# Chapter 6

# *Delivery, Forwarding, and Routing of IP Packets*

## Objectives

*Upon completion you will be able to:*

- *Understand the different types of delivery and the connection*
- *Understand forwarding techniques in classful addressing*
- *Understand forwarding techniques in classless addressing*
- *Understand how a routing table works*
- *Understand the structure of a router*

# 6.1 DELIVERY

***The network layer supervises delivery, the handling of the packets by the underlying physical networks. Two important concepts are the type of connection and direct versus indirect delivery.***

***Connection Types***
***Direct Versus Indirect Delivery***

# 6.1 Delivery

## Connection Types

- Connection Oriented Service – First connection established from source to dst., then packets are sent after one another. When all packets are delivered, connection is terminated.
  - Routers do not calculate route for each individual packet.

- Connectionless Service – Each packet independent, no relationship with other packets. Every packet may or may not travel the same path.

Note:

***IP is a connectionless protocol.***

# 6.1 Delivery

## Direct Vs Indirect Delivery

- Direct Delivery – Dst is host connected to same physical Network.
  - Or the delivery is between last router and dst host.

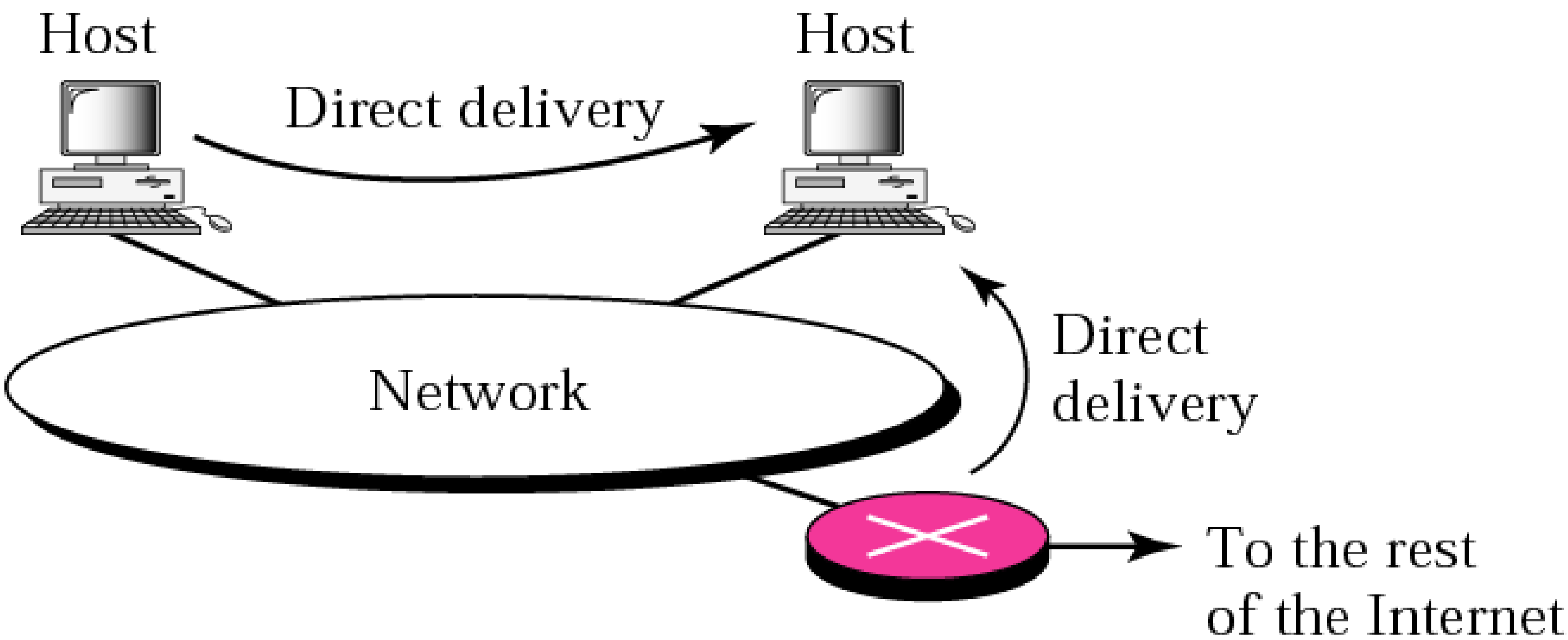
The sender can easily determine if delivery is direct. (By checking network address of dst. )

- Sender finds dst. Physical addr. Done by Data-link layer.
- This process is called mapping of IP to Physical addr. (ARP)



