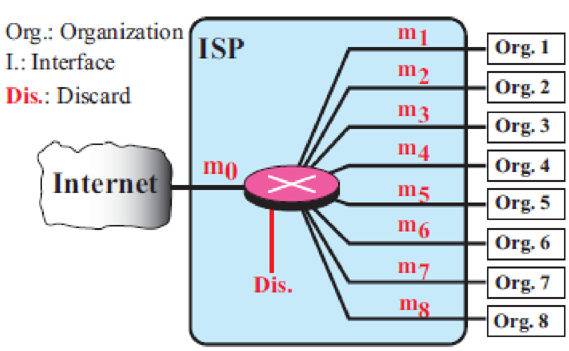
First address: 16.12.64.0/**20** Last address: 16.12.79.255/**20**

The prefix length for each organization is $n_i = 32 - \log_2 256 = 24$. We assume that the addresses are allocated from the beginning of the ISP block with each organization consuming 256 addresses. The following shows how addresses are allocated. Note that the prefix for each block is 24 bits.

Block	First address		Last address	*n*
1	16.12.64.0/**24**	→	16.12.64.255/**24**	**24**
2	16.12.65.0/**24**	→	16.12.65.255/**24**	**24**
3	16.12.66.0/**24**	→	16.12.66.255/**24**	**24**
4	16.12.67.0/**24**	→	16.12.67.255/**24**	**24**
5	16.12.68.0/**24**	→	16.12.68.255/**24**	**24**
6	16.12.69.0/**24**	→	16.12.69.255/**24**	**24**
7	16.12.70.0/**24**	→	16.12.70.255/**24**	**24**
8	16.12.71.0/**24**	→	16.12.71.255/**24**	**24**
Unassigned	16.12.72.0/**21**	→	16.12.79.255/**21**	**21**

The unallocated addresses, which can be reserved for the future use of the ISP, are 16.12.72.0/**21** to 16.12.79.255/**21**, for a total of 2048 addresses.

b. The simplified outline is given below. Note that packets having destination addresses with the last prefix in the figure are discarded until these addresses are assigned.



Forwarding table

Prefix	Interface
Default	m_0
0001000 00001100 01000000	m_1
0001000 00001100 01000001	m_2
0001000 00001100 01000010	m_3
0001000 00001100 01000011	m_4
0001000 00001100 01000100	m_5
0001000 00001100 01000101	m_6
0001000 00001100 01000110	m_7
0001000 00001100 01000111	m_8
0001000 00001100 01001	**Dis.**

P18-22. An ISP is granted the block 80.70.56.0/21. The ISP needs to allocate addresses for two organizations each with 500 addresses, two organizations each with 250 addresses, and three organizations each with 50 addresses.

a. Find the number and range of addresses in the ISP block.

b. Find the range of addresses for each organization and the range of unallocated addresses.

c. Show the outline of the address distribution and the forwarding table.

a) Given ISP as an address 80.70.56.0/21, therefore the prefix length is 21.

• The number of addresses in the given ISP are N= 2^{32-21}= 2^{11}= 2048 addresses are present in the given block

• The first address can be calculated by converting the given address into binary format and performing an AND operation with its subnet mask that is

01010000 01001000 00111000 00000000- given address

AND 11111111 11111111 11111000 00000000 subnet mask

Result 01010000 01001000 00111000 00000000 first Address

• Therefore the first address in decimal format is 80.70.56.0/21, by adding 2047 addresses to the first address we get the last address of the block that is 80.70.63.255/21.

• The range of the address is 80.70.56.0/21 to 80.70.63.255/21

b) Given that 2 organizations are to be assigned 500 addresses each, 2 organizations have to be assigned 250 addresses each and 3 organizations must be assigned 50 addresses each.

• According to CIDR rules each organization or in a block the number of addresses must be a power of 2, as 500, 250, 50 are not power of 2.

• To satisfy the CIDR restriction 1, assign 512, 256, 64 block of addresses for the organization instead of 500, 250, 64.

