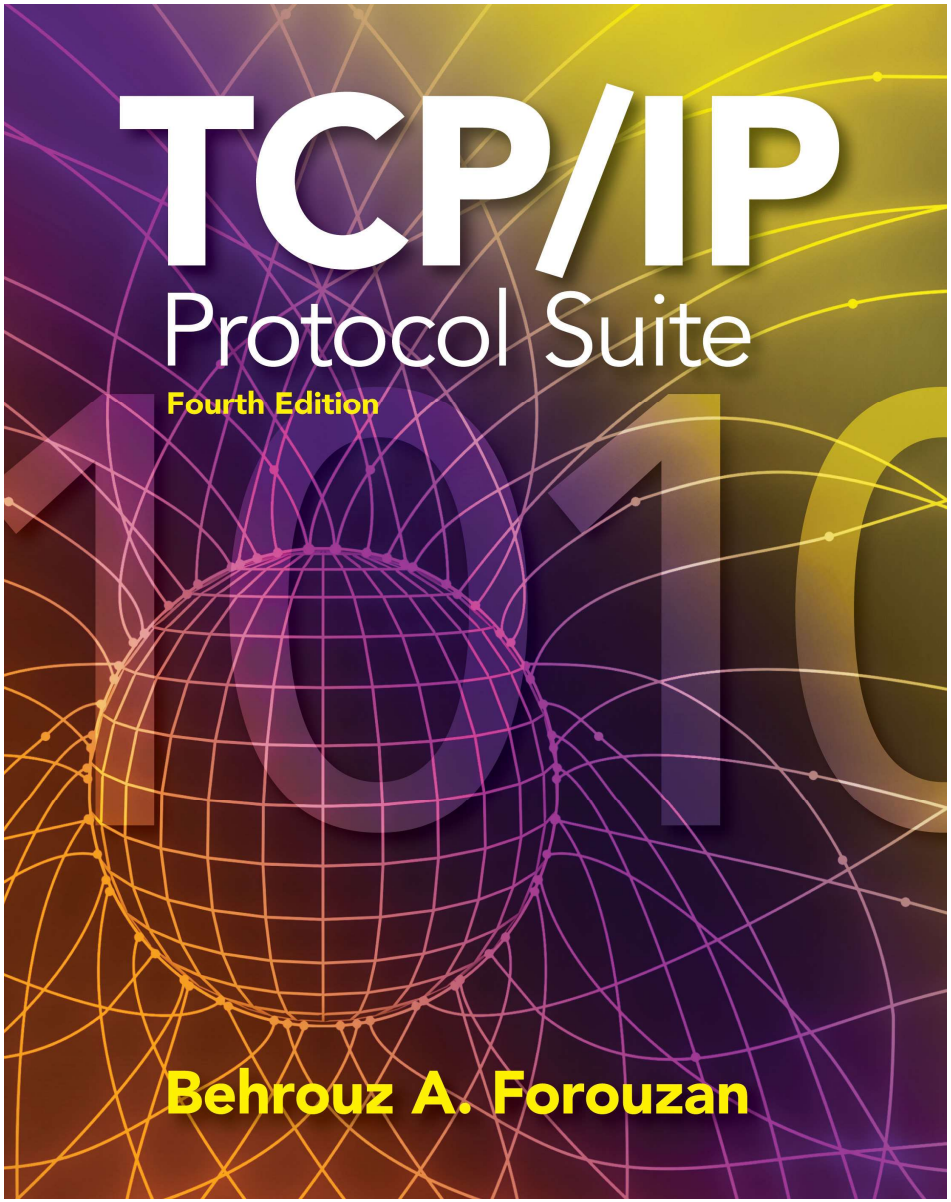
Chapter 6

Delivery and Forwarding of IP Packets



OBJECTIVES:

- To discuss the delivery of packets in the network layer and distinguish between direct and indirect delivery.
- To discuss the forwarding of packets in the network layer and distinguish between destination-address–based forwarding and label-based forwarding.
- To discuss different forwarding techniques, including next-hop, network-specific, host-specific, and default.
- To discuss the contents of routing tables in classful and classless addressing and some algorithms used to search the tables.
- To introduce MPLS technology and show how it can achieve label based forwarding.
- To list the components of a router and explain the purpose of each component and their relations to other components.

Chapter Outline

6.1 Delivery

6.2 Forwarding

6.3 Structure of a Router

6-1 DELIVERY

The network layer supervises the handling of the packets by the underlying physical networks. We define this handling as the delivery of a packet. The delivery of a packet to its final destination is accomplished using two different methods of delivery: direct and indirect.

Topics Discussed in the Section

- ✓ **Direct Delivery**
- ✓ **Indirect Delivery**

Figure 6.1 *Direct delivery*

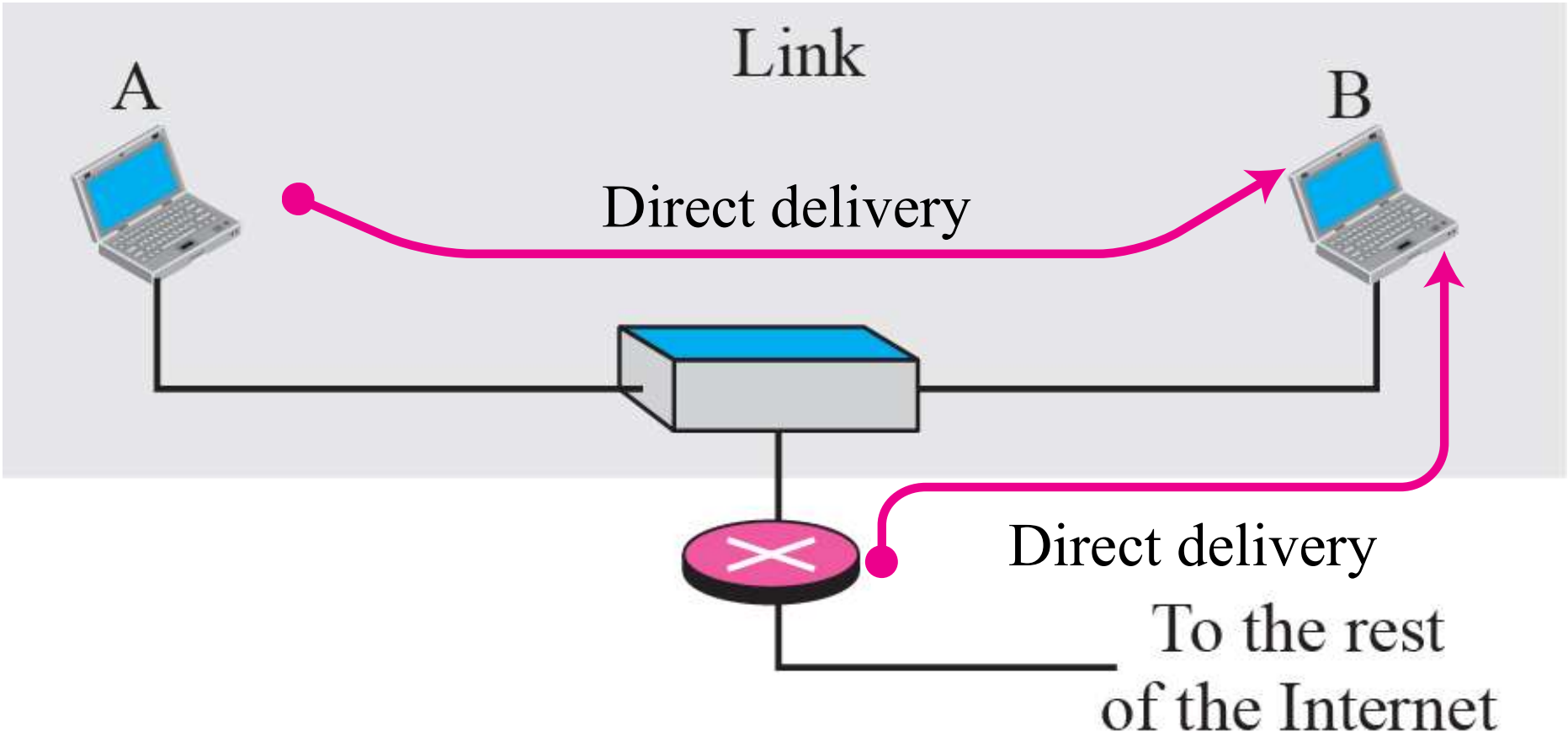
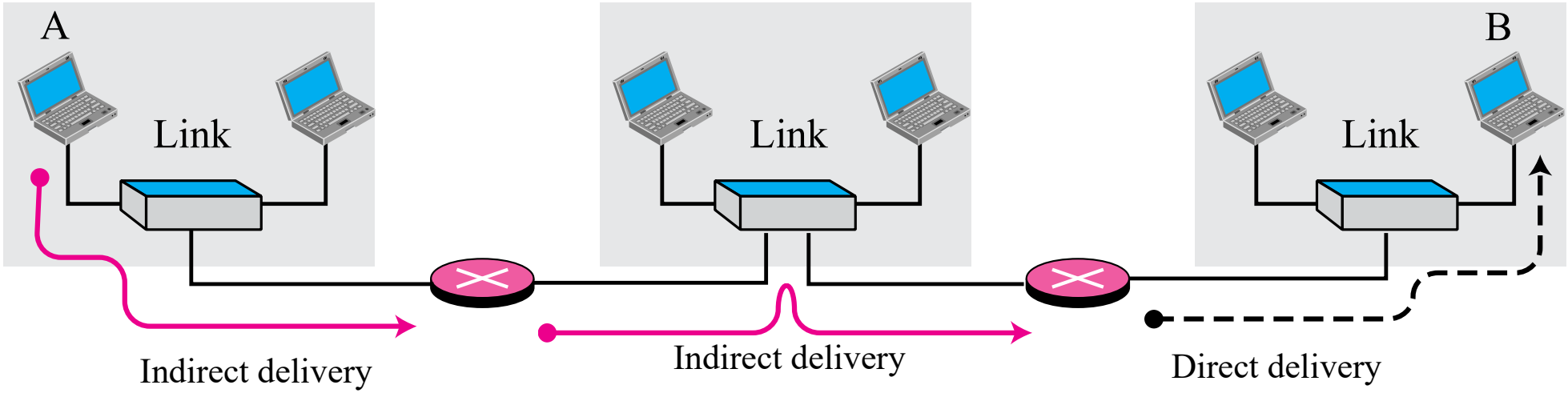