**Figure 6.1** ***Direct delivery***

# Figure 6.1 *Direct delivery*

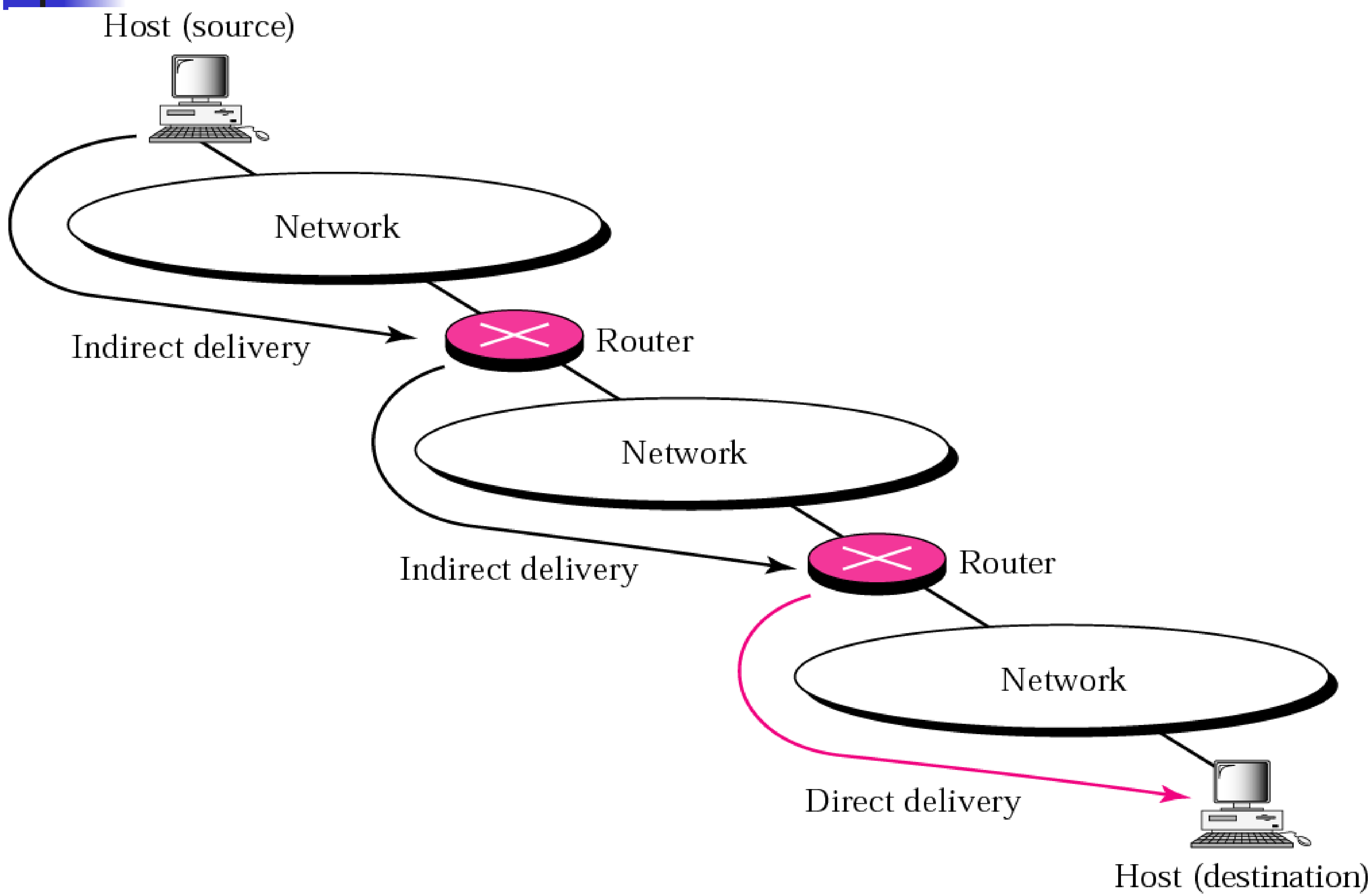


# 6.1 Delivery

## Direct Vs Indirect Delivery

- Indirect Delivery – Dst is host connected to other network.
- Packet goes from router to router.
- Sender uses Dst. IP addr. And routing table to find IP addr of next router.
- Sender uses ARP to find physical addr. Of next router.

## Figure 6.2 *Indirect delivery*



# 6.2 FORWARDING

***Forwarding means to place the packet in its route to its destination. Forwarding requires a host or a router to have a routing table. .***

***Forwarding Techniques***
***Forwarding with Classful Addressing***
***Forwarding with Classless Addressing***
***Combination***

## Forwarding Techniques

Next Hop Method – Routing table holds only the addr. Of next hop instead of complete route.

