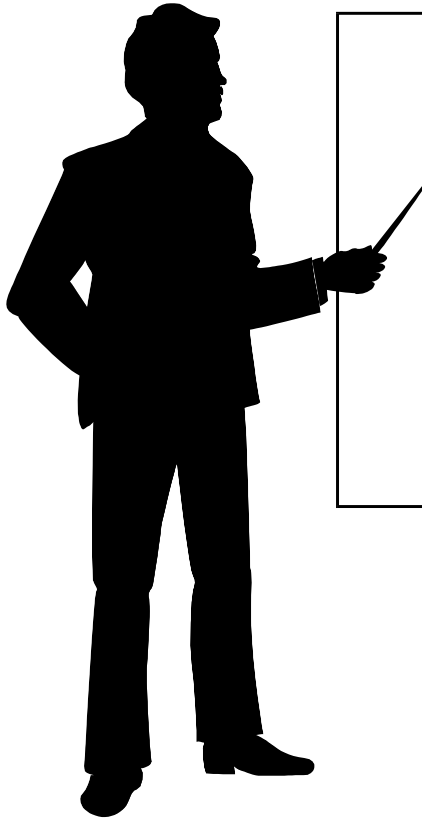


Chapter 6 Delivery and Forwarding of IP Packets

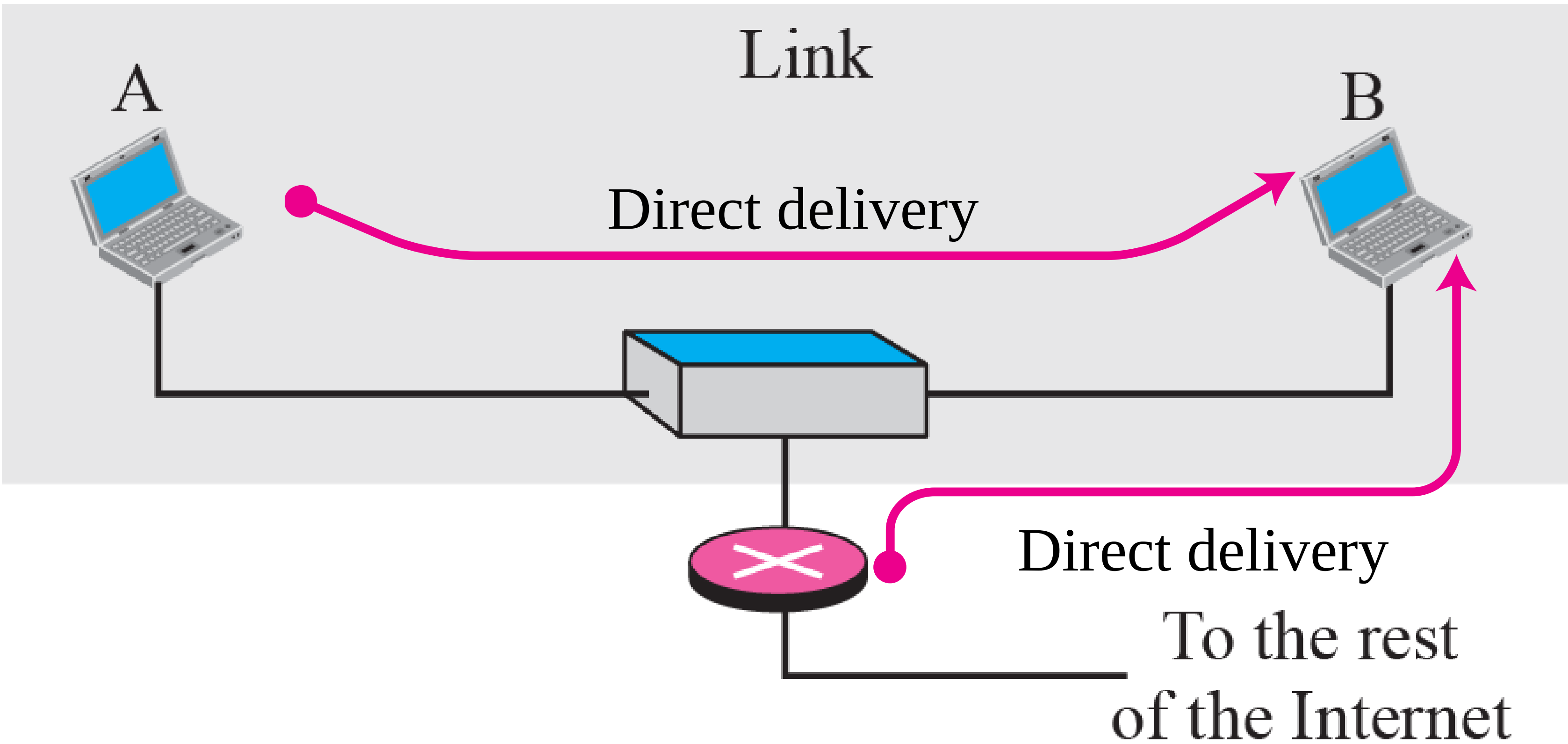
6.1 Delivery

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

Direct Delivery

- The final destination of the packet is a host connected to the same physical network as the deliverer.
- Source and destination of the packet are located on the same physical network
- Delivery between last router and the destination host
- Extract the network address of the destination and compare this address with the addresses of the networks to which it is connected
  - If a match is found, the delivery is direct
- The sender uses the destination IP address to find the destination physical address

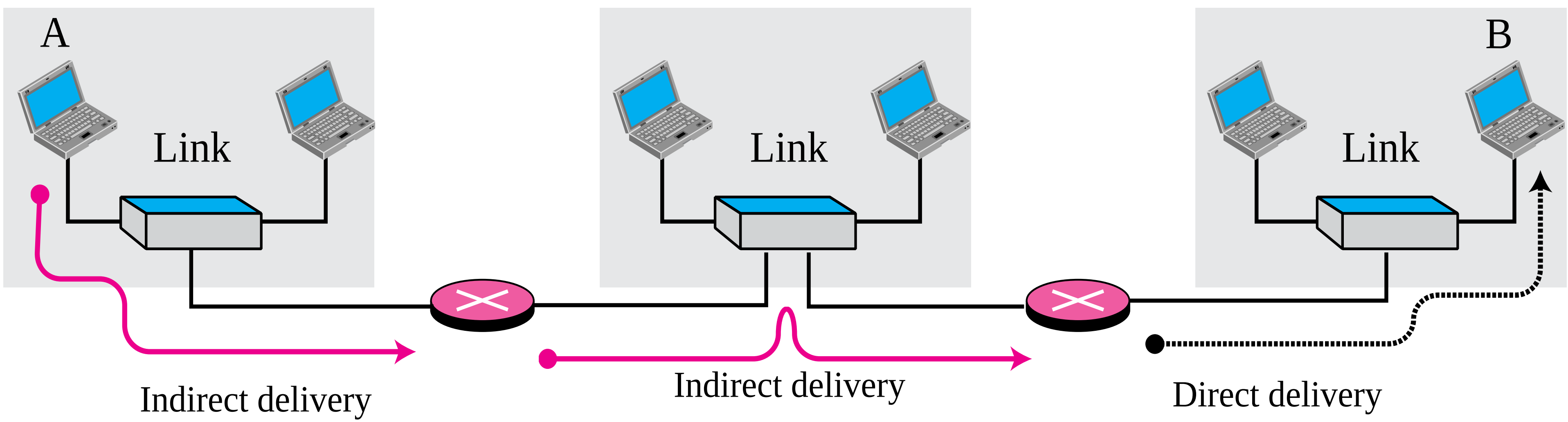
Direct Delivery



Indirect Delivery

- The destination host in not on the same network as the delivery
- The packet goes from router to router until it reaches the one connected to the same physical network
- The sender uses the destination IP address and a routing table to find IP address of the next router

Indirect Delivery



6.2 Forwarding

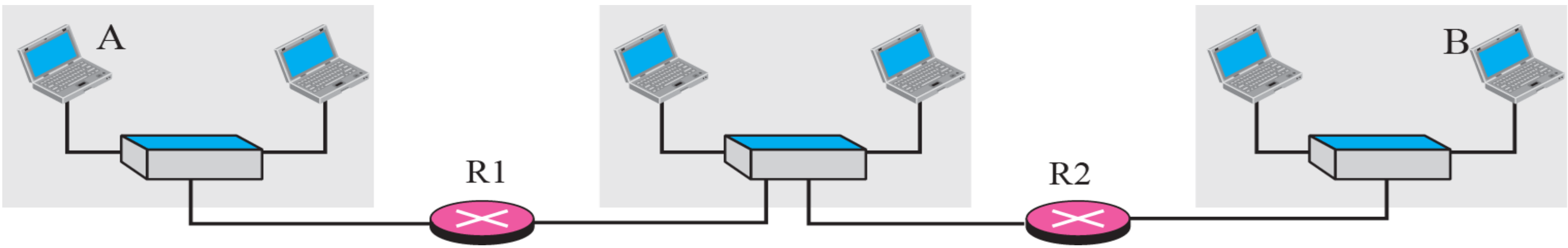
- Forwarding means to place the packet in its route to its destination
  - Since the Internet today is made of a combination of links, forwarding means to deliver the packet to the next hop
- Although IP protocol was originally designed as a connectionless protocol, today the tendency is to use IP as a connection-oriented protocol based on the label attached to an IP datagram

Forwarding

- **Forwarding based on destination address**
  - **Next-hop**
  - **Network- Specific Method**
  - **Host-Specific Method**
  - **Default Method**
- **Forwarding Based on Label**

Next-Hop Method

- One technique to reduce the contents of a routing table
- The routing table holds only the address of the next hop instead of information about the complete route