Figure 6.2 *Indirect delivery*



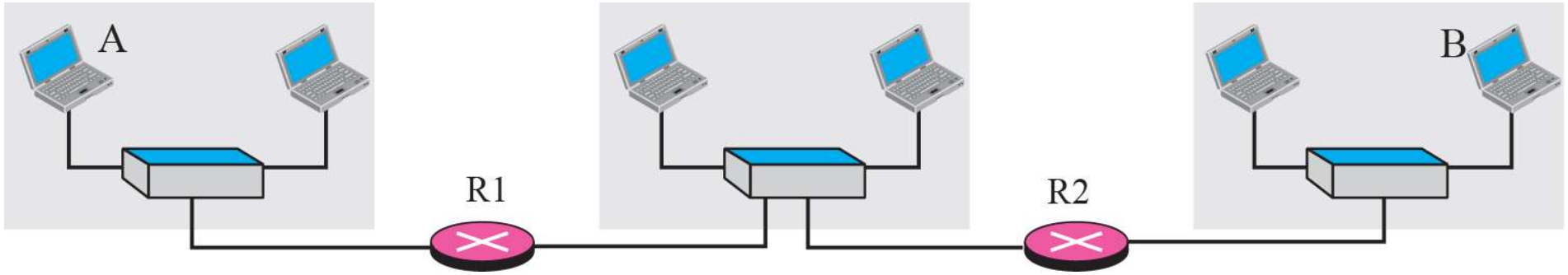
6-2 FORWARDING

Forwarding means to place the packet in its route to its destination. Since the Internet today is made of a combination of links (networks), forwarding means to deliver the packet to the next hop (which can be the final destination or the intermediate connecting device). Although the IP protocol was originally designed as a connectionless protocol, today the tendency is to use IP as a connection-oriented protocol.

Topics Discussed in the Section

- ✓ **Forwarding Based on Destination Address**
- ✓ **Forwarding Based on Label**

Figure 6.3 *Next-hop method*



A

Destination	Route
Host B	R1, R2, Host B

R1

Destination	Route
Host B	R2, Host B

R2

Destination	Route
Host B	Host B

a. Routing tables based on route

A

Destination	Next Hop
Host B	R1

R1

Destination	Next Hop
Host B	R2

R2

Destination	Next Hop
Host B	---

b. Routing tables based on next hop

What would be the ideal routing table type for the topology shown. The network has many applications running that are delay sensitive.