• After assigning 2 blocks of 512 addresses each, 2 blocks of 256 addresses each, 3 blocks of 64 addresses each from 2048 addresses, 320 addresses are left out unassigned.

• Block1: let the first address be 80.70.56.0, as there are 512 addresses, the prefix length is 23, then the last address is the first address + 511.

• For the unassigned block as there are 320 addresses, according CIDR restriction the number of addresses in a block should be a power of 2, divide the unassigned block into two parts, unassigned block1 contains 256 addresses and Block2 contains 64 addresses.

• Therefore the ranges for each organization are assuming that all the blocks are continuous

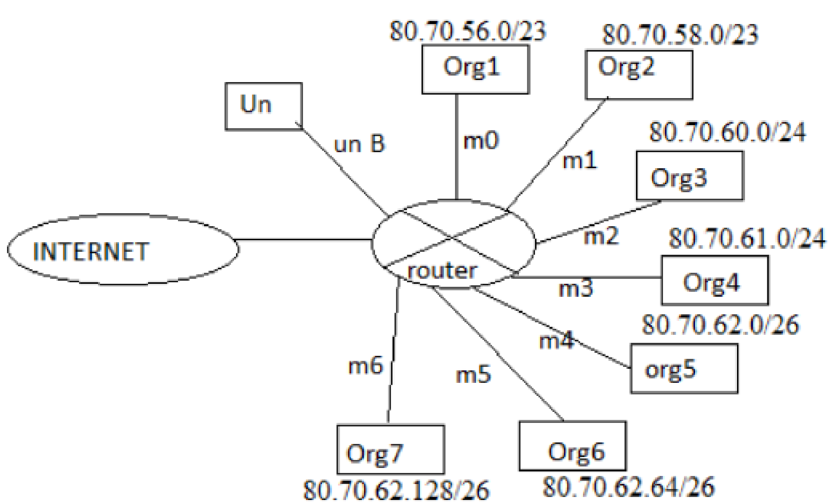
• Therefore the ranges for each organization are assuming that all the blocks are continuous

Block name	Block size	Prefix	Range
Block1	512	$32\text{-}\log_2 512 = 23$	80.70.56.0/23 to 80.70.57.255/23
Block2	512	$32\text{-}\log_2 512=23$	80.70.58.0/23 to 80.70.59.255/23
Block3	256	$32\text{-}\log_2 256=24$	80.70.60.0/24 to 80.70.60.255/24
Block4	256	$32\text{-}\log_2 256=24$	80.70.61.0/24 to 80.70.61.255/24
Block5	64	$32\text{-}\log_2 64= 26$	80.70.62.0/26 to 80.70.62.63/26
Block6	64	$32\text{-}\log_2 64= 26$	80.70.62.64/26 to 80.70.62.127/26
Block7	64	$32\text{-}\log_2 64= 26$	80.70.62.128/26 to 80.70.62.191/26
Un B1	256	$32\text{-}\log_2 256=24$	80.70.62.192/24 to 80.70.63.191/24
Un B2	64	$32\text{-}\log_2 64= 26$	80.70.63.192/26 to 80.70.63.255/26

c) The forwarding table of a router can be given as:

Subnet mask	Interface
01010000 01000110 0011100	m0
01010000 01000110 0011101	m1
01010000 01000110 00111100	m2
01010000 01000110 00111101	m3
01010000 01000110 00111110 00	m4
01010000 01000110 00111110 01	m5
01010000 01000110 00111110 10	m6
01010000 01000110 00111110 11	un b1
01010000 01000110 00111111	un b2

d) The diagrammatic representation of the router and the interfaces is given below:



P18-23. An organization is granted the block 130.56.0.0/16. The administrator wants to create 1024 subnets.

a. Find the number of addresses in each subnet.

b. Find the subnet prefix.

c. Find the first and the last address in the first subnet.

d. Find the first and the last address in the last subnet.