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

Network Specific Method

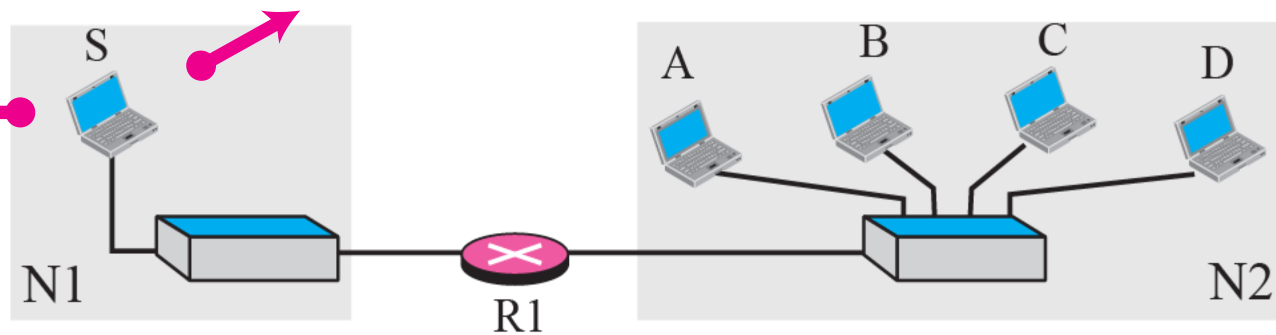
- Reduce the routing table and simplify the searching process
- The routing table has only one entry that defines the address of the destination network itself

Network-specific routing table for host S

Destination	Next Hop
N2	R1

Host-specific routing table for host S

Destination	Next Hop
A	R1
B	R1
C	R1
D	R1

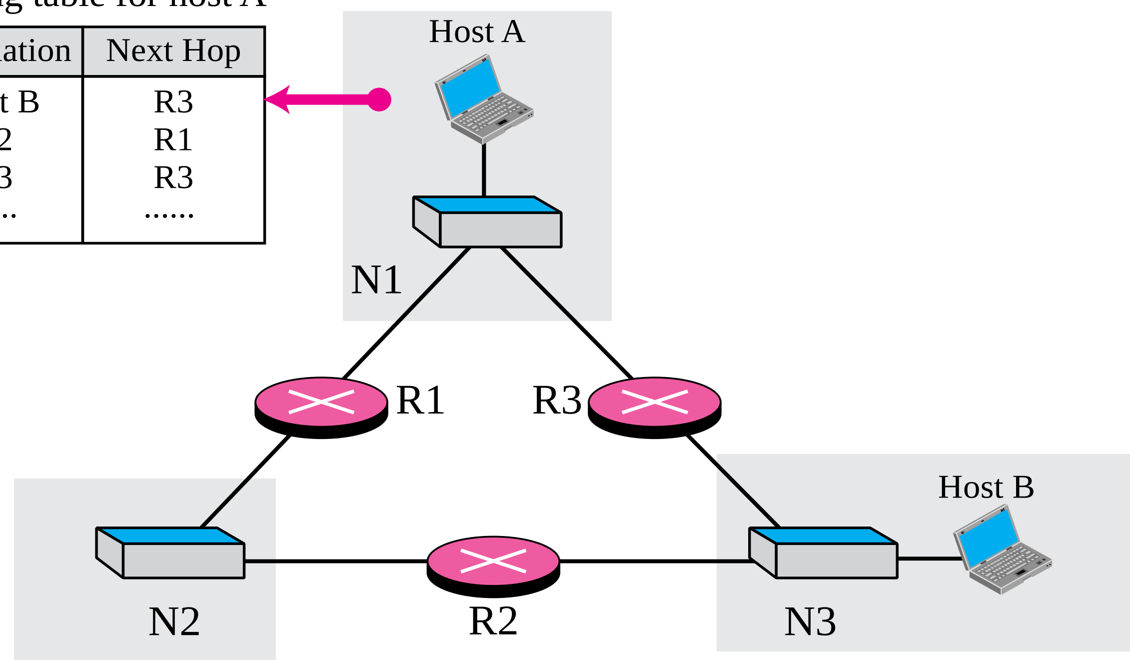


Host-Specific Method

- The Destination host address is given in the routing table
- Inverse of network-specific method
- When administrator wants to have more control

Routing table for host A

Destination	Next Hop
Host B	R3
N2	R1
N3	R3
……	……

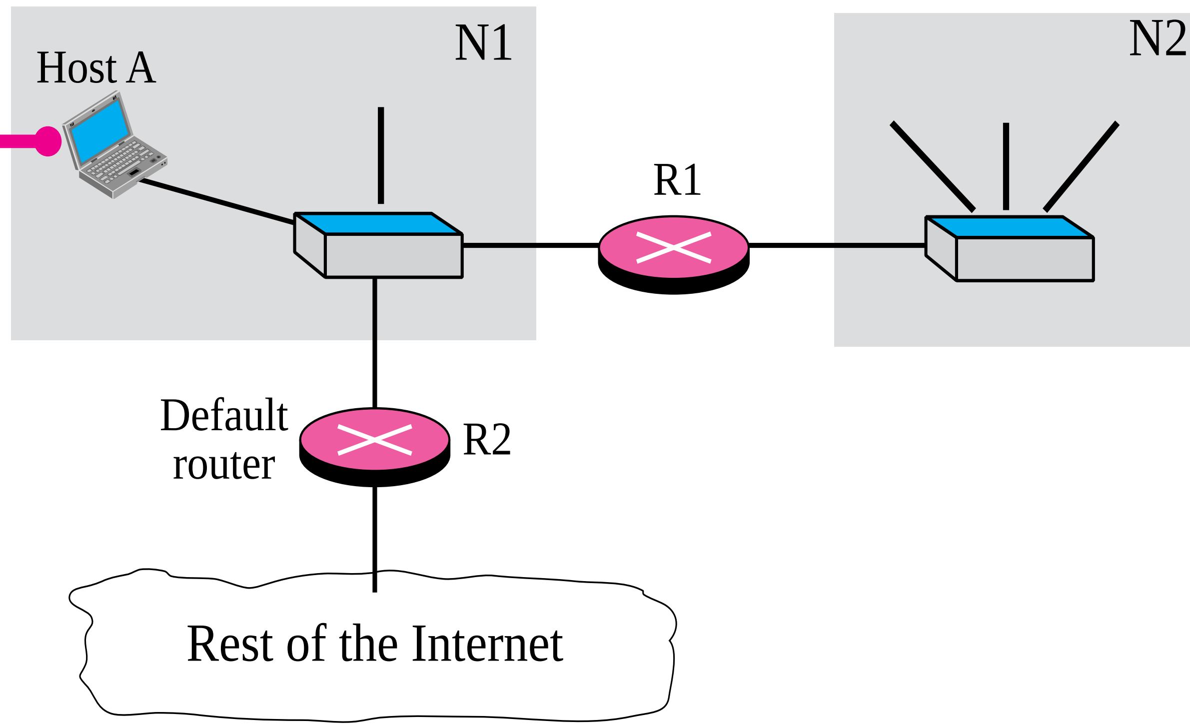


Default Method

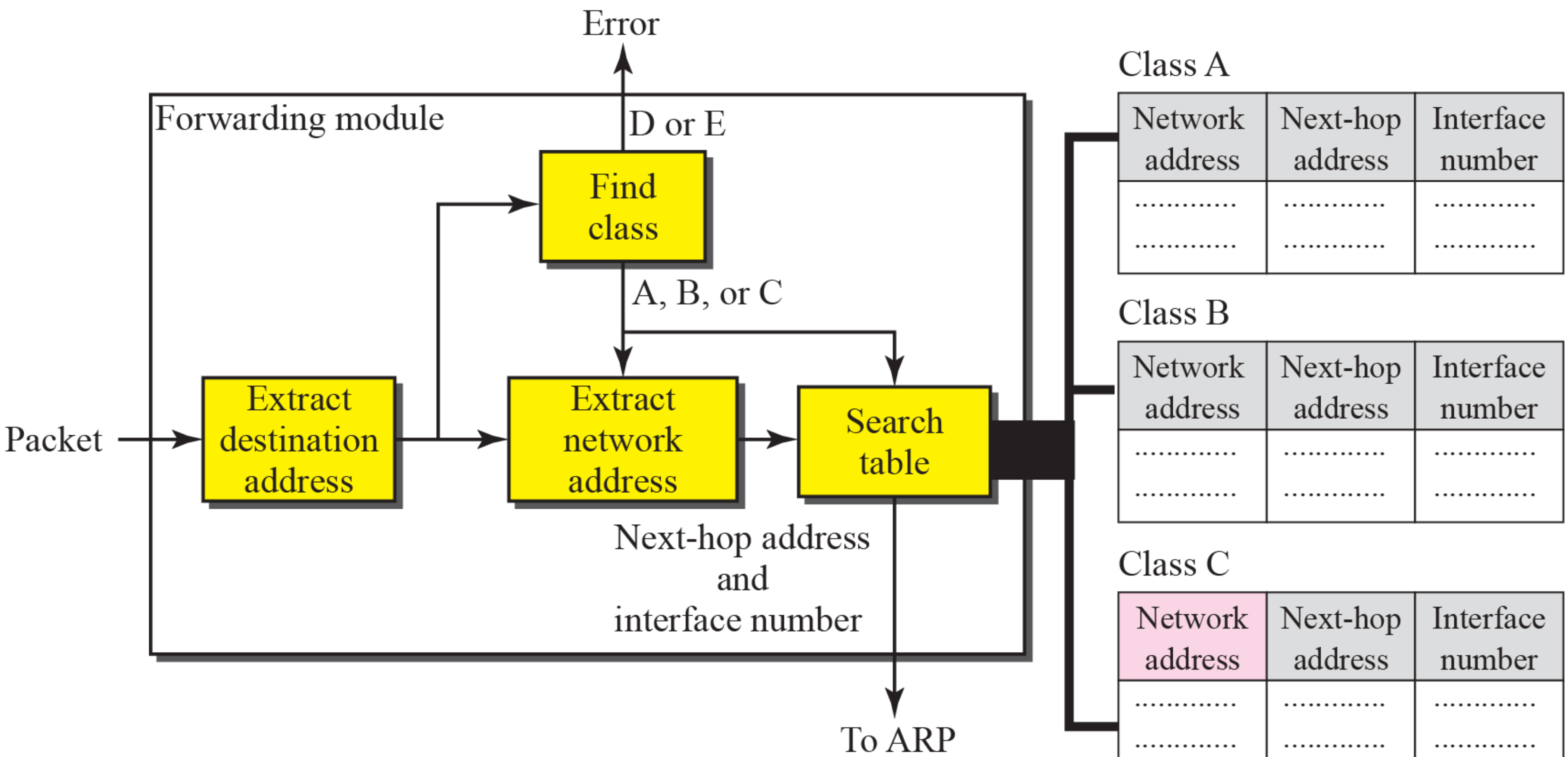
- Instead of listing all networks in the entire Internet host can just have one entry called the default