➢See Fig.



**Figure 6.1** ***Direct delivery***

# Figure 6.3 *Next-hop method*

Routing table for host A

| Destination | Route |
|---|---|
| Host B | R1, R2, Host B |

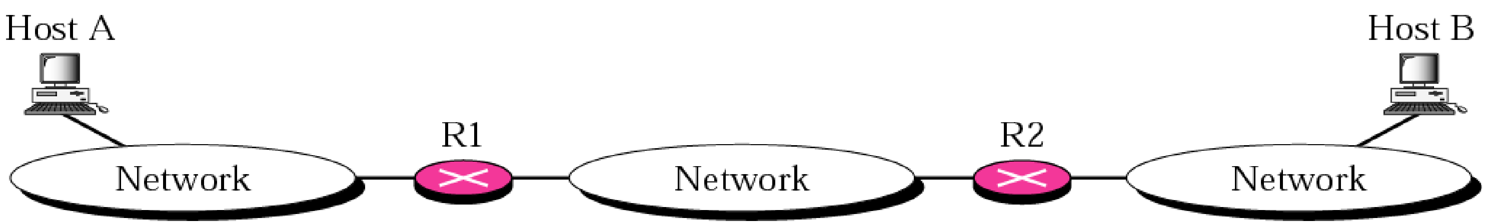
Routing table for R1

| Destination | Route |
|---|---|
| Host B | R2, Host B |

Routing table for R2

| Destination | Route |
|---|---|
| Host B | Host B |

a. Routing tables based on route




Routing table for host A

| Destination | Next Hop |
|---|---|
| Host B | R1 |

Routing table for R1

| Destination | Next Hop |
|---|---|
| Host B | R2 |

Routing table for R2

| Destination | Next Hop |
|---|---|
| Host B | Ñ |

b. Routing tables based on next hop

# *6.2 Forwarding*

## Forwarding Techniques

Network specific Method – To reduce the routing table and simplify searching process.

- Every entry defines address of destination network itself.
- Ex. If 1000 hosts attached to same network only one entry exists instead of 1000.
- See fig.

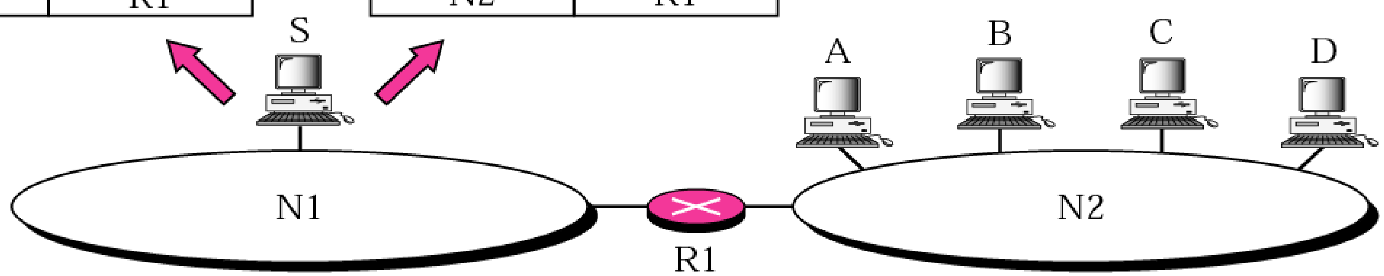
# **Figure 6.4** *Network-specific method*

Routing table for host S based on host-specific method

| Destination | Next Hop |
|---|---|
| A | R1 |
| B | R1 |
| C | R1 |
| D | R1 |

Routing table for host S based on network-specific method

| Destination | Next Hop |
|---|---|
| N2 | R1 |



## Forwarding Techniques

Host specific Method – Dst. Host address is given in routing table.

- Efficiency sacrificed for other advantages as more control over routing.
- Also used for checking the route or providing security measures.
- See fig.