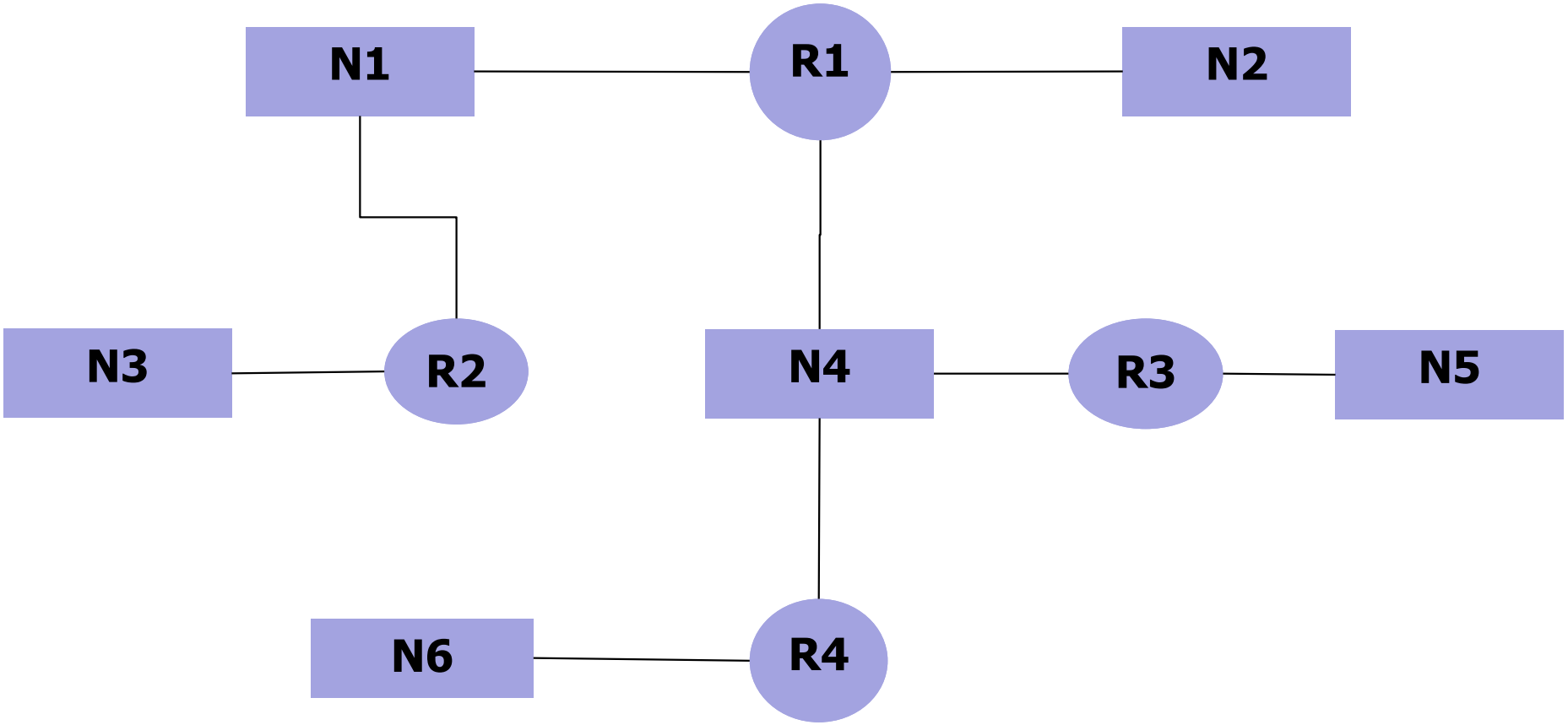


Figure 6.4 *Network-specific method*

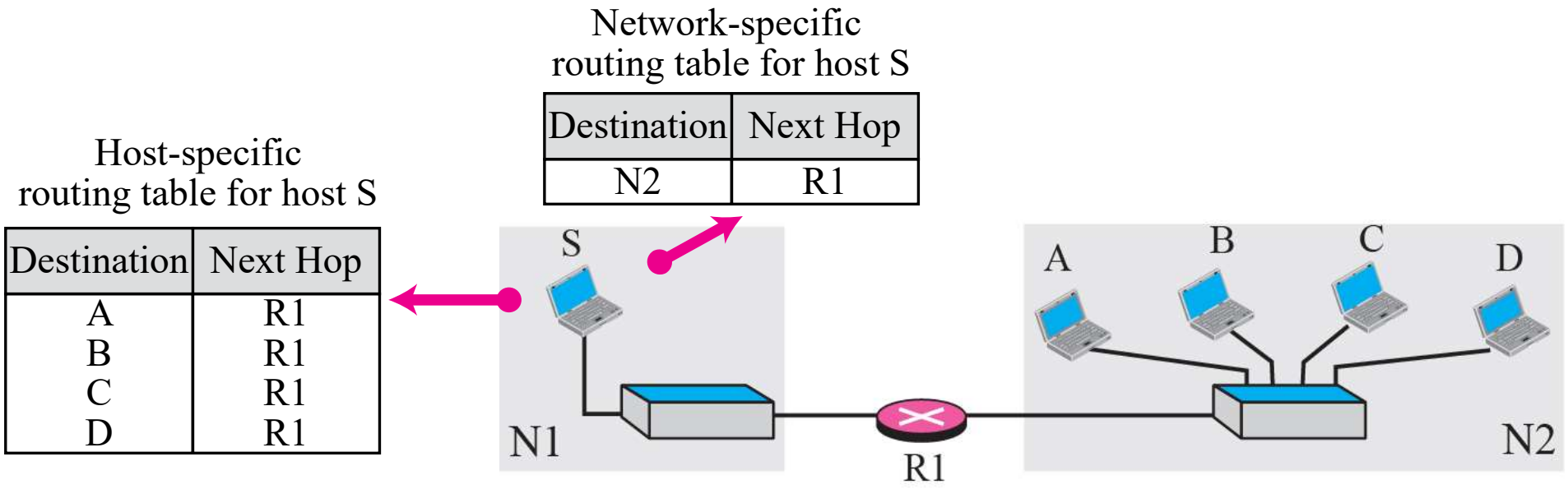


Figure 6.5 *Host-specific routing*

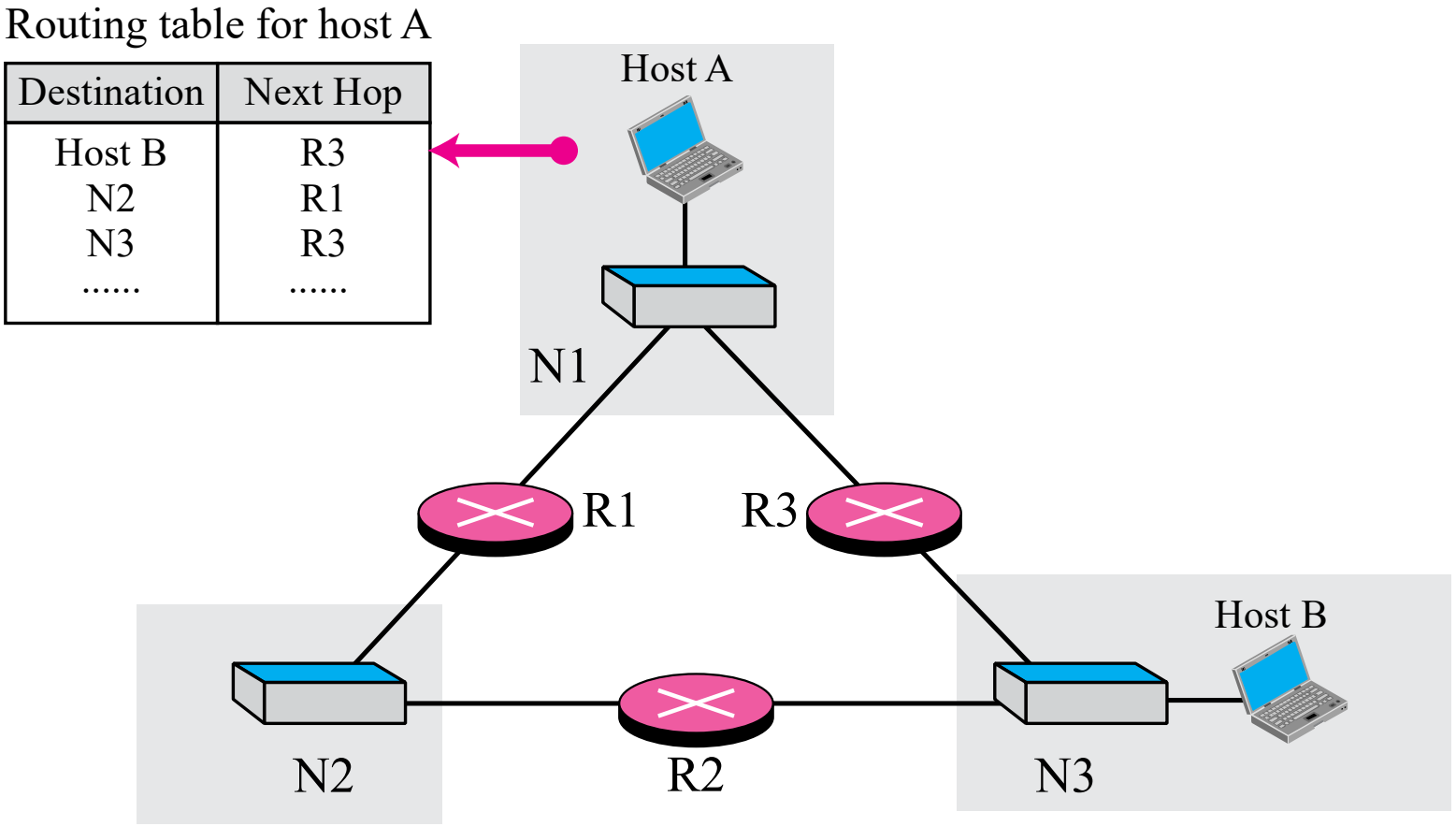


Figure 6.6 *Default routing*

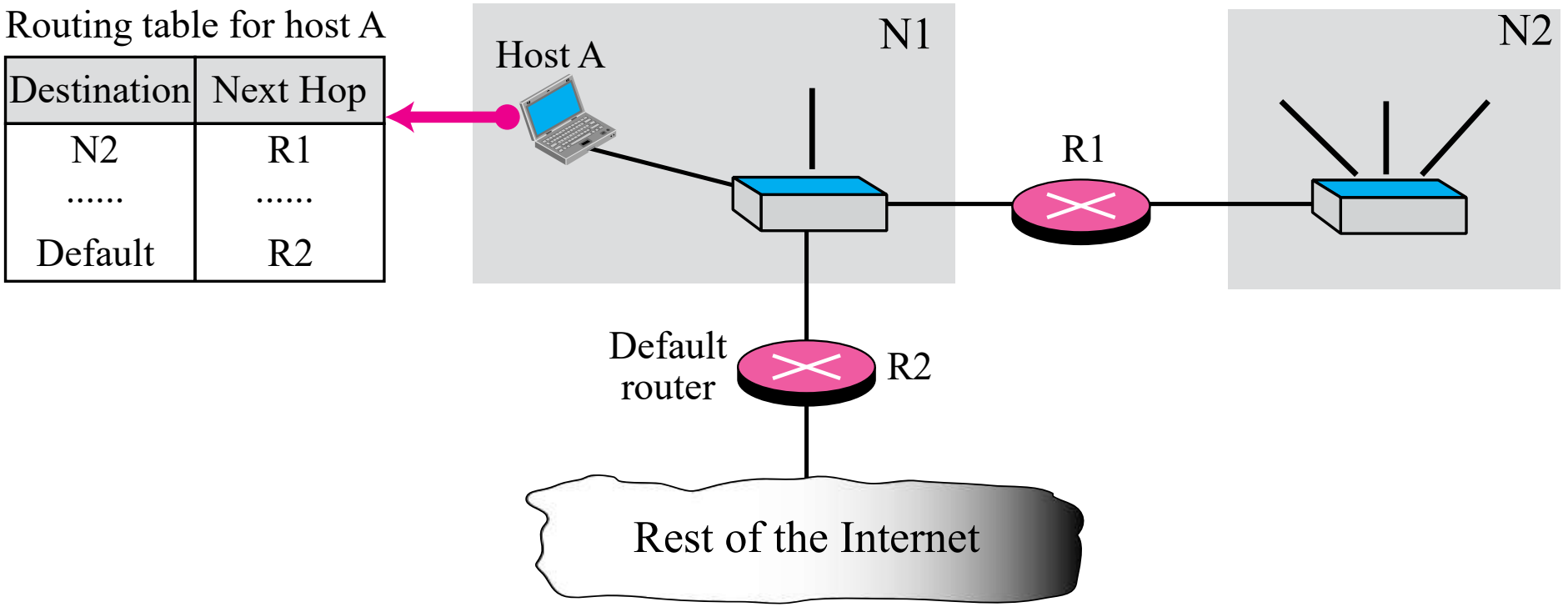
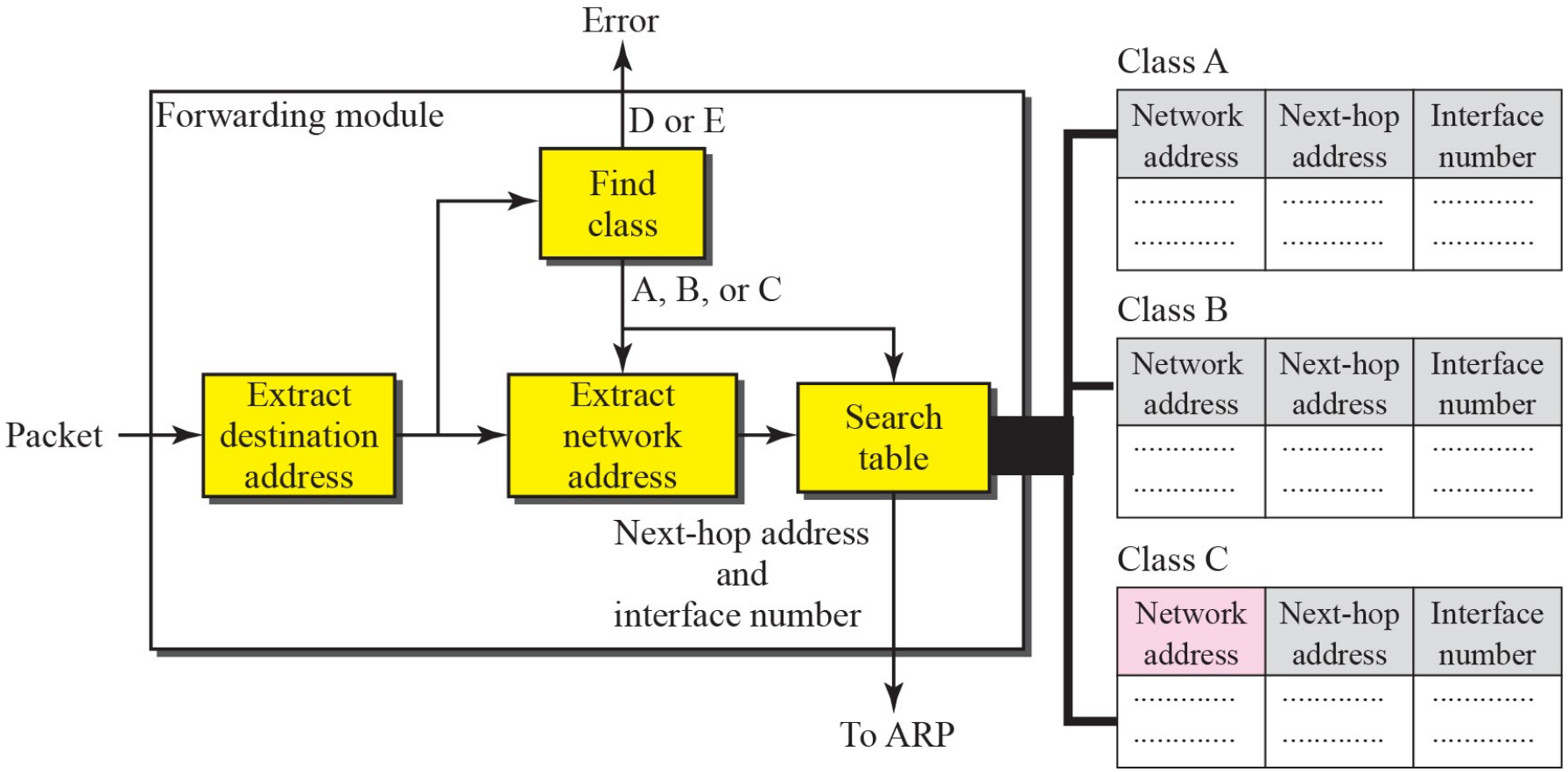


Figure 6.7 *Simplified forwarding module in classful address without subnetting*



Example 6.1

Figure 6.8 shows an imaginary part of the Internet. Show the routing tables for router R1.

Solution

Figure 6.9 shows the three tables used by router R1. Note that some entries in the next-hop address column are empty because in these cases, the destination is in the same network to which the router is connected (direct delivery). In these cases, the next-hop address used by ARP is simply the destination address of the packet as we will see in Chapter 8.