Routing table for host A

Destination	Next Hop
N2	R1
……	……
Default	R2



Simplified Forwarding Module in Classful Address without Subnetting



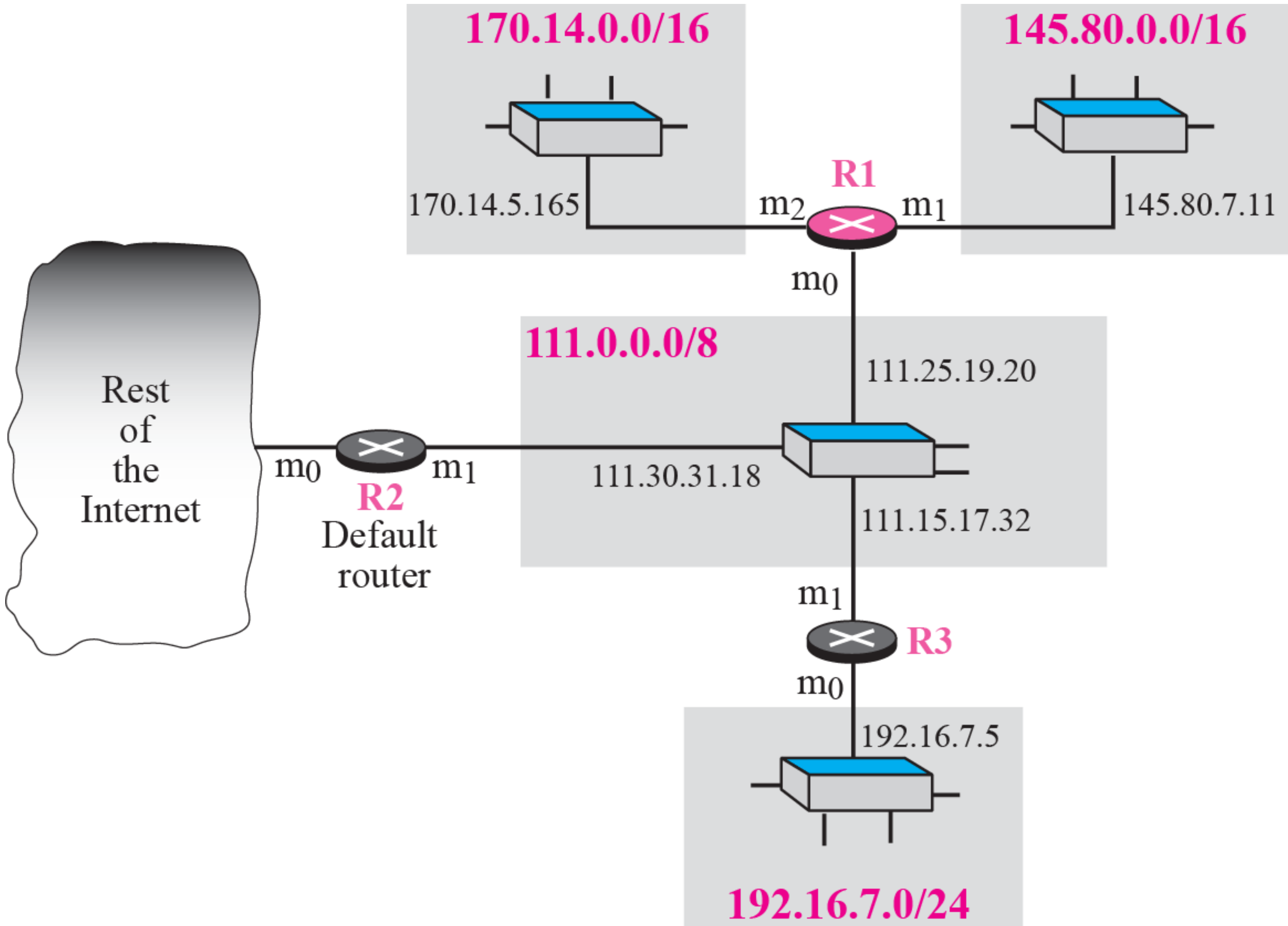
Example 6.1

- 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. 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



: Figure 6.8 : Table 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

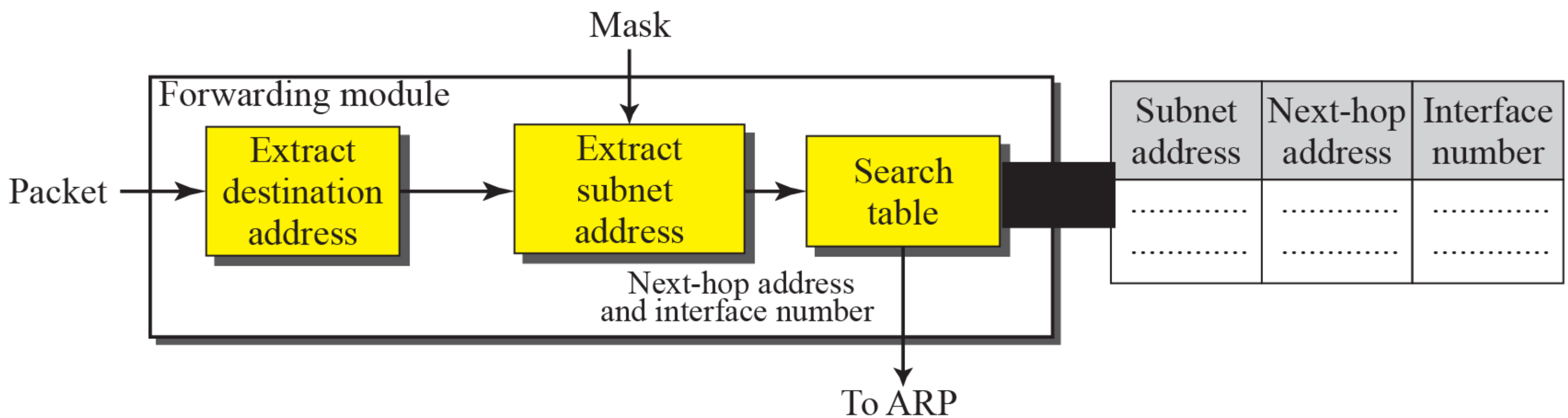
Example 6.2

- 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 in binary is 11000000 00010000 00000111 00001110. 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 making off the left-most 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)