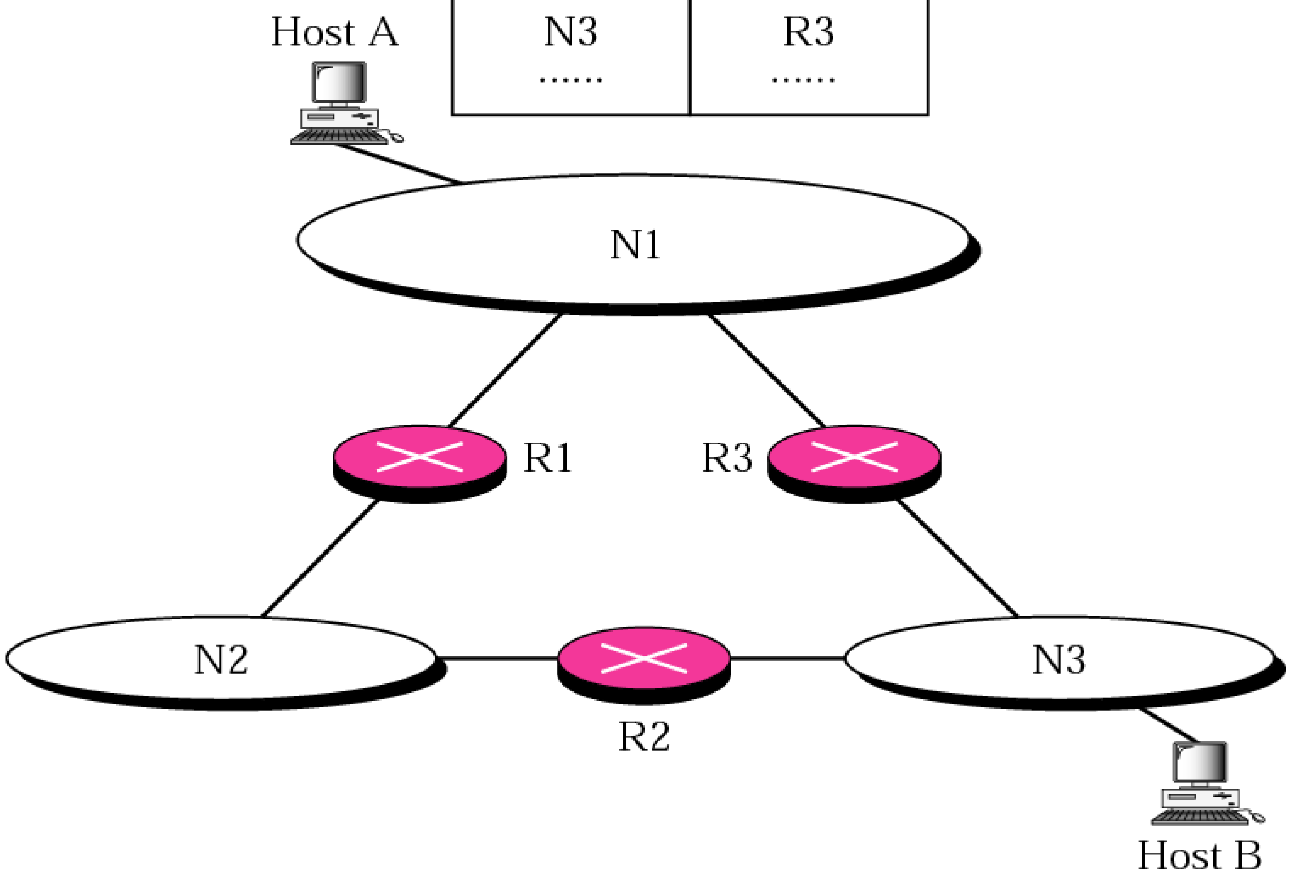


**Figure 6.1** ***Direct delivery***

## **Figure 6.5** *Host-specific routing*

Routing table for host A

| Destination | Next Hop |
|---|---|
| Host B | R3 |
| N2 | R1 |
| N3 | R3 |
| ...... | ...... |