Figure 6.8 *Configuration for routing, Example 6.1*

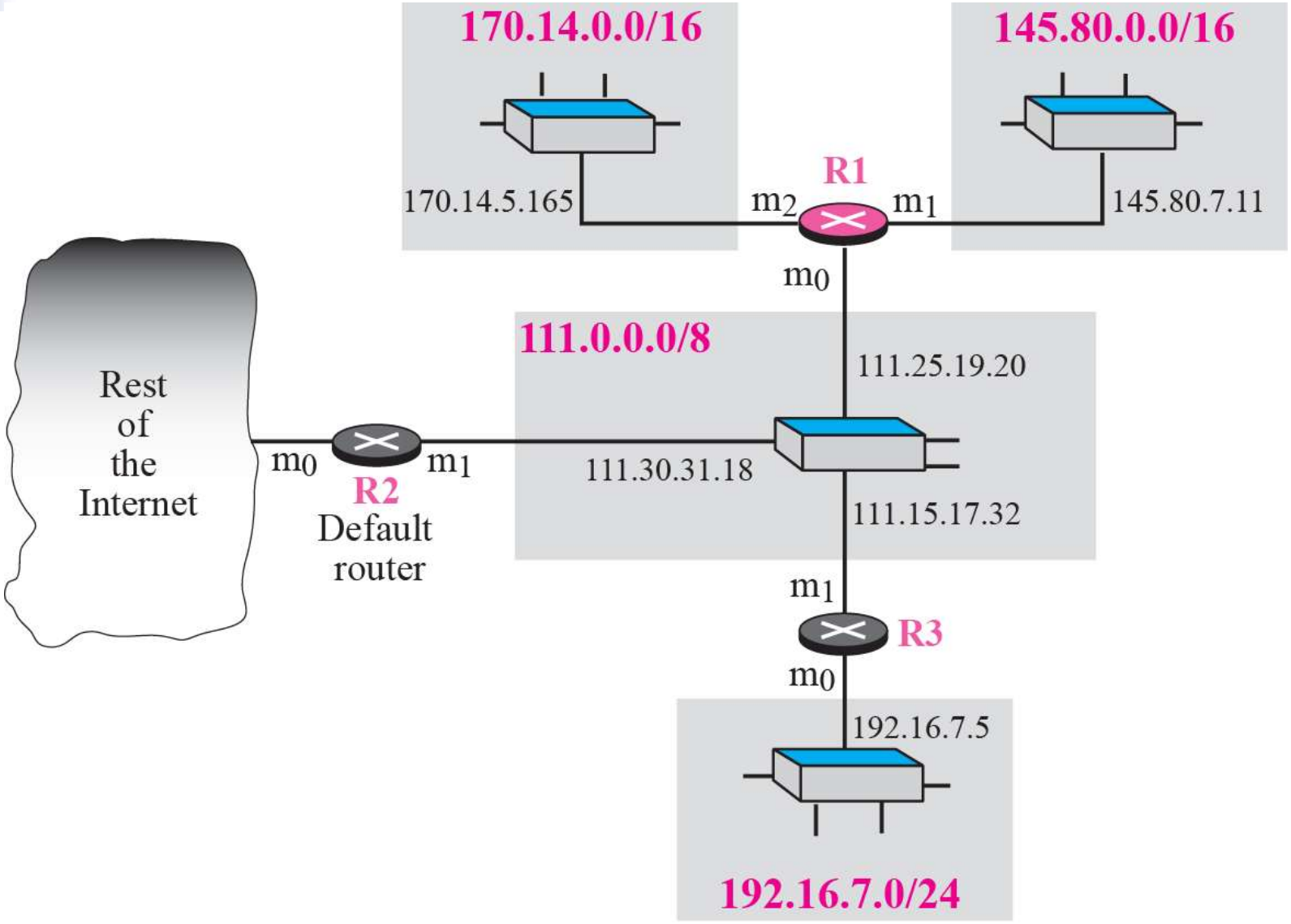


Figure 6.9 *Tables for Example 6.1*

Class A

Network address	Next-hop address	Interface
111.0.0.0	----------	m0

Class B

Network address	Next-hop address	Interface
145.80.0.0	----------	m1
170.14.0.0	----------	m2

Class C

Network address	Next-hop address	Interface
192.16.7.0	111.15.17.32	m0

Default: 111.30.31.18, m0

Example 6.2

Router R1 in Figure 6.8 receives a packet with destination address 192.16.7.14. Show how the packet is forwarded.

Solution

The destination address is

11000000 00010000 000001110 0001110.

A copy of the address is shifted 28 bits to the right. The result is

00000000 00000000 00000000 00001100 or 12.

The destination network is class C. The network address is extracted by masking off the leftmost 24 bits of the destination address; the result is 192.16.7.0. The table for Class C is searched. The network address is found in the first row. The next-hop address 111.15.17.32. and the interface m0 are passed to ARP (see Chapter 8).

Example 6.3

Router R1 in Figure 6.8 receives a packet with destination address 167.24.160.5. Show how the packet is forwarded.

Solution

The destination address in binary is

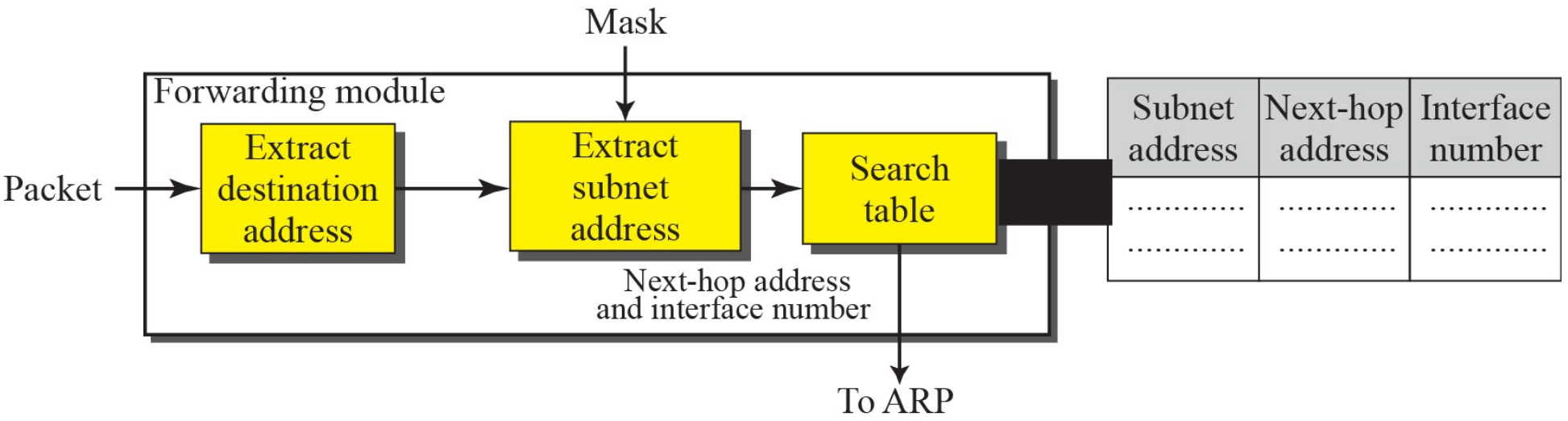
10100111 00011000 10100000 00000101.

A copy of the address is shifted 28 bits to the right. The result is

00000000 00000000 00000000 00001010 or 10.

The class is B. The network address can be found by masking off 16 bits of the destination address, the result is 167.24.0.0. The table for Class B is searched. No matching network address is found. The packet needs to be forwarded to the default router (the network is somewhere else in the Internet). The next-hop address 111.30.31.18 and the interface number m0 are passed to ARP.

Figure 6.10 *Simplified forwarding module in classful address with subnetting*

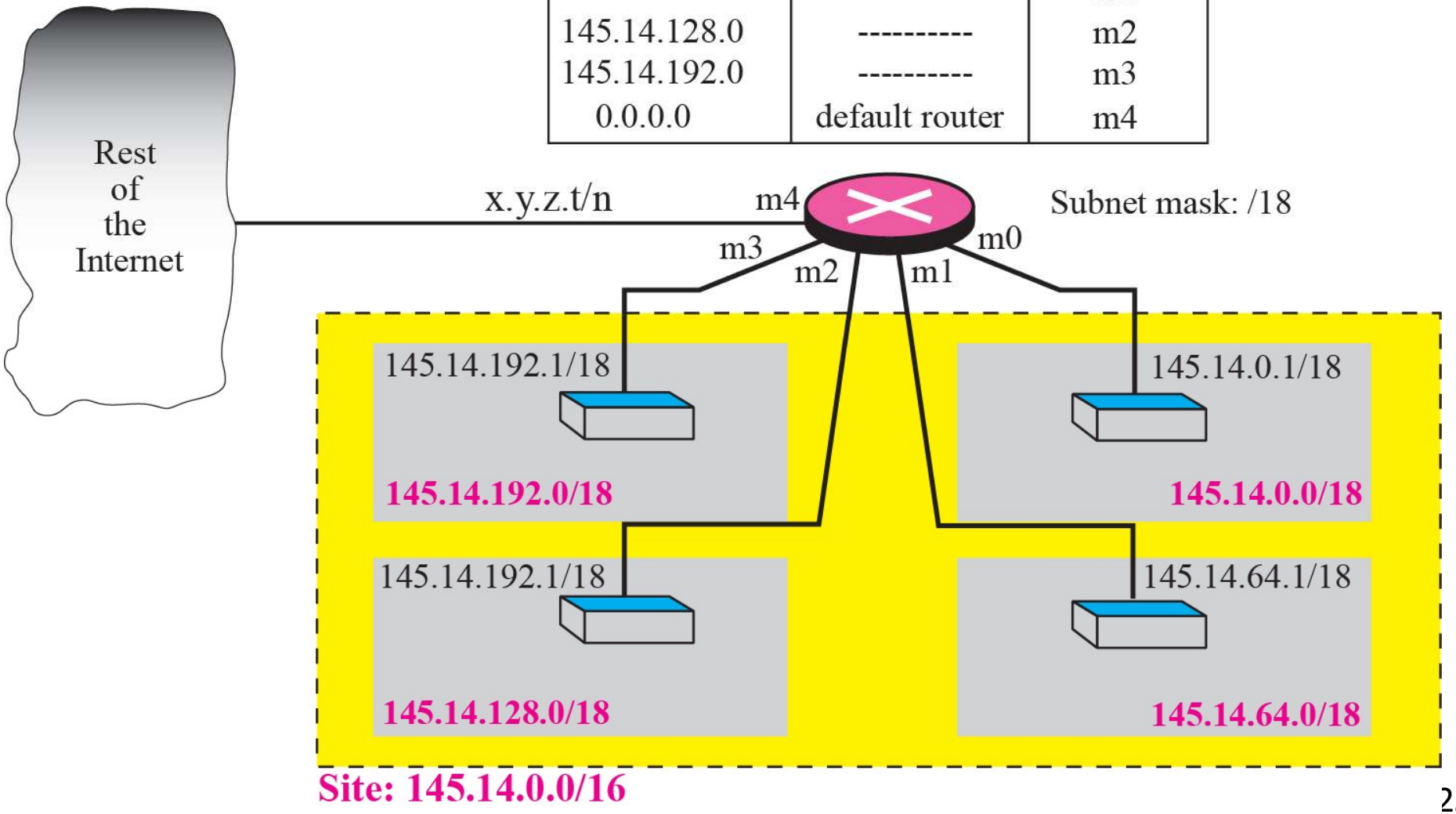


Example 6.4

Figure 6.11 shows a router connected to four subnets. Note several points. First, the site address is 145.14.0.0/16 (a class B address). Every packet with destination address in the range 145.14.0.0 to 145.14.255.255 is delivered to the interface m4 and distributed to the final destination subnet by the router. Second, we have used the address x.y.z.t/n for the interface m4 because we do not know to which network this router is connected. Third, the table has a default entry for packets that are to be sent out of the site. The router is configured to apply the subnet mask /18 to any destination address.