Simplified Forwarding Module in Classful Address with Subnetting

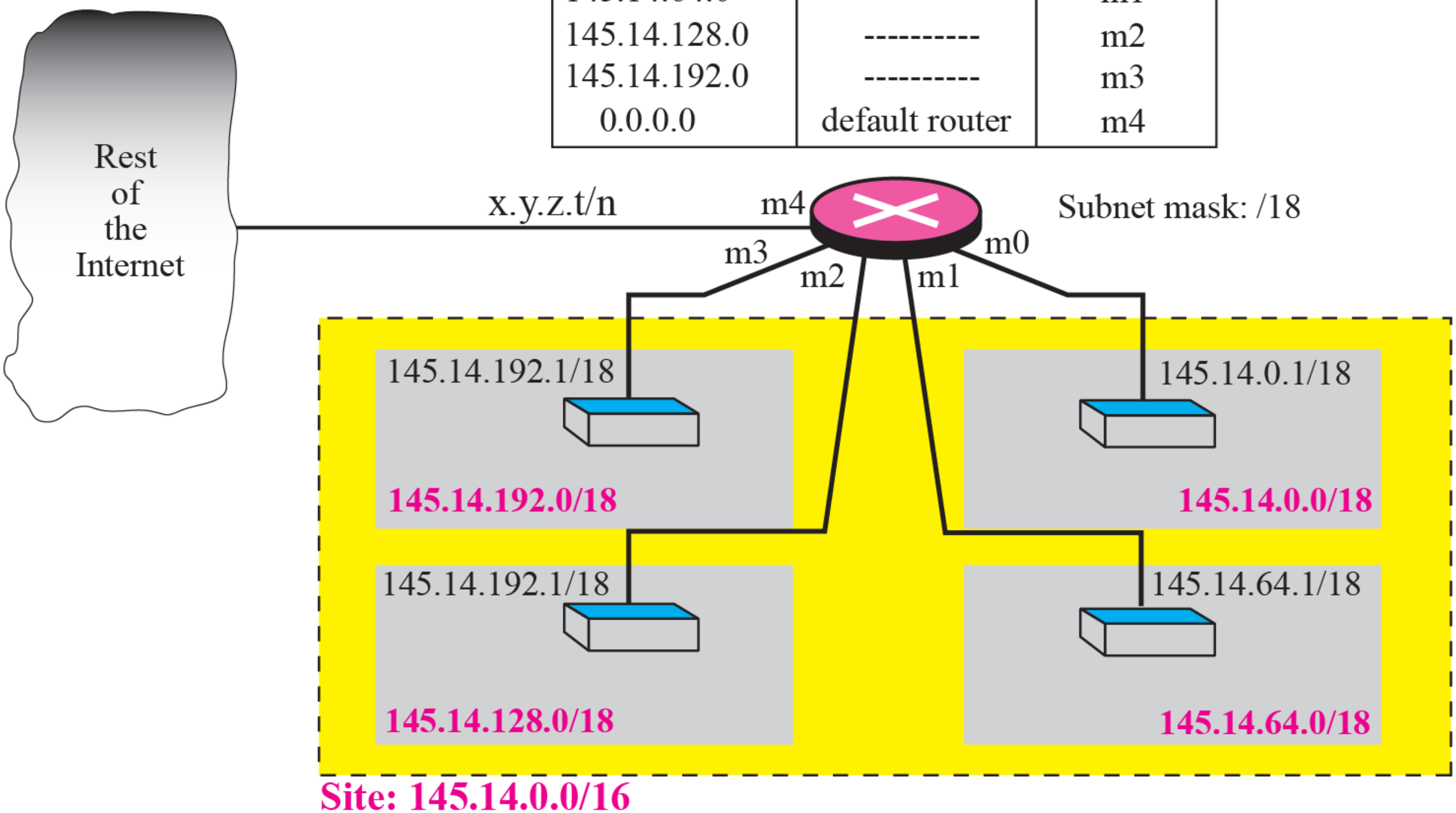


Example 6.4

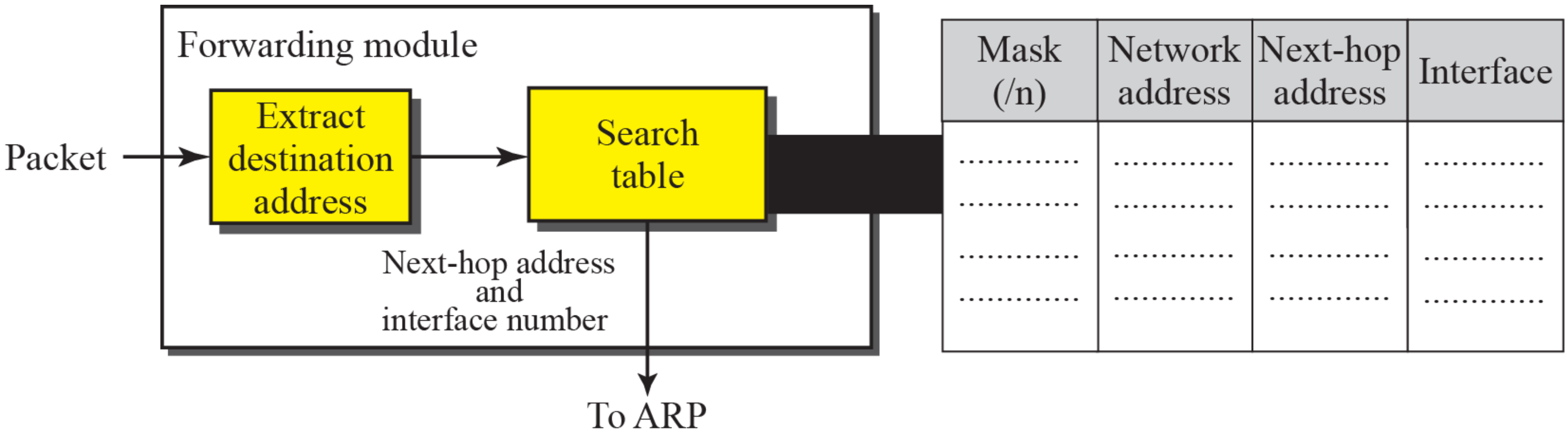
- Figure 6.11 shows a router connected to four subnets. Note several points. First, the site address is 145.14.0.0/16 (a class B address). Every packet with destination address in the range 145.14.0.0 to 145.14.255.255 is delivered to the interface m4 and distributed to the final destination subnet by 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



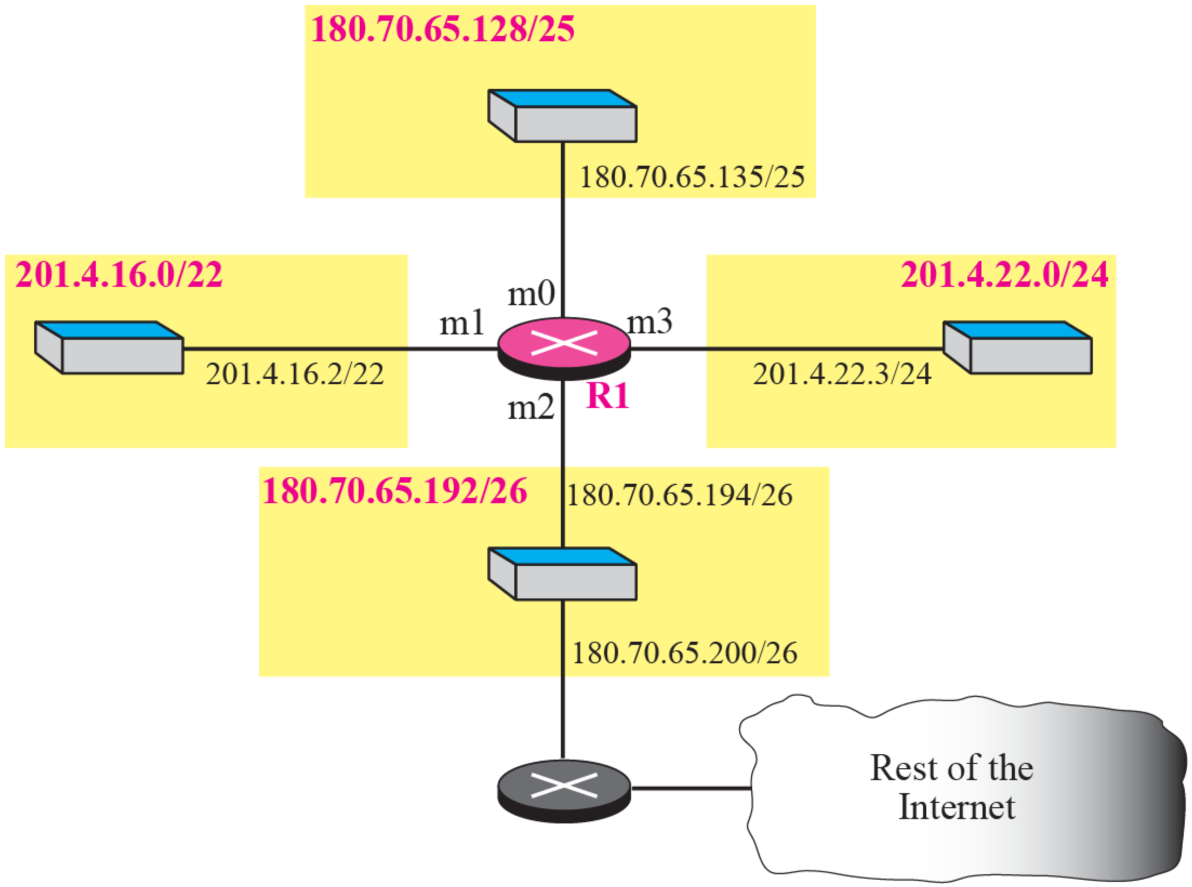
Simplified Forwarding Module in Classless Address



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

Example 6.7

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



Routing Table for router R1 in previous Figure

Solution

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

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 matched the corresponding network address. The next-hop address and the interface number m0 are passed to ARP

Example 6.11

- Can we find the configuration of a router if we know only its routing table? The routing table for router R1 us given in Table 6.2. Can we draw its topology?

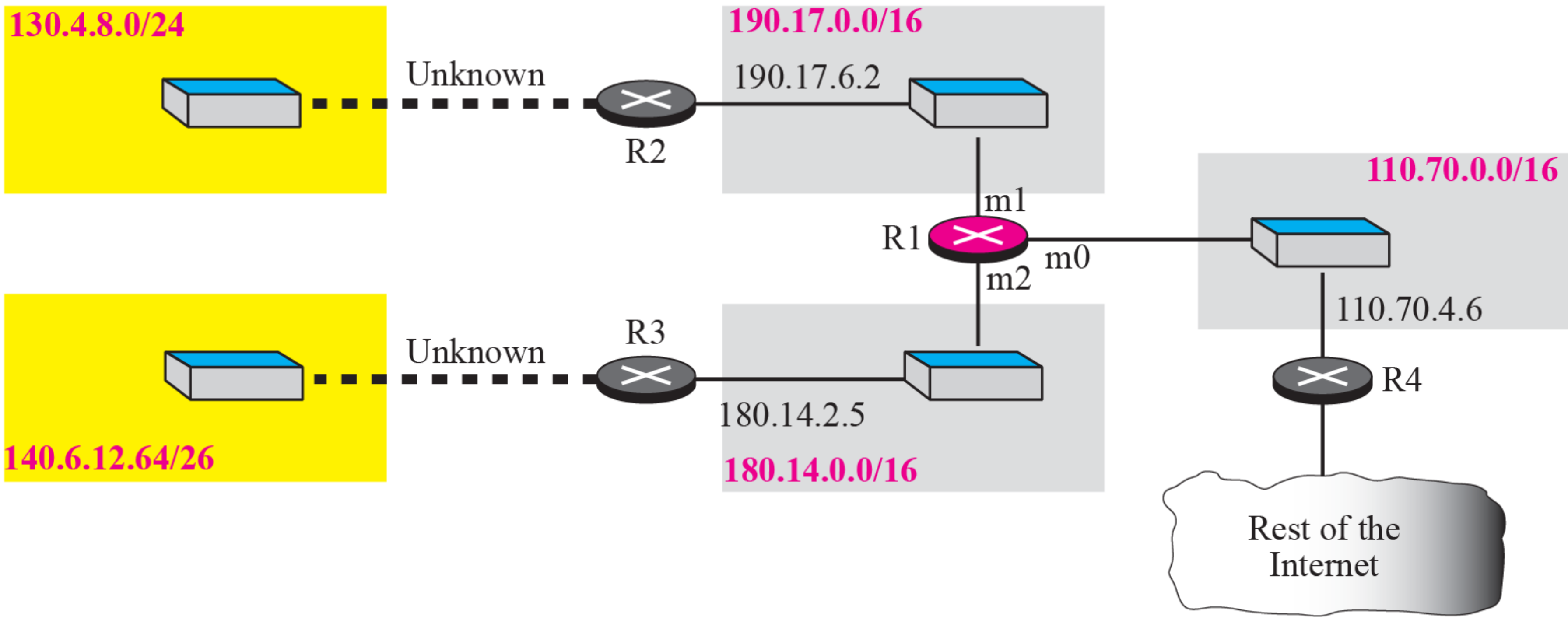
- *Solution*

  We know some facts but we don't have all for a define topology. We know that router R1 has three interface: m0, m1, and m2. We know that there are three notworks directly connected to router R1. We know that there are two networks indirectly connected to R1. There must be at least three other router involved. We know to which networks these routers are connected by looking at their IP addresses. So we can put them at their appropriate place. We know that one router, the default router, is connected to the rest of the Internet. But there is some missing information. We do not know if network 130.4.8.0 is directly connected to router R2 or through a point-to-point network (WAN) and another router. We do not know if network 140.6.12.64 is connected to router R3 directly or through a point-to-point network and another router. Point-to-point networks normally do not have an entry in the routing table because no hosts are connected to them. Figure 6.14 shows our guessed topology