## Forwarding Techniques

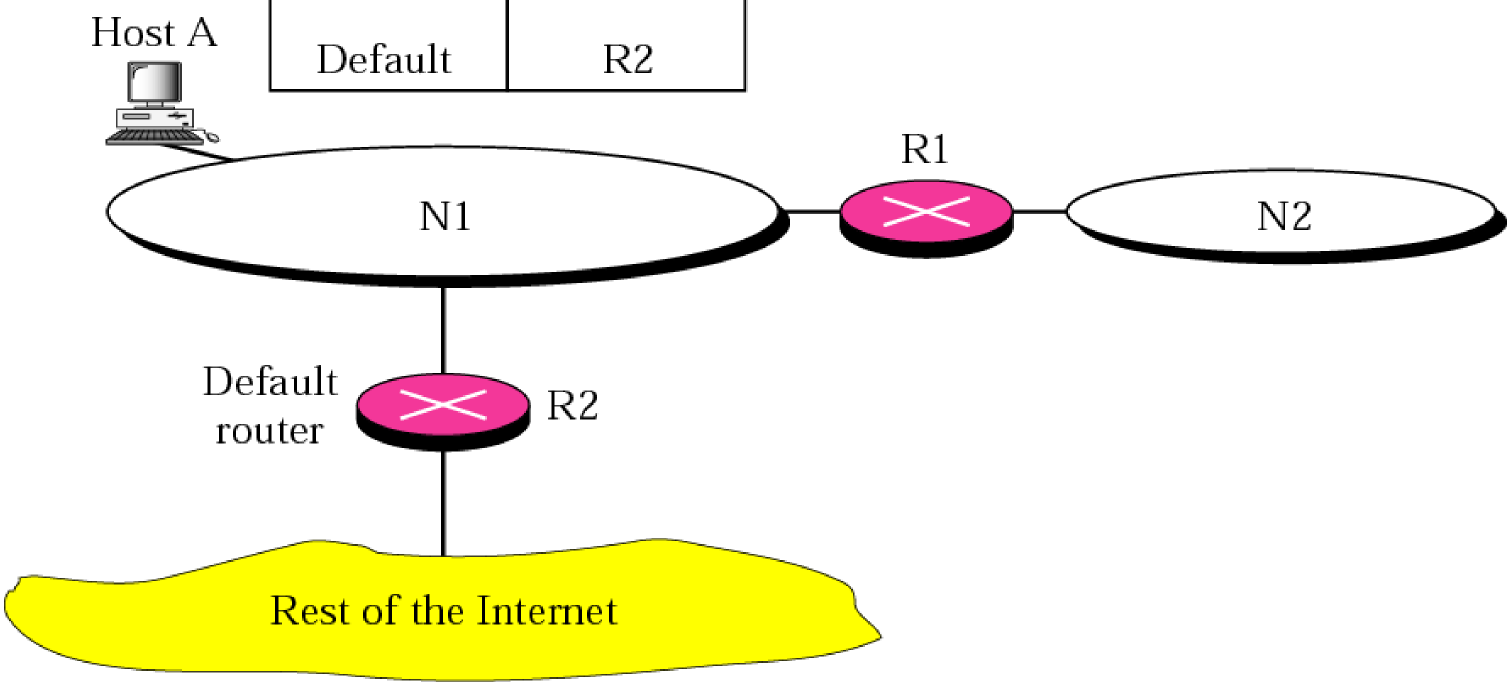
Default Routing Method – Host can have just one entry called default.

- A can have default entry with network address 0.0.0.0
- See fig.

# **Figure 6.6** *Default routing*

Routing table for host A

| Destination | Next Hop |
|---|---|
| N2 | R1 |
| ...... | ...... |
| Default | R2 |