Figure 6.11 *Configuration for Example 6.4*

Subnet address	Next-hop address	Interface number
145.14.0.0	----------	m0
145.14.64.0	----------	m1
145.14.128.0	----------	m2
145.14.192.0	----------	m3
0.0.0.0	default router	m4



Example 6.5

The router in Figure 6.11 receives a packet with destination address 145.14.32.78. Show how the packet is forwarded.

Solution

The mask is /18. After applying the mask, the subnet address is 145.14.0.0. The packet is delivered to ARP (see Chapter 8) with the next-hop address 145.14.32.78 and the outgoing interface m0.

Example 6.6

A host in network 145.14.0.0 in Figure 6.11 has a packet to send to the host with address 7.22.67.91. Show how the packet is routed.

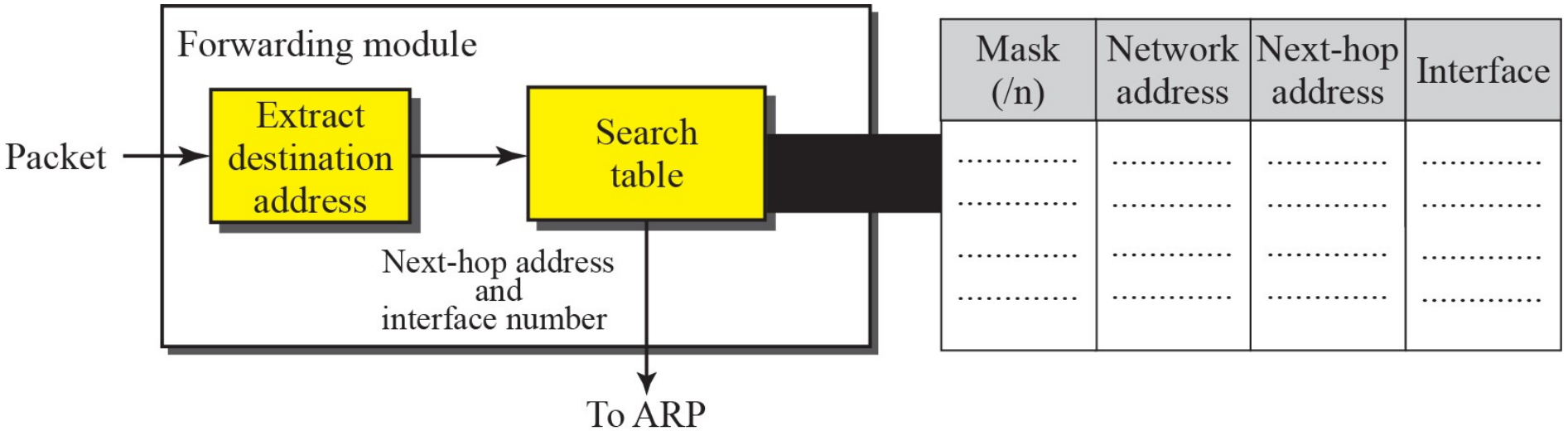
Solution

The router receives the packet and applies the mask (/18). The network address is 7.22.64.0. The table is searched and the address is not found. The router uses the address of the default router (not shown in figure) and sends the packet to that router.

Note

In classful addressing we can have a routing table with three columns; in classless addressing, we need at least four columns.

Figure 6.12 *Simplified forwarding module in classless address*



Example 6.7

Make a routing table for router R1 using the configuration in Figure 6.13.

Solution

Table 6.1 shows the corresponding table

Figure 6.13 *Configuration for Example 6.7*

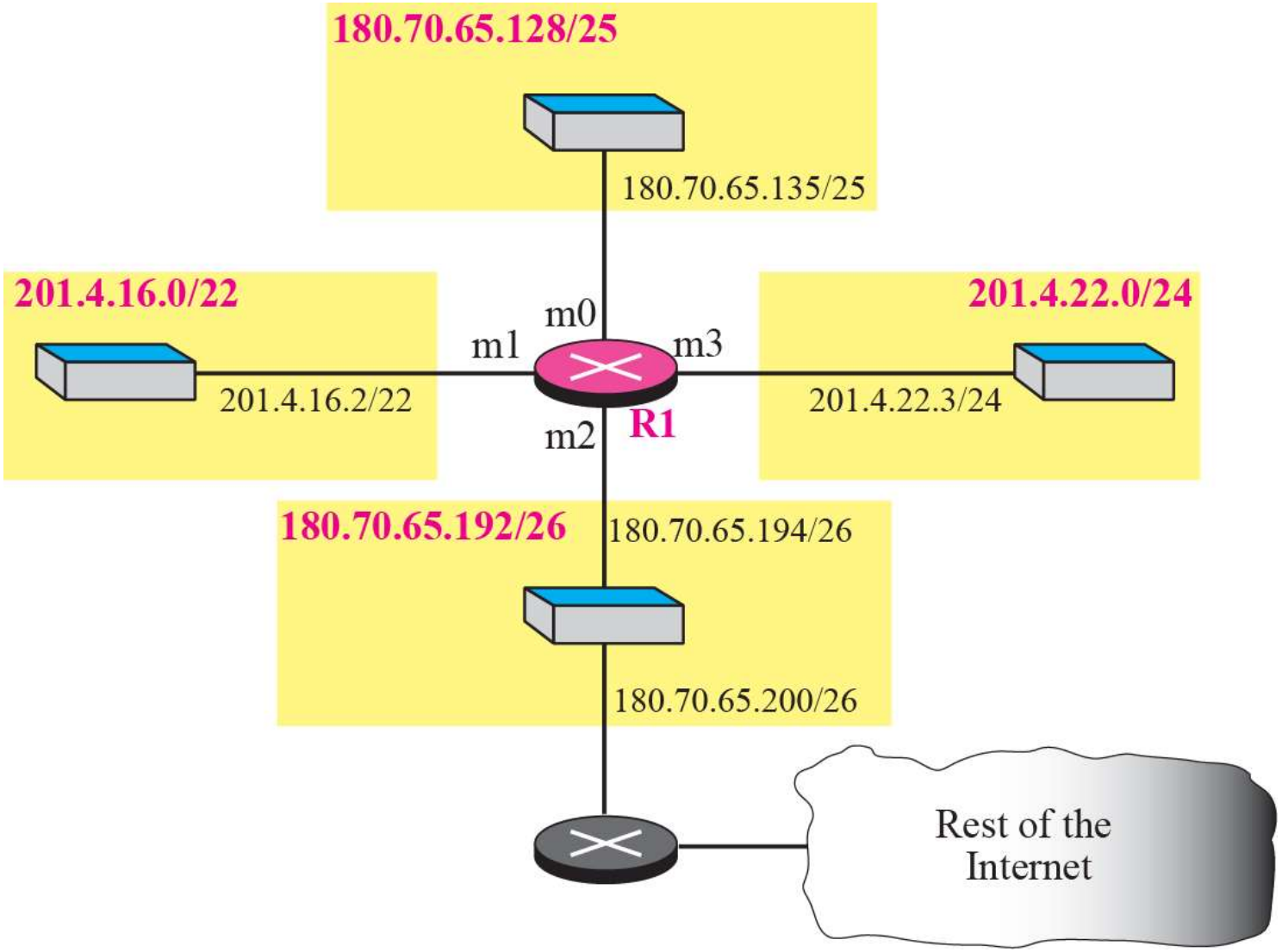
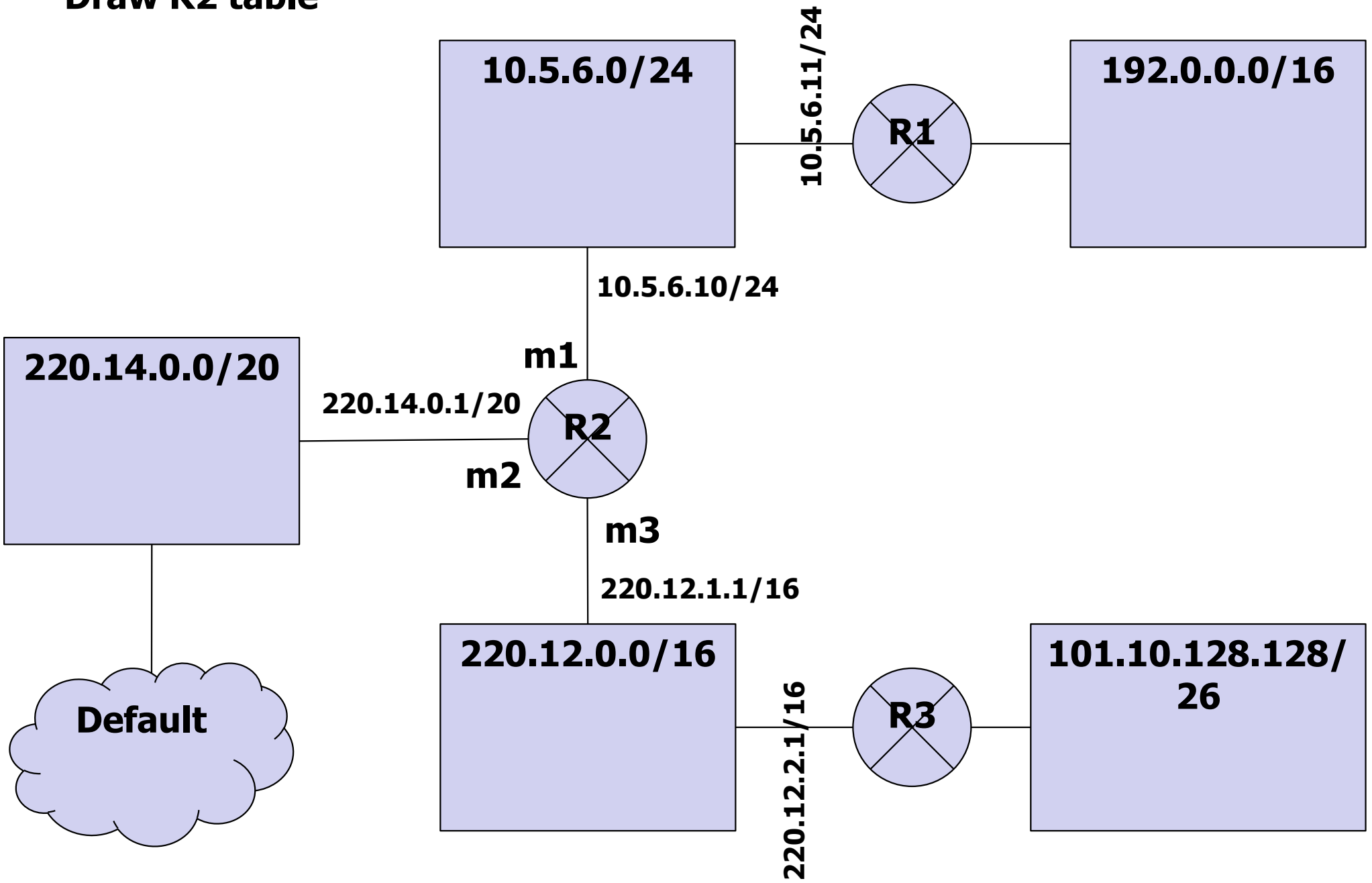