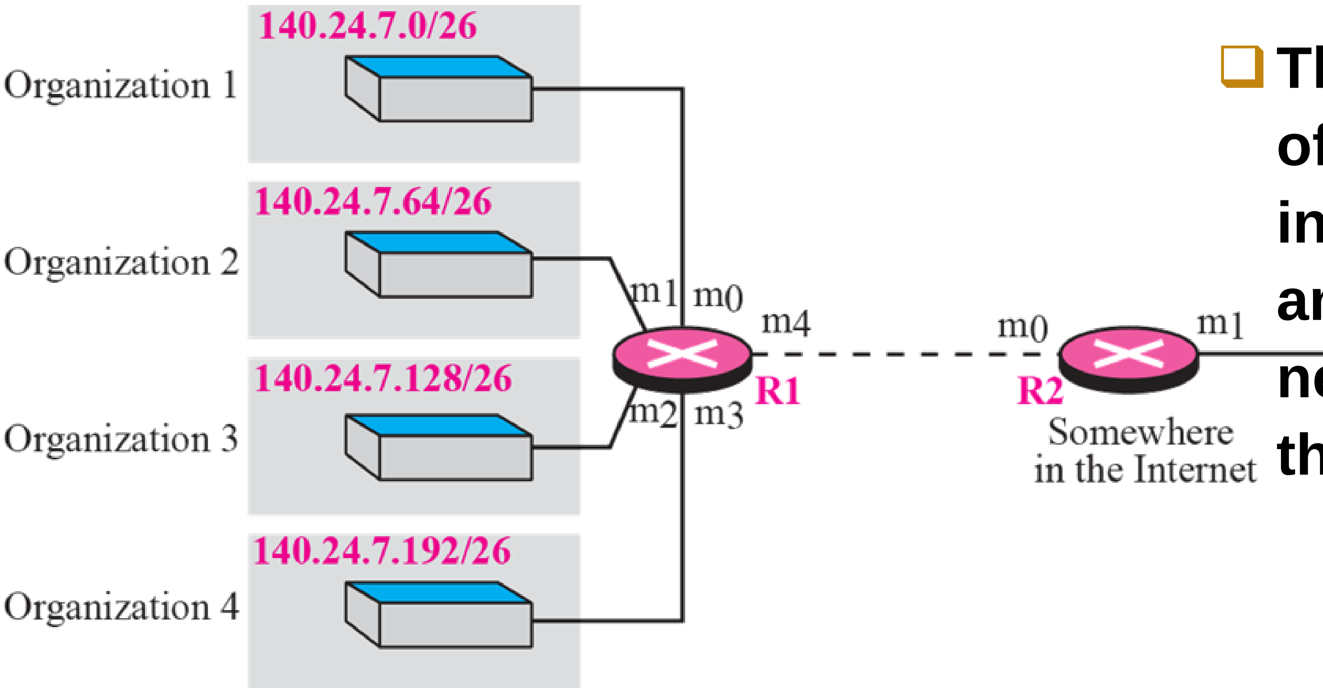
Routing Table for Example 6.11 : Table 6.1

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

Guessed Topology for Example 6.11



Address Aggregation



- The increased size of the table results in an increase in the amount of time needed to search the table

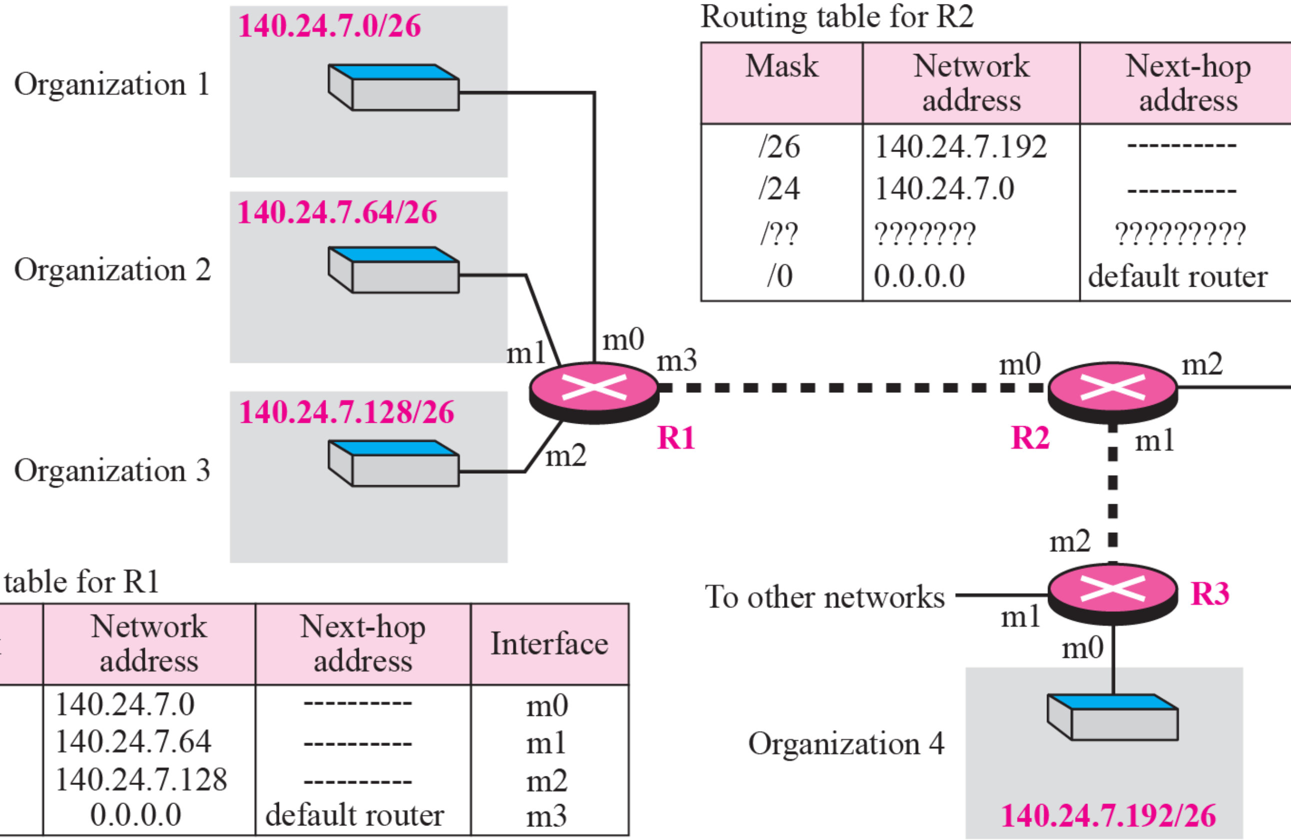
Mask	Network address	Next-hop address	Interface
/26	140.24.7.0	----------	m0
/26	140.24.7.64	----------	m1
/26	140.24.7.128	----------	m2
/26	140.24.7.192	----------	m3
/0	0.0.0.0	default router	m4

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

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

Routing table is sorted from the longest mask to the shortest mask.

Routing

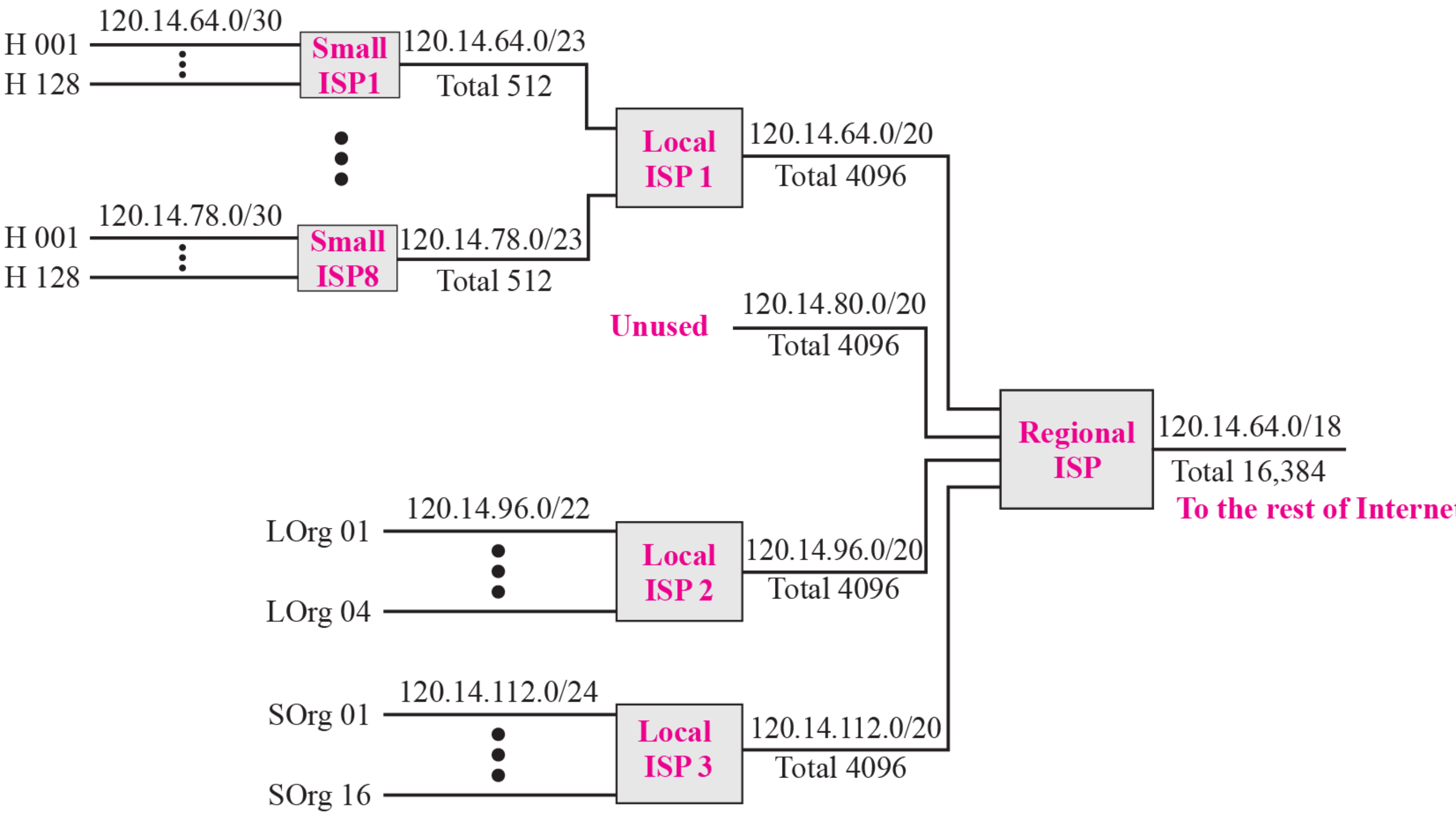
- **Hierachical Routing**
  - **To solve the problem of gigantic routing table.**
  - **If the routing table has a sense of hierarchy like the Internet architecture, the routing table can be decrease in size**
- **Geographical Routing**
  - **Divide the entire address space into a few large block**