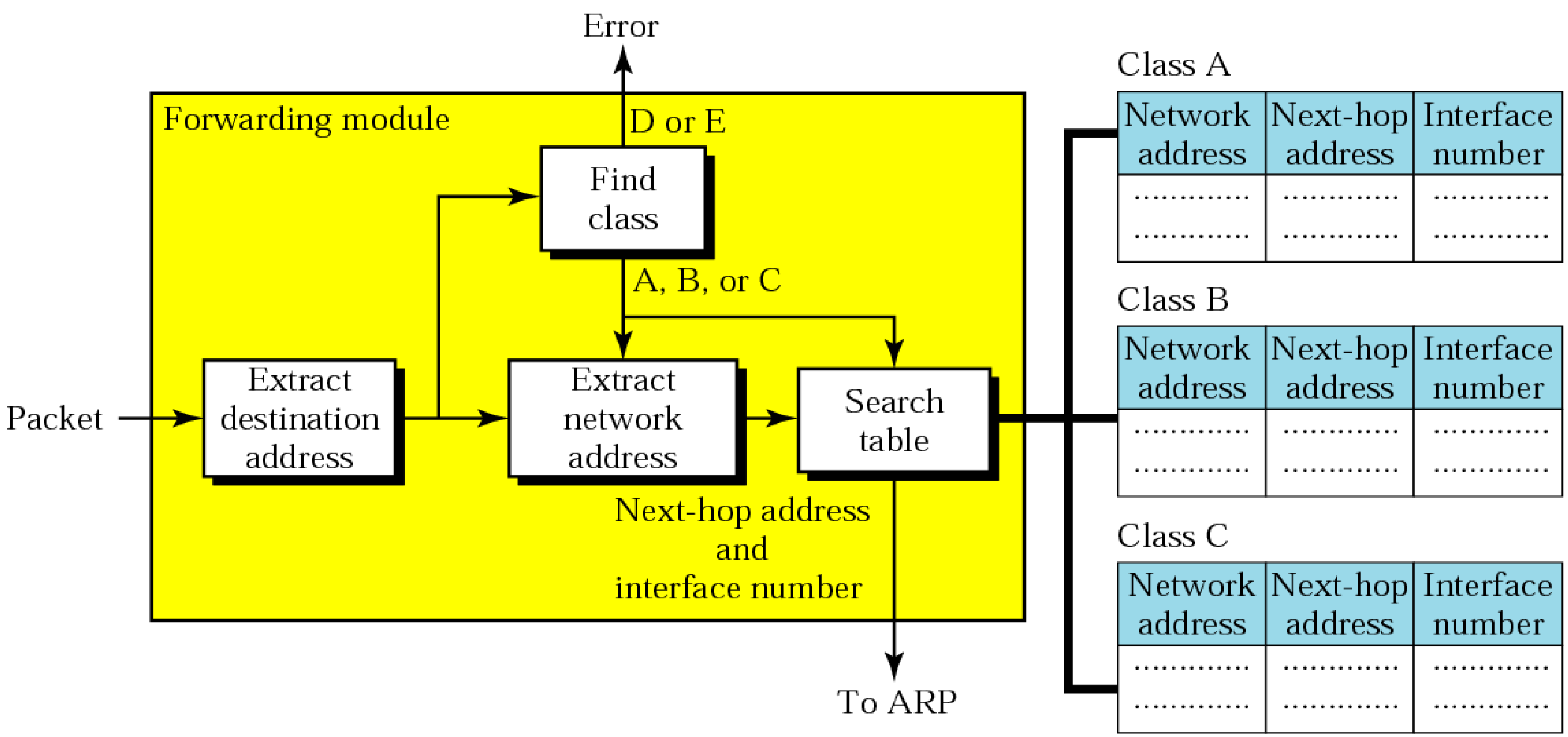
# 6.2 Forwarding

## Forwarding with classful Addressing

Forwarding without subnetting – Forwarding designed using three tables, one for each class. Three tables makes searching more efficient.

- Each routing table has three columns
  - Network addr. Of dst. Network. (We use network-specific Forwarding.)
  - Next hop address (Empty for direct delivery)
  - Interface number (Defines outgoing port)
- See fig.