Table 6.1 *Routing table for router R1 in Figure 6.13*

Mask	*Network Address*	*Next Hop*	*Interface*
/26	180.70.65.192	-	m2
/25	180.70.65.128	-	m0
/24	201.4.22.0	-	m3
/22	201.4.16.0	....	m1
Default	Default	180.70.65.200	m2

Draw R2 table



Example 6.8

Show the forwarding process if a packet arrives at R1 in Figure 6.13 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 (the destination address of the packet in this case) and the interface number m0 are passed to ARP (see Chapter 8) for further processing.**

Example 6.9

Show the forwarding process if a packet arrives at R1 in Figure 6.13 with the destination address 201.4.22.35.

Solution

The router performs the following steps:

1. **The first mask (/26) is applied to the destination address. The result is 201.4.22.0, which does not match the corresponding network address (row 1).**
2. **The second mask (/25) is applied to the destination address. The result is 201.4.22.0, which does not match the corresponding network address (row 2).**
3. **The third mask (/24) is applied to the destination address. The result is 201.4.22.0, which matches the corresponding network address.**

Example 6.10

Show the forwarding process if a packet arrives at R1 in Figure 6.13 with the destination address 18.24.32.78.

Solution

This time all masks are applied to the destination address, but no matching network address is found. When it reaches the end of the table, the module gives the next-hop address 180.70.65.200 and interface number m2 to ARP (see Chapter 8). This is probably an outgoing package that needs to be sent, via the default router, to someplace else in the Internet.

Example 6.11

Now let us give a different type of example. Can we find the configuration of a router if we know only its routing table? The routing table for router R1 is given in Table 6.2. Can we draw its topology?

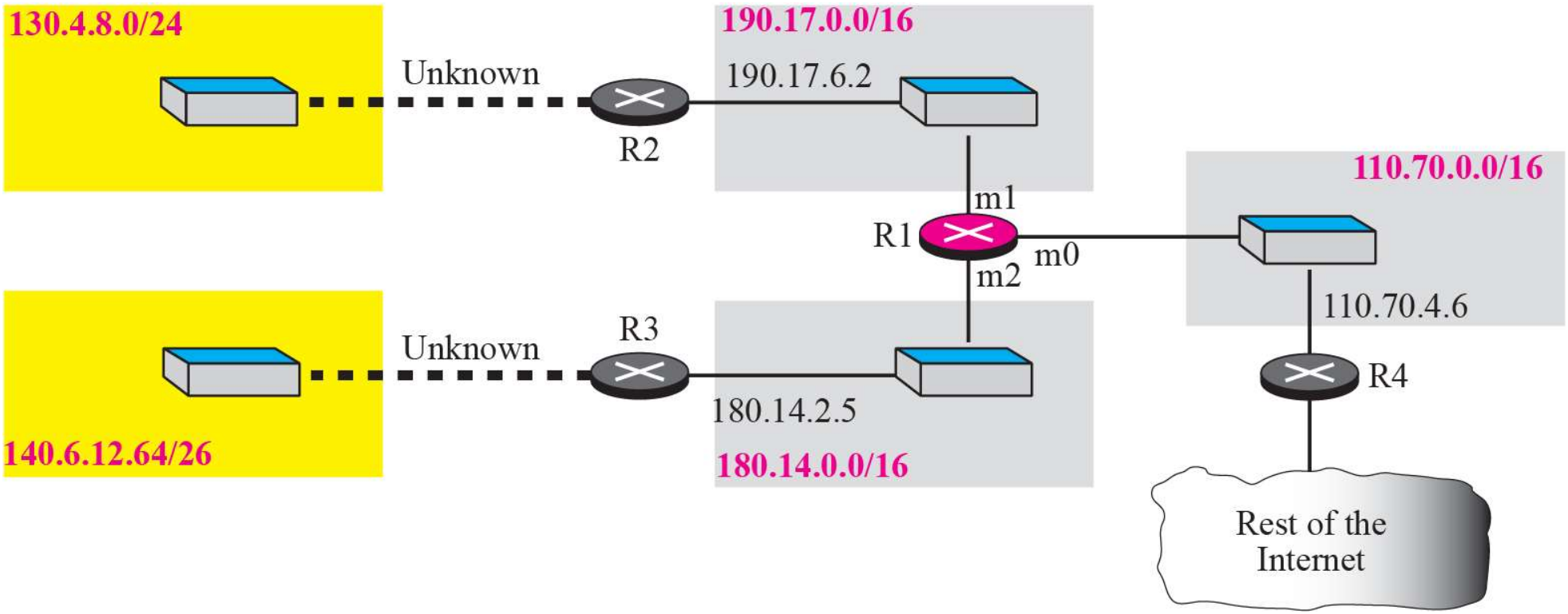
Solution

We know some facts but we don't have all for a definite topology. We know that router R1 has three interfaces: m0, m1, and m2. We know that there are three networks directly connected to router R1. We know that there are two networks indirectly connected to R1. There must be at least three other routers involved (see next-hop column). We do not know if network 140.6.12.64 is connected to router R3 directly or through a point-to-point network (WAN) and another router. Figure 6.14 shows our guessed topology.

Table 6.2 *Routing table for Example 6.11*

Mask	*Network Address*	*Next-Hop Address*	*Interface Number*
/26	140.6.12.64	180.14.2.5	m2
/24	130.4.8.0	190.17.6.2	m1
/16	110.70.0.0	----------	m0
/16	180.14.0.0	----------	m2
/16	190.17.0.0	----------	m1
Default	Default	110.70.4.6	m0

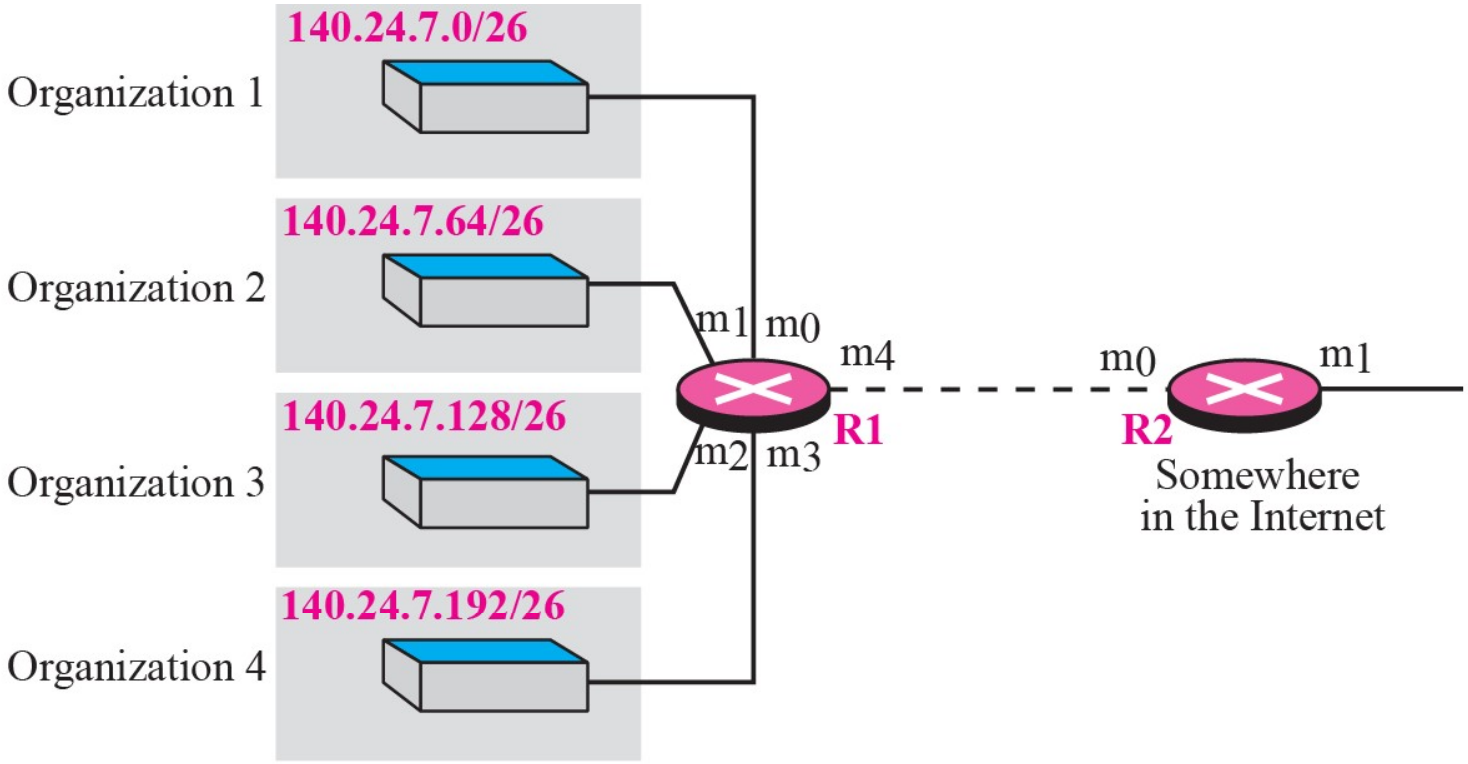
Figure 6.14 *Guessed topology for Example 6.11*



Draw the network for following table:

Mask	Network Add	Next Hop	Interface
24	10.0.0.0		M0
23	11.11.8.0		M1
20	120.20.0.0		M3
16	180.0.0.0		M2
16	110.10.0.0	10.0.1.1	M0
16	220.120.0.0	120.20.1.1	M3
16	1.0.0.0	120.20.1.1	M3
Default	Default	120.20.1.1	M3

Figure 6.15 *Address aggregation*



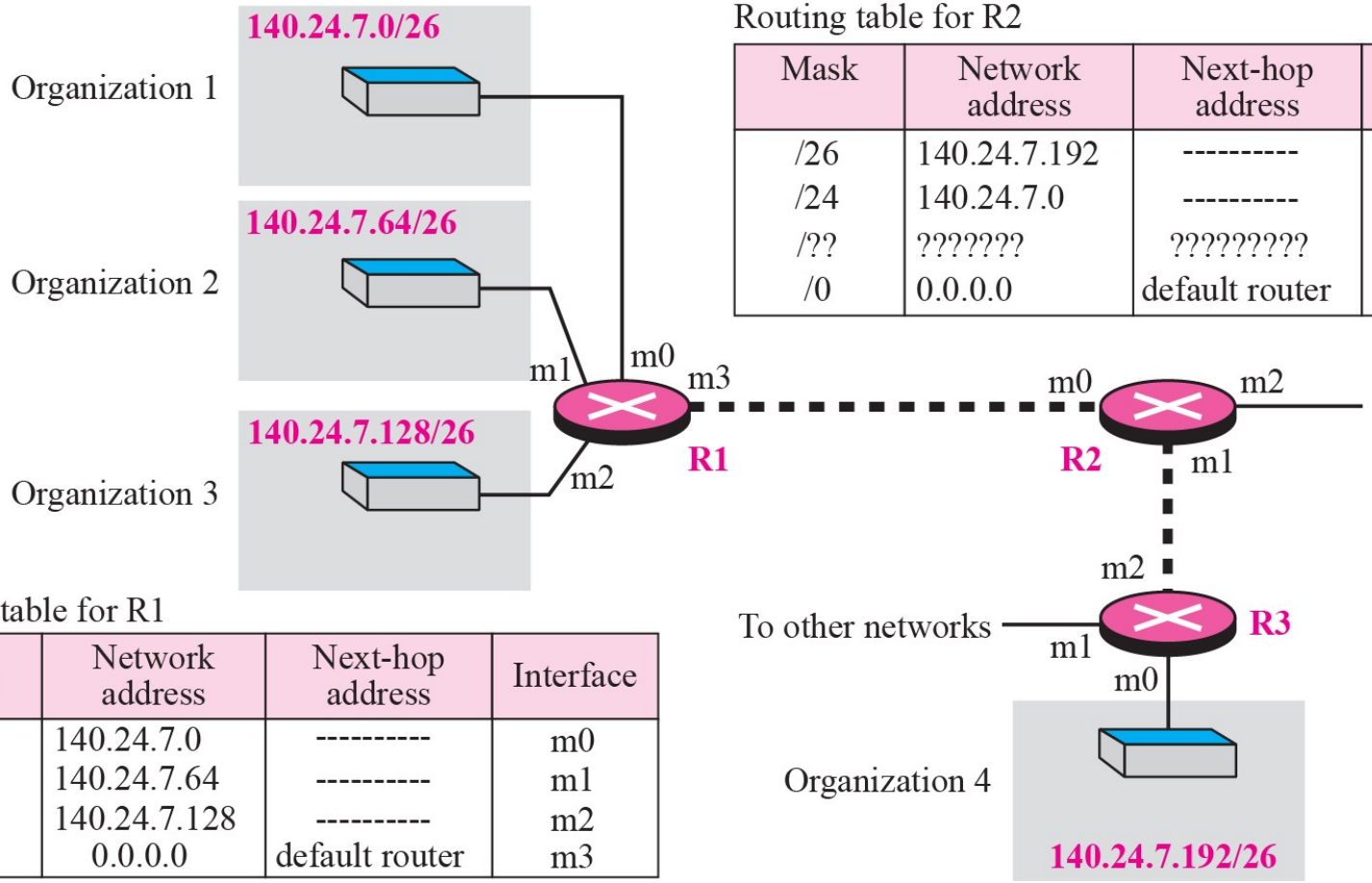
Mask	Network address	Next-hop address	Interface
/26	140.24.7.0	----------	m0
/26	140.24.7.64	----------	m1
/26	140.24.7.128	----------	m2
/26	140.24.7.192	----------	m3
/0	0.0.0.0	default router	m4

Routing table for R1

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

Routing table for R2

Figure 6.16 *Longest mask matching*



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

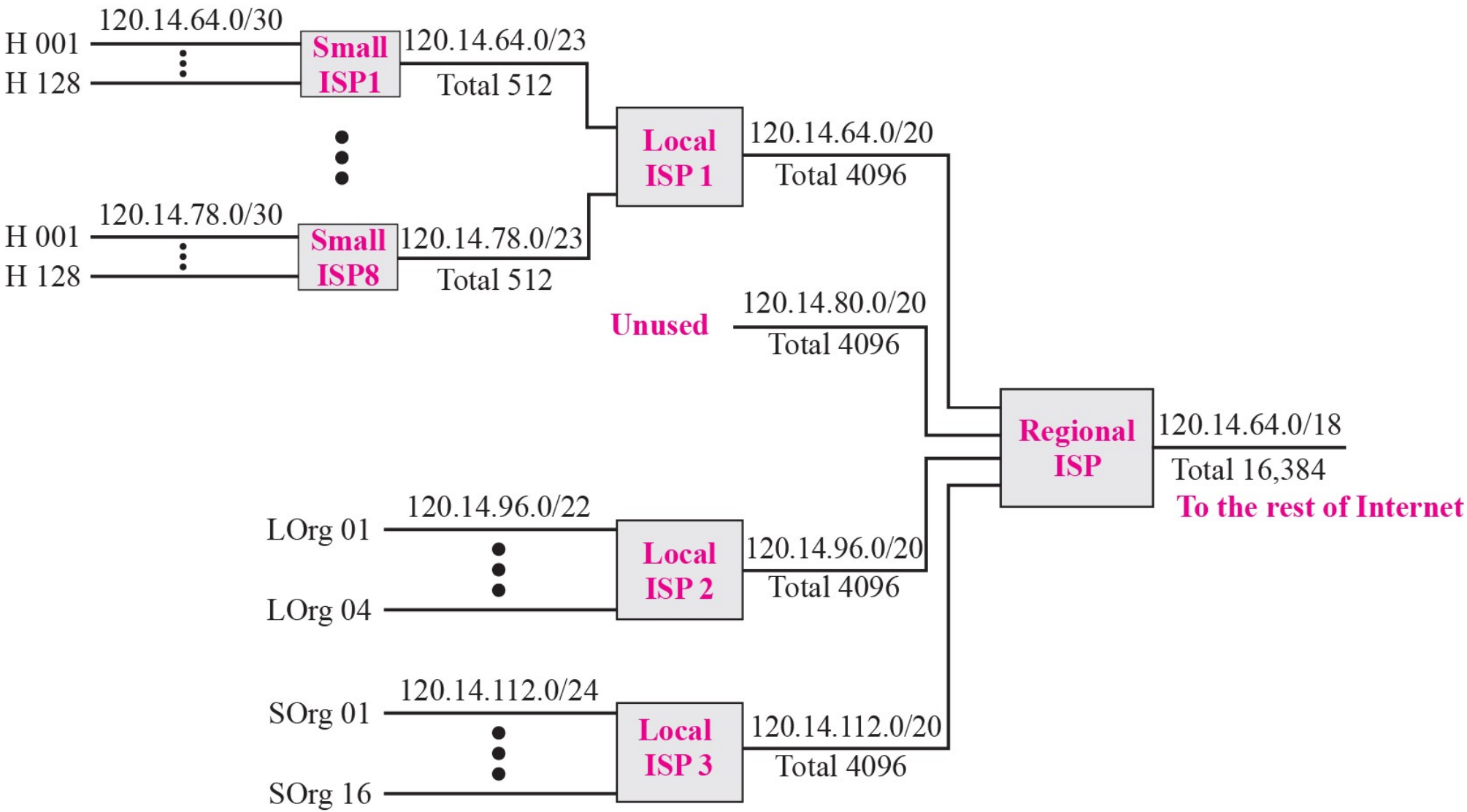
Routing table for R3

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

Example 6.12

As an example of hierarchical routing, let us consider Figure 6.17. A regional ISP is granted 16,384 addresses starting from 120.14.64.0. The regional ISP has decided to divide this block into 4 subblocks, each with 4096 addresses. Three of these subblocks are assigned to three local ISPs, the second subblock is reserved for future use. Note that the mask for each block is /20 because the original block with mask /18 is divided into 4 blocks.