P18-23. The total number of addresses in the organization is $N = 2^{32-16} = 65{,}536$.

a. Each subnet can have $N_{sub} = 65{,}536 / 1024 = 64$ addresses.

b. The subnet prefix for each subnet is $n_{sub} = 32 - \log_2 N_{sub} = 32 - 6 = 26$.

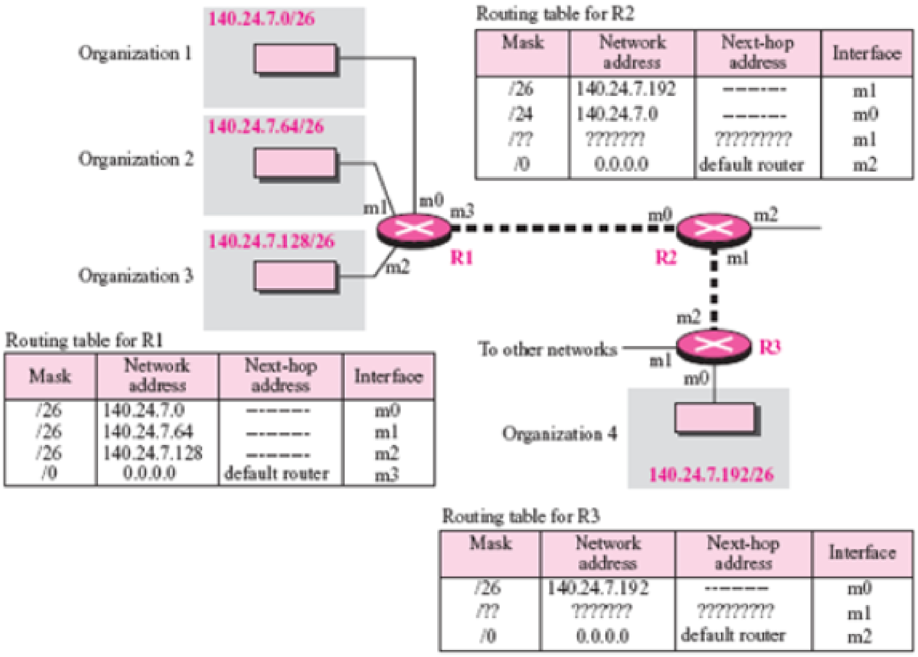
c. Now we can calculate the first and the last address in the first subnet. The first address is the beginning address of the block; the last address is the first address plus 63.

First address: 130.56.0.0/**26** Last address: 130.56.0.63/**26**

d. To find the first address in subnet 1024, we need to add 65,472 (1023 × 64) in base 256 (0.0.255.192) to the first address in subnet 1. The last address can then be found by adding 63 to the first.

First address: 130. 56.255.192/**26** Last address: 130. 56.255.255/**26**

P18-24. Can router R1 in Figure 18.35 receive a packet with destination address 140.24.7.194? What will happen to the packet if this occurs?



Routing table for R2

Mask	Network address	Next-hop address	Interface
/26	140.24.7.192	-------	m1
/24	140.24.7.0	-------	m0
/??	???????	?????????	m1
/0	0.0.0.0	default router	m2

Routing table for R1

Mask	Network address	Next-hop address	Interface
/26	140.24.7.0	-------	m0
/26	140.24.7.64	-------	m1
/26	140.24.7.128	-------	m2
/0	0.0.0.0	default router	m3

Routing table for R3

Mask	Network address	Next-hop address	Interface
/26	140.24.7.192	-------	m0
/??	???????	?????????	m1
/0	0.0.0.0	default router	m2

Packets:

• Grouping data into different pieces in communication protocol.

• The pieces of data are called a packet.

• Packet has some information which is as follows:

• **Header:** Header can be used to control information at the start of packet.

• **Payload:** Payload has the actual data.

• **Trailer:** Trailer can be used to control information at the end of packet and also used to support the protocol operation.

Packet terminology:

• Packet has no standard terminology.