    - US, EU, Asia, Africa and so on
- **Routing table search algorithms**
  - **See the Chapter 11**

Example 6.12

- As an example of hierarchical routing, let us consider Figure 6.17. A regional ISP is a granted 16,384 addresses starting from 120.14.64.0. The regional ISP has decided to divided to divide this block into 4 subblocks, each with 4096 addresses. Three of these subblock 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.

Hierarchical Routing with ISPs



Forwarding Based on Label

- Change IP to behave like a connection-oriented protocol in witch the routing is replaced by switching

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.

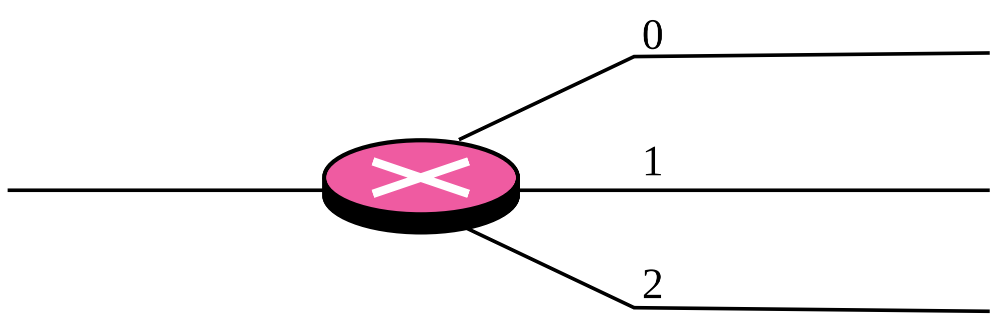
Figure 6.18 : Forwarding based on Destination Address

Routing Table

Mask (/n)	Network address	Next-hop address	Interface
32	NF		
32	NF		
31	NF		
31	NF		
31	NF		
31	NF		
31	NF		
30	F	y	2
29			
⋮			

Legend

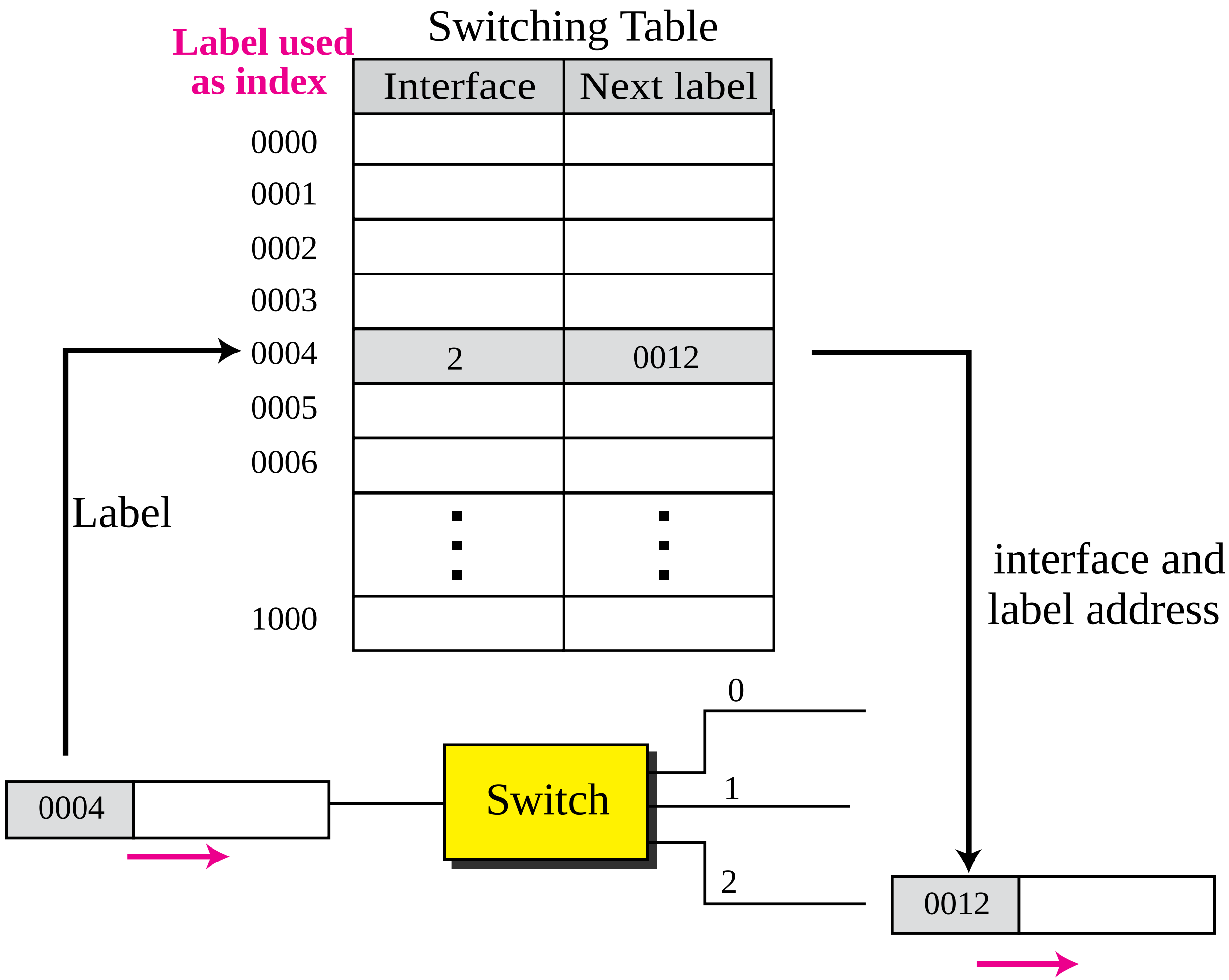
→ : Compare
NF:Not found
F :Found



Example 6.14

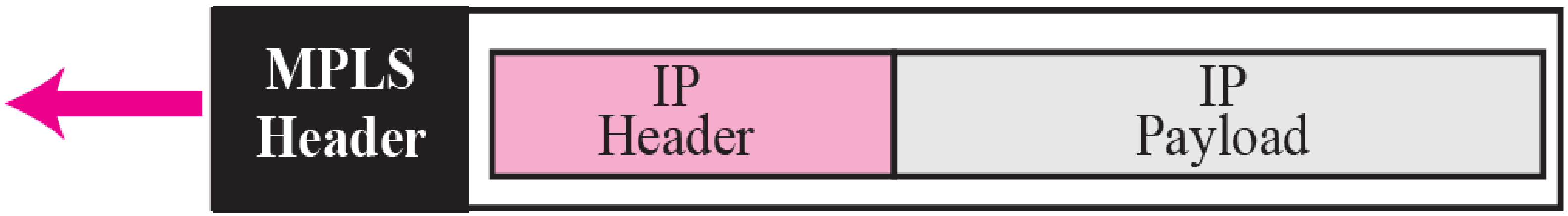
- Figure 6.19 shows a simple example of using a label to access a switching table. Since the labels are used as the index to the table, finding the information in the table is immediate.