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

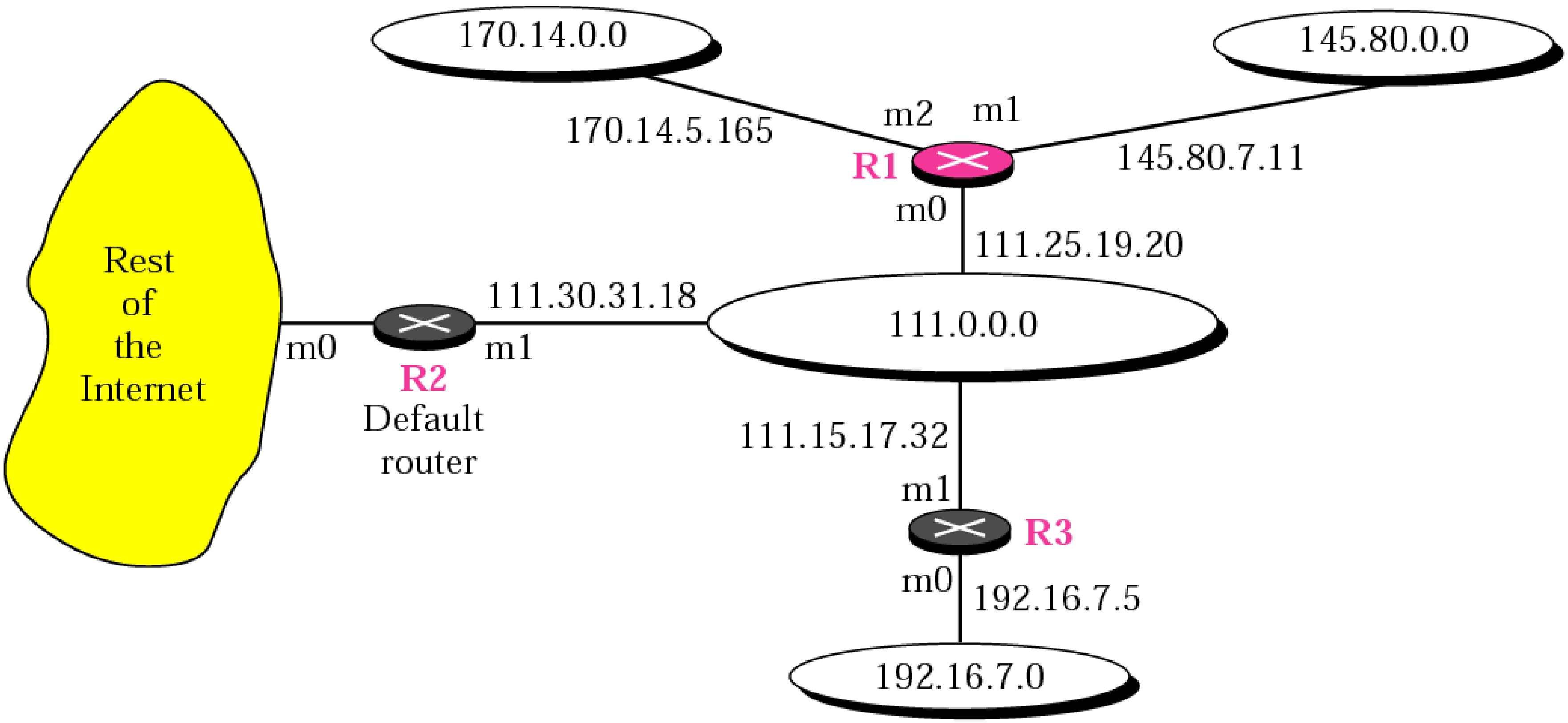


## *Example 1*

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

**See Next Slide**

## Figure 6.8 *Configuration for routing, Example 1*



## *Example 1* *(Continued)*

### *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 7.***

**See Next Slide**

# **Figure 6.9** *Tables for Example 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 2*

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

## *Example 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 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.***

## *Example 3*

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

## *Example 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.***

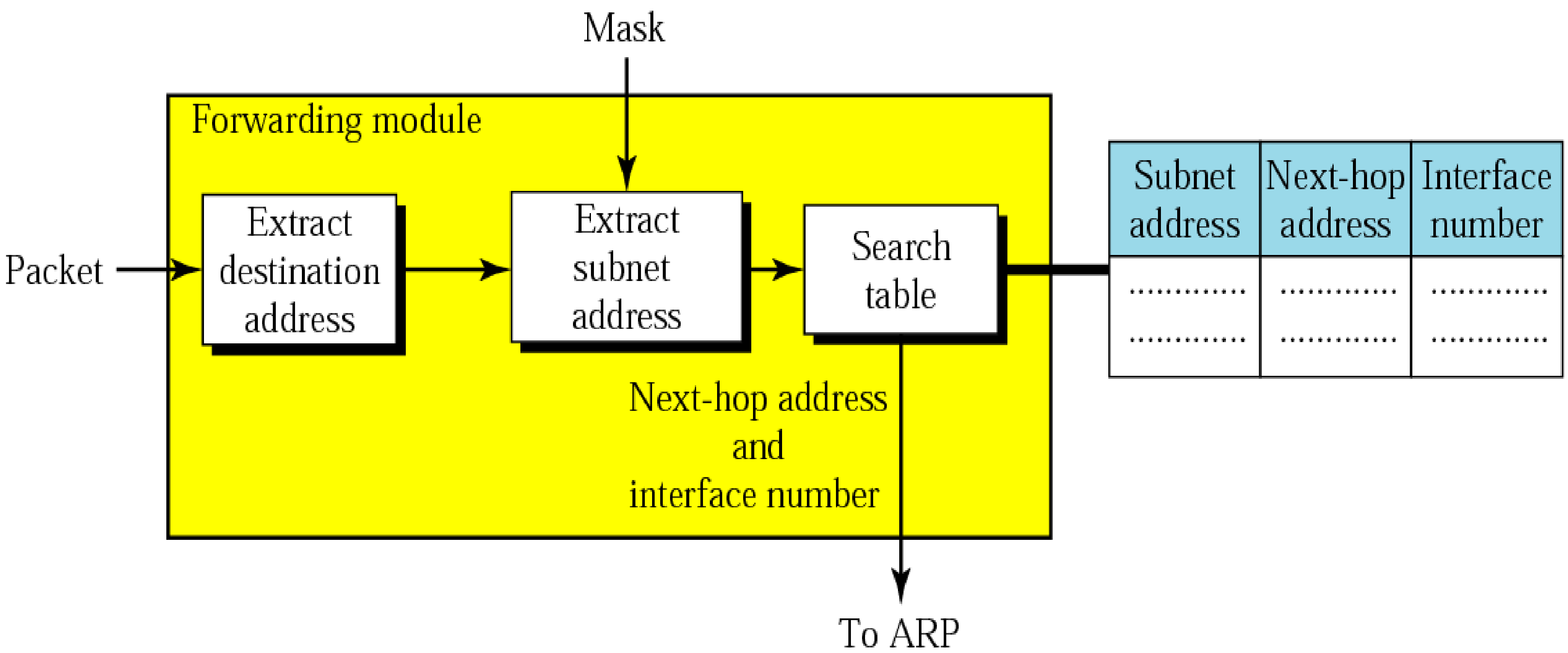
# 6.2 Forwarding

Forwarding with classful Addressing

Forwarding with subnetting – Subnetting happens inside organization.