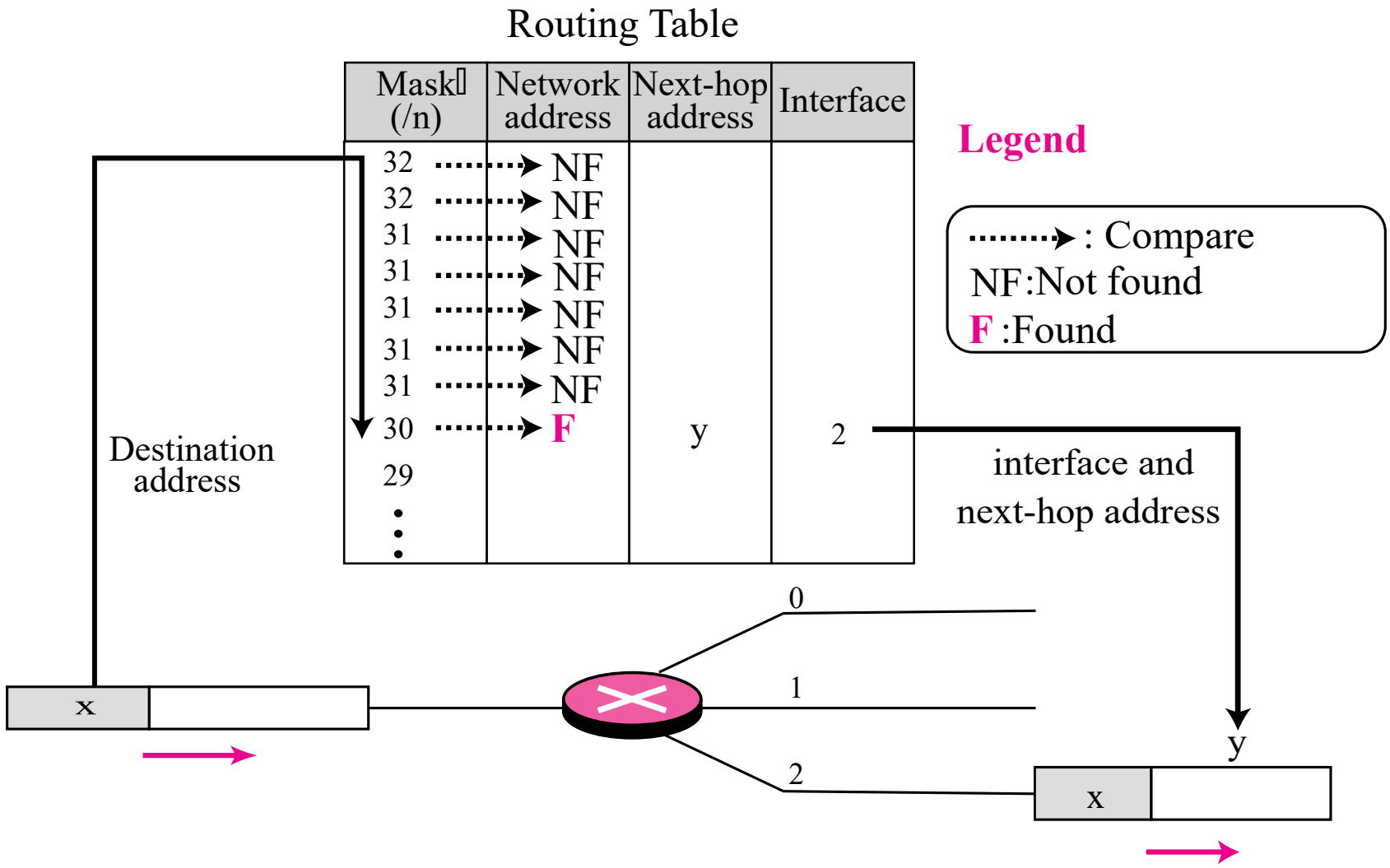
Figure 6.17 *Hierarchical routing with ISPs*



Example 6.13

Figure 6.18 shows a simple example of searching in a routing table using the longest match algorithm. Although there are some more efficient algorithms today, the principle is the same. When the forwarding algorithm gets the destination address of the packet, it needs to delve into the mask column. For each entry, it needs to apply the mask to find the destination network address. It then needs to check the network addresses in the table until it finds the match. The router then extracts the next hop address and the interface number to be delivered to the ARP protocol for delivery of the packet to the next hop.

Figure 6.18 *Example 6.13: Forwarding based on destination address*



Example 6.14

Figure 6.19 shows a simple example of using a label to access a switching table. Since the labels are used as the index to the table, finding the information in the table is immediate.

Figure 6.19 *Example 6.14: Forwarding based on label*

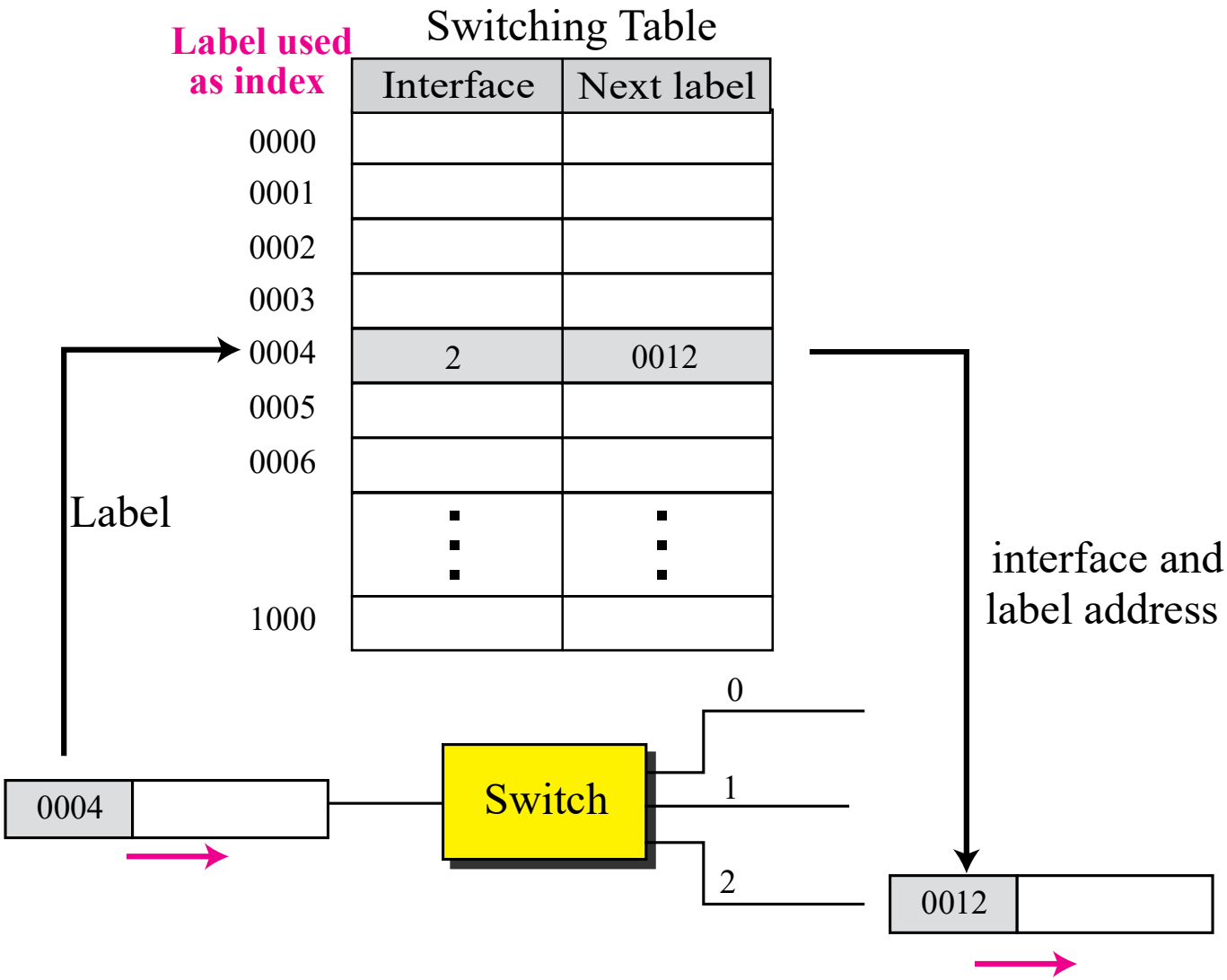


Figure 6.20 *MPLS header added to an IP packet*

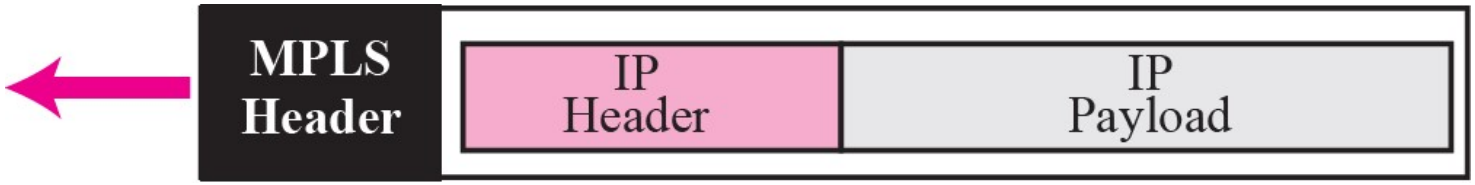
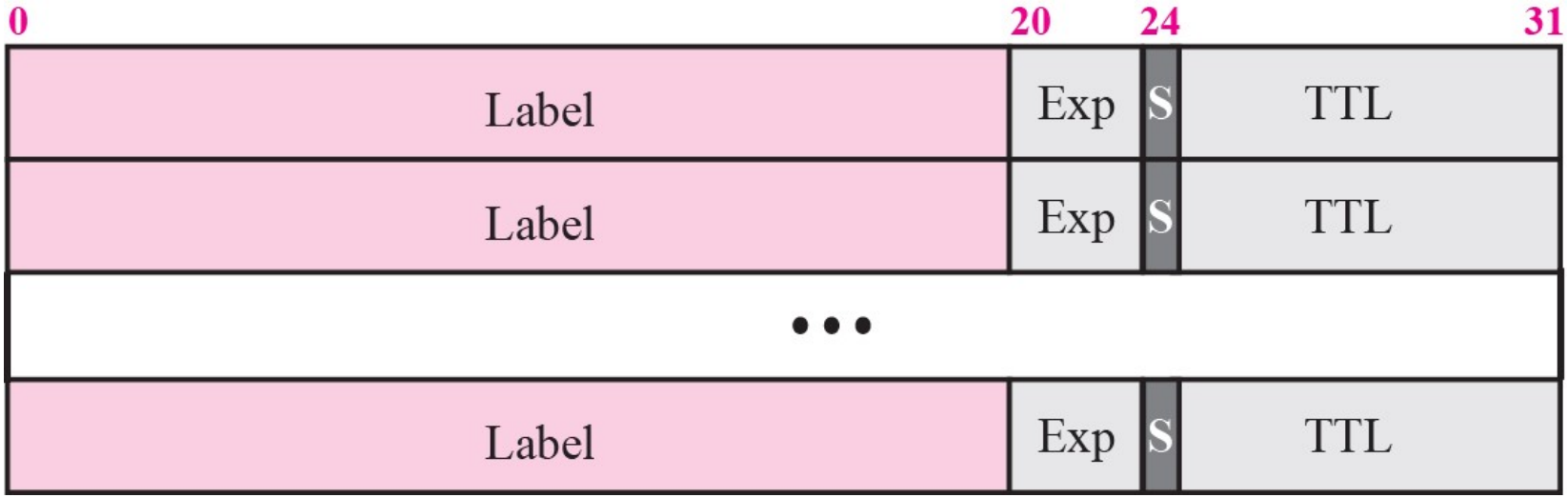


Figure 6.21 *MPLS header made of stack of labels*



6-3 STRUCTURE OF A ROUTER

In our discussion of forwarding and routing, we represented a router as a black box that accepts incoming packets from one of the input ports (interfaces), uses a routing table to find the output port from which the packet departs, and sends the packet from this output port. In this section we open the black box and look inside. However, our discussion won't be very detailed; entire books have been written about routers. We just give an overview to the reader.