Figure 6.19 : Forwarding based on Label

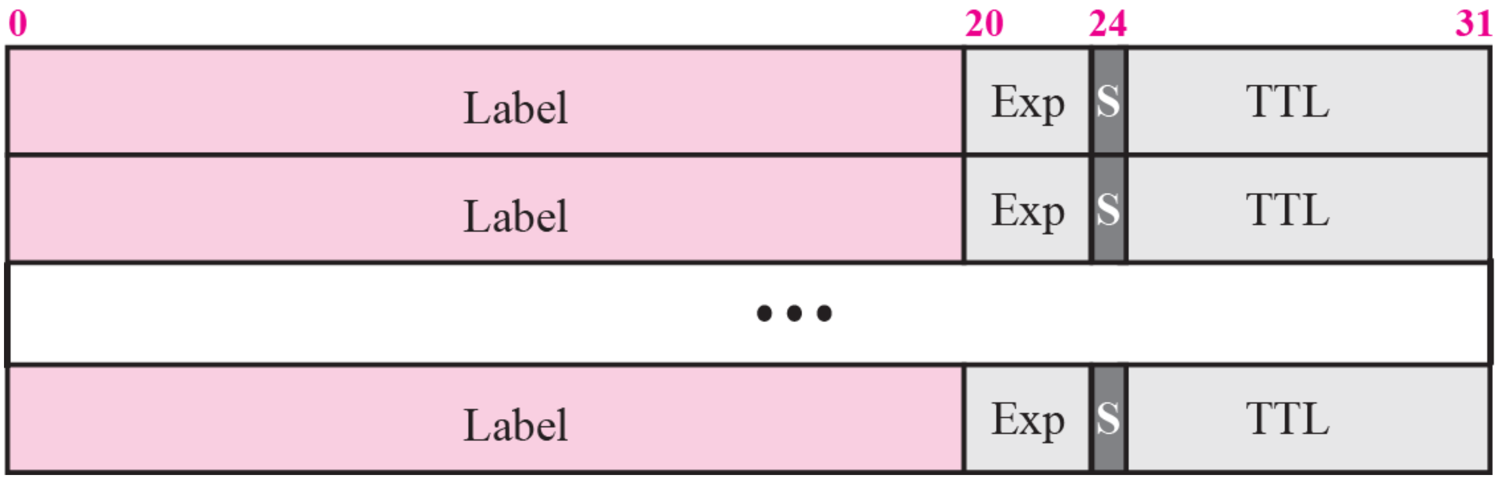


MPLS(Multi-Protocol Label Switching)

- During the 1980s, several vendors created routers that implement switching technology.
- When behaving like a router, MPLS can forward the packet based on the destination address; when behaving like a switch, it can forward a packet based on label.
- A new header is needed
- MPLS header added to an IP packet



MPLS header made of stack of labels

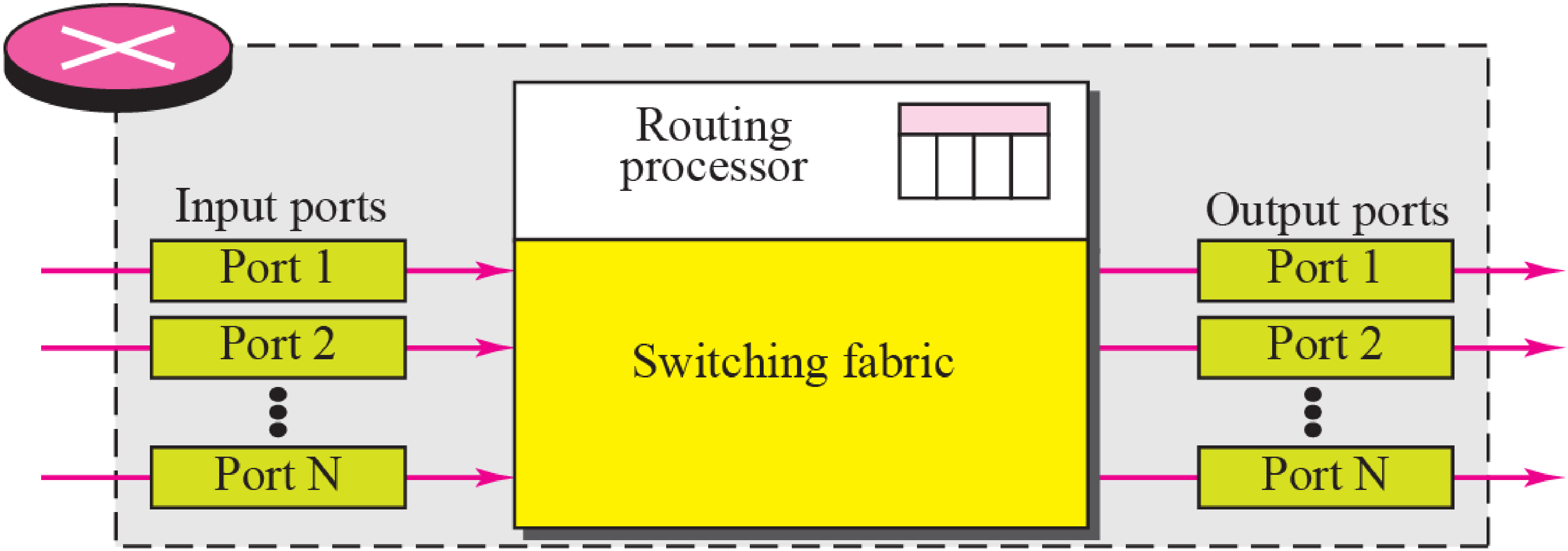


- **Label : This 20-bit a field defines the label that is used to index the routing table in the router**
- **Exp : This 3-bit field is reserved for experimental purposes**
- **S : The one-bit stack field defines the situation of the subheader in the stack. When the bit is 1, it means that the header is the last one in the stack**
- **TTL : 8-bit field, similar to the TTL field in the IP datagram**

6.3 Structure of a Router

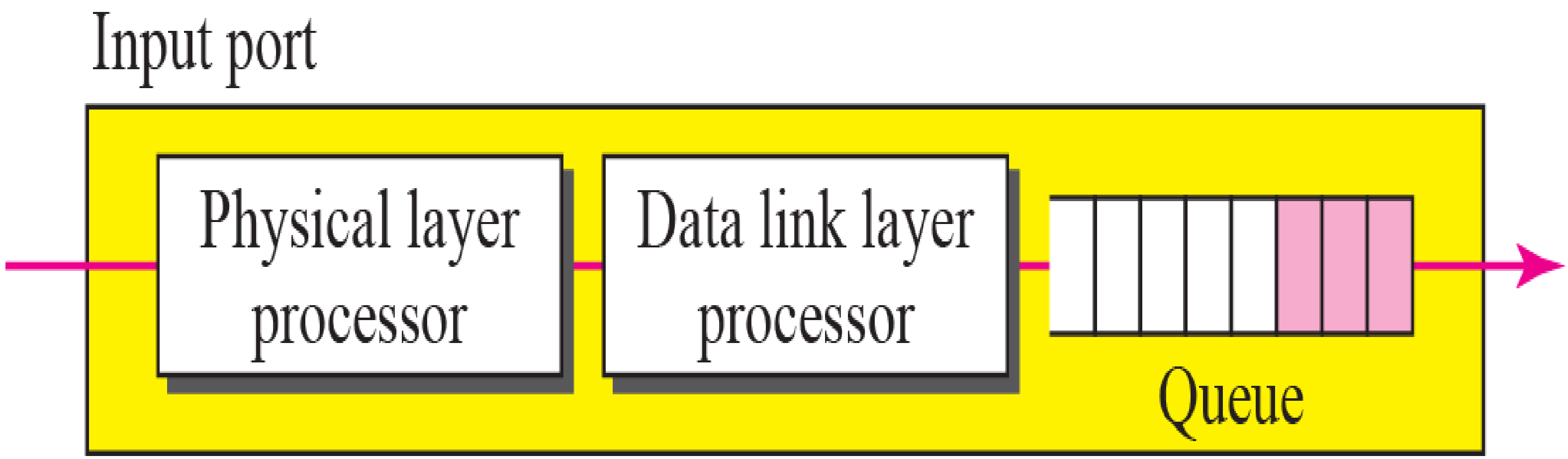
- **Router is**
  - Black box that accepts incoming packets, uses a routing table to find the output port, and sends the packets
- **In this section,**
  - Open the black box and look inside.
  - But this is a just an review and our discussion will not be very detaoled.