• Packet has the different names which are as follows: Frame, Datagrams, segment, package, and message.

• Different layers have the different name of packets which is as follows:

• **Application Layer:** Message.

• **Transport Layer:** TCP (transmission control protocol) segment, UDP (User datagram protocol) datagram.

• **Data Link Layer:** Frame

• **Network Layer:** Datagram.

Routers:

• Router is a type of software in computer science.

• Router is a type of device which is used to determines the best possible way to send the packets to its destination.

• Router is a type of dispatcher that determines the way to send the packet information.

• In order to send the packet to its destination, it maintains the table and use different types of routing algorithm to find the cost-effective path for the packets.

Destination address:

• What is the final address of the packets?

There are following way to forward a packet which arrives at R1 with final address 140.24.7.194:

• Firstly, it determines the destination address of the packets.

• 140.24.7.194

• Then it will determine the binary value of the above IP address.

• 10001100.00011000.00000111.11000010

• There are five classes defines in computer networking and using the three classes and remaining two classes is for future use and range of these classes are:

• **Class A:** This has the range 0-127.

• **Class B:** This has the range 128-191.

• **Class C:** This has the range 192-223.

• **Class D:** This has the range 224-239. This can be used for multicasting.

• **Class E:** This has the range 240-255.This is reserved for future use.

• From the above class range, the IP address 140.24.7.194 belongs to the Class B.

• So, the destination network of the IP address is Class B.

• From the following routing table R1 which is given in figure 6.16 in the book. There are some mask, network address, corresponding next-hop and interface is present. The mask is as follows:

• Mask/26 which has the net mask in decimal is:255.255.255.192

• For Mask/26 the net mask in binary is:

11111111.11111111.11111111. 11000000

• Net mask is used to calculate the network address from the IP address (140.24.7.194) with the help of bitwise AND (&) between the net mask and given IP address.

• In IP address 140.24 is used for class B network and 7.194 is used for subnet mask to identify the network address through the mask/26 which can be calculated as follows:

• Binary of 7 and 194: 0 0 0 0 0 1 1 1 and 1 1 0 0 0 0 1 0

• Binary of 255 and 192: 1 1 1 1 1 1 1 1 and 1 1 0 0 0 0 0 0

• Calculating the bitwise & will get 0 0 0 0 0 1 1 1 and 1 1 0 0 0 0 0 0

• The resultant value will be in decimal 7 and 192.

• From the above calculation, the network address is for mask/26 is 140.24.7.192.

• If the above address 140.24.7.194 arrives at the router R3, it will send to the interface m0.

• Suppose if the address 140.24.7.194 arrives at the router R2, it will send to the interface m1 and then to the router R3.

• The above calculated address 140.24.7.192 does not match with the given network address of routing table of R1. So, this will not accept this address (140.24.7.194).

• There is only one way by which the router R1 can accept the address which name is as follows that is mention in the figure:

• Organization 1 which has the network address 140.24.7.0.

• Organization 2 which has the network address 140.24.7.64.

• Organization 3 which has the network address 140.24.7.128.

P18-25. Assume router R2 in Figure 18.35 receives a packet with destination address 140.24.7.42. How is the packet routed to its final destination?

P18-25. The packet is sent to router R1 and eventually to organization 1 as shown below:

a. Router R2 applies the mask /26 to the address (or it extracts the leftmost 26 bits) resulting in the network address/mask of 140.24.7.0/26, which does not match with the first entry in the forwarding table.

b. Router R2 applies the mask /24 to the address (or it extracts the leftmost 24 bits) resulting in the network address/mask of 140.24.7.0/24, which matches with the second entry in the forwarding table. The packet is sent out from interface m0 to router R1.

c. Router R1 applies the mask /26 to the address (or it extracts the leftmost 26 bits) resulting in the network address/mask of 140.24.7.0/26, which matches with the first entry in the forwarding table. The packet is sent out from interface m0 to organization 1.