Router Component



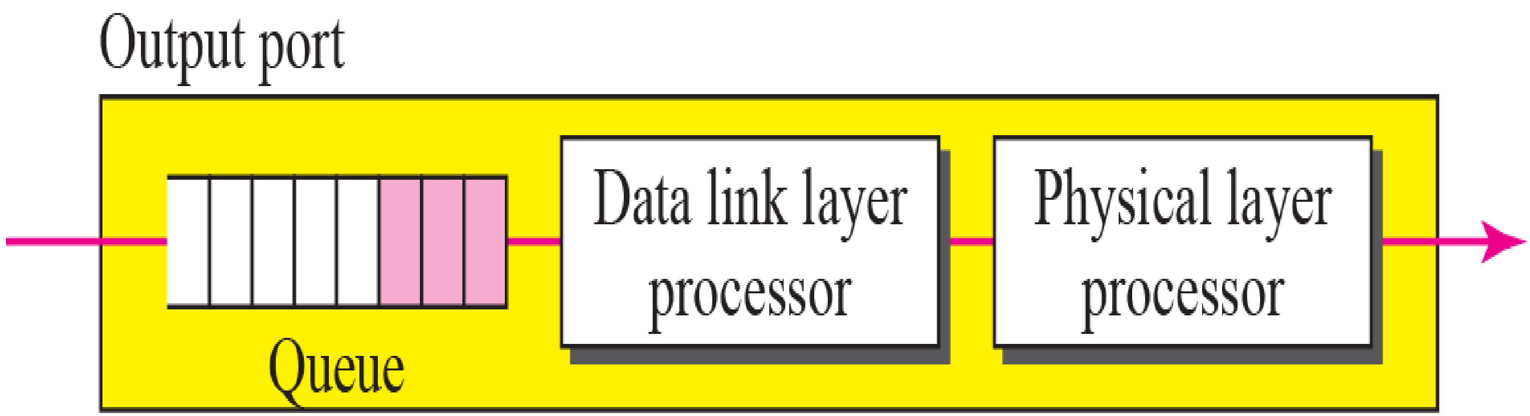
Input Port

- Perform the physical and data link layer functions of router



Output Port

- Perform the same function as the input port, but in reverse order



Routing Processor and Switching Fabric

Routing Processor

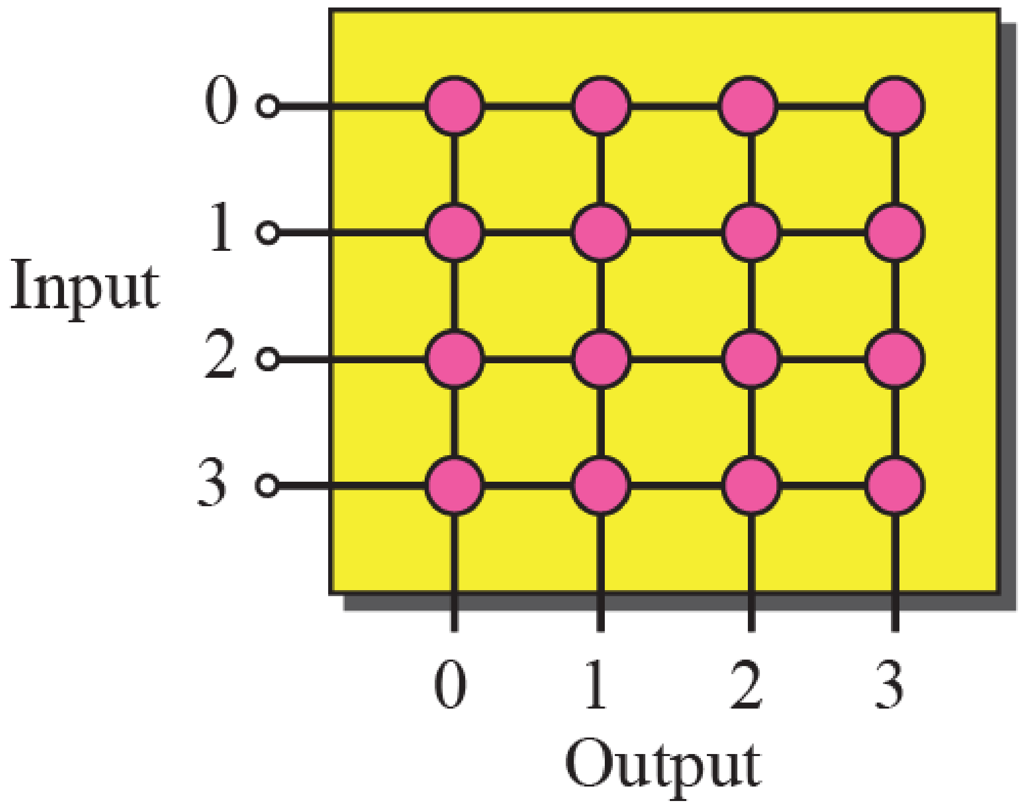
- Perform the functions of the network layer
- The destination address is used to find the address of next hop and the output port number from which the packet is sent out

Switching Fabric

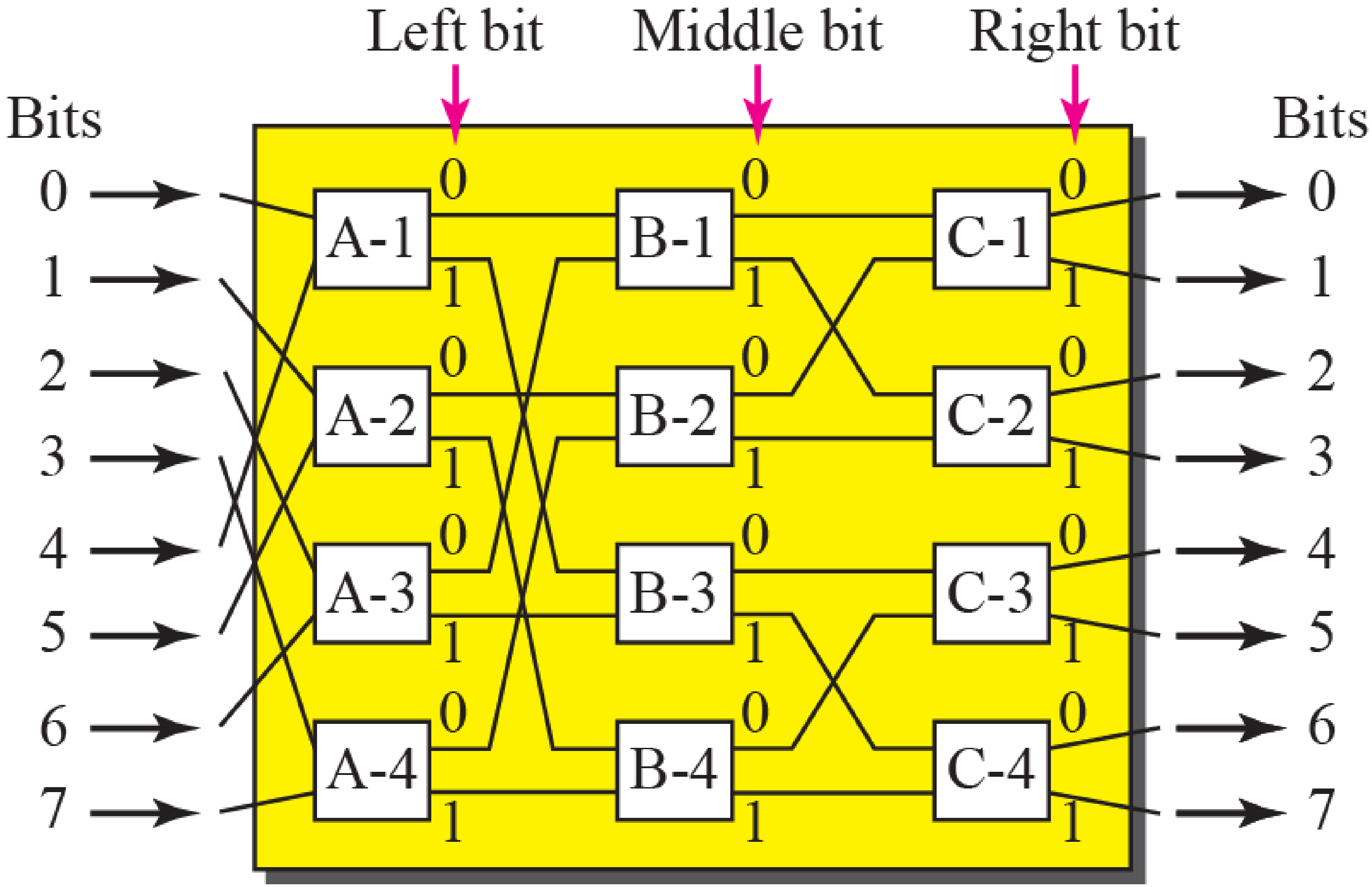
- The most difficult task in a router
- Move the packet from the input queue to output queue
- Routers use a variety of switching fabrics

Crossbar Switch

- Connects n inputs to n outputs in a grid
- Using electronic microswitches at each cross point

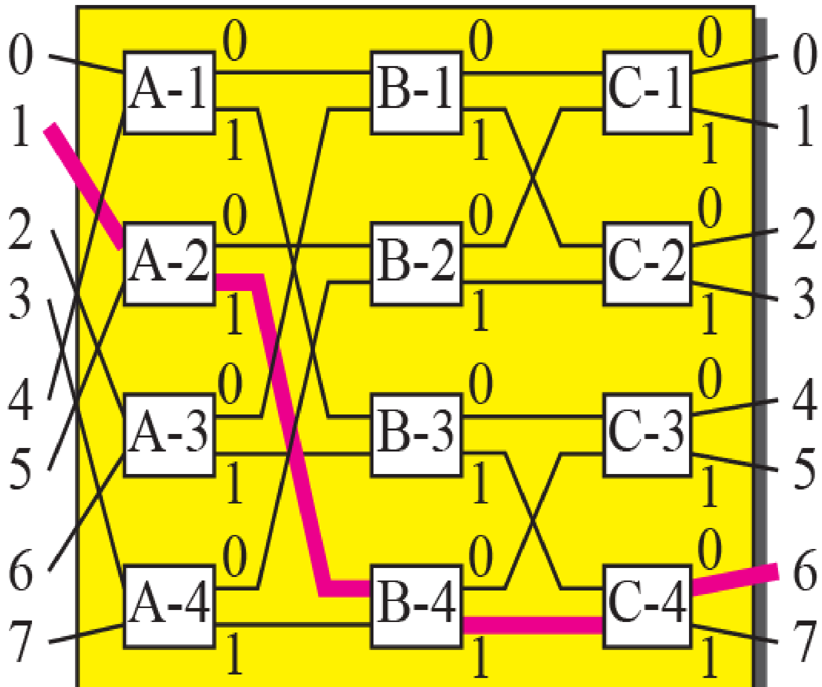


Banyan Switch

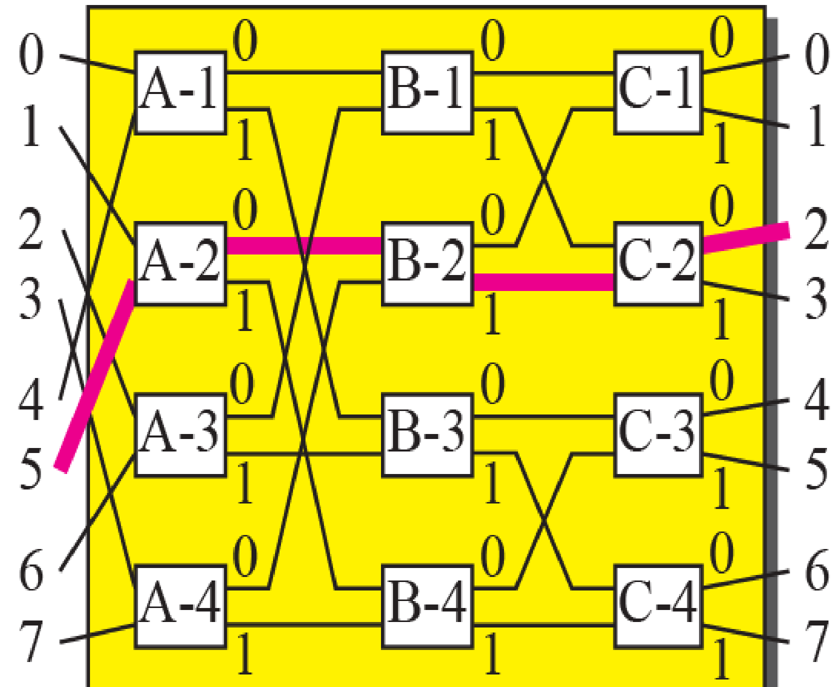


Example of routing in a banyan switch

- Arrange arrival packets according to output ports



a. Input 1 sending to output 6 (110)



b. Input 5 sending to output 2 (010)

Batcher-banyan Switch