- If variable length subnetting, we need several tables otherwise we need
- only one table
- See fig.
- The process
  - Extract dst. Addr. Of packet.
  - Use mask to extract subnet address.
  - Search table using subnet addr. To find next-hop addr. & interface
  - Number.
  - Next-hop addr and interface addr. Are given to ARP.

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

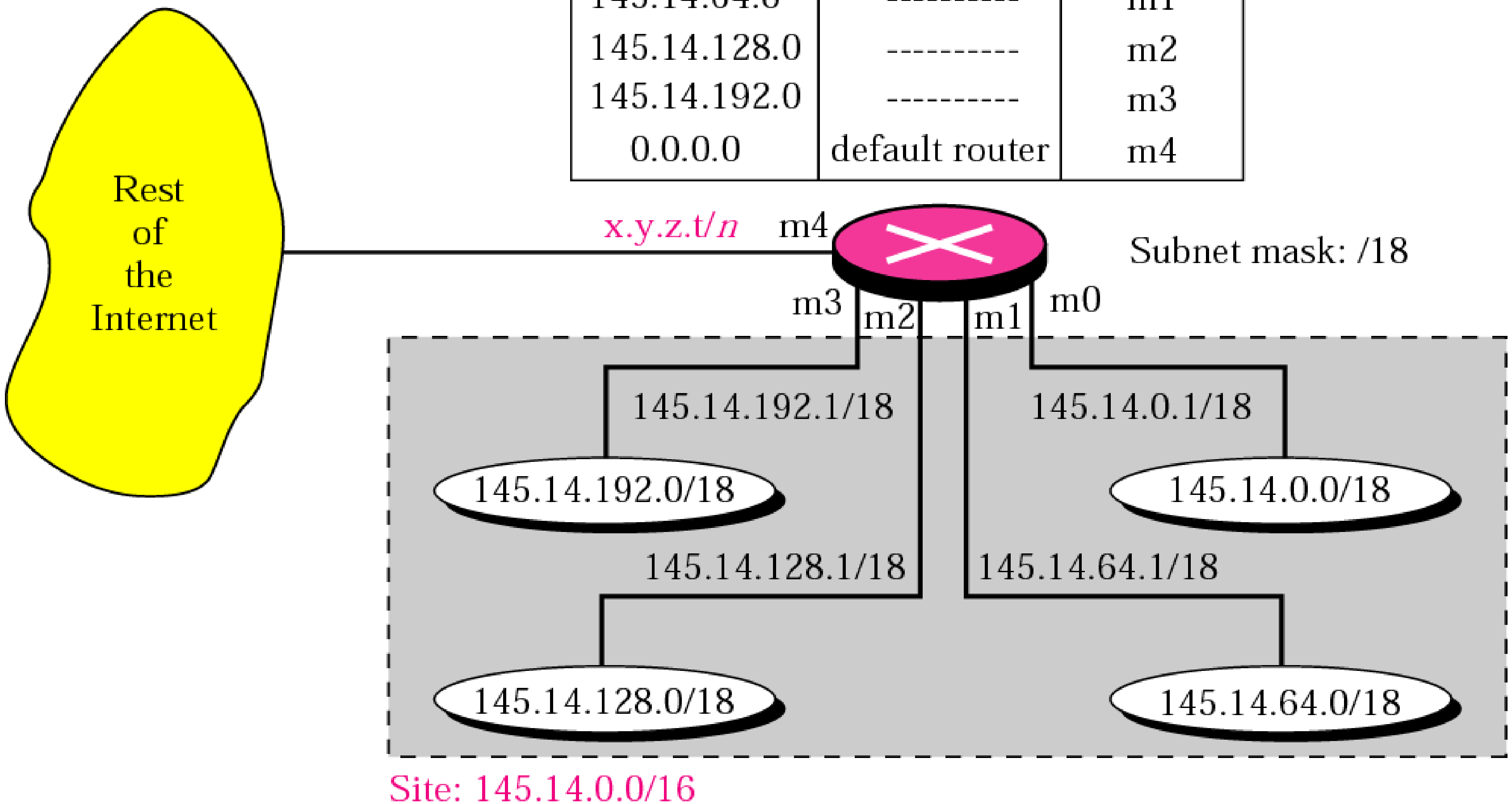


## *Example 4*

***Figure 6.11 shows a router connected to four subnets.***

**See Next Slide**

| 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 4* *(Continued)*

***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 mask /18 to any destination address.***

## *Example 5*

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

## *Example 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 with the next-hop address 145.14.32.78 and the outgoing interface m0.***

## *Example 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.***

## Example 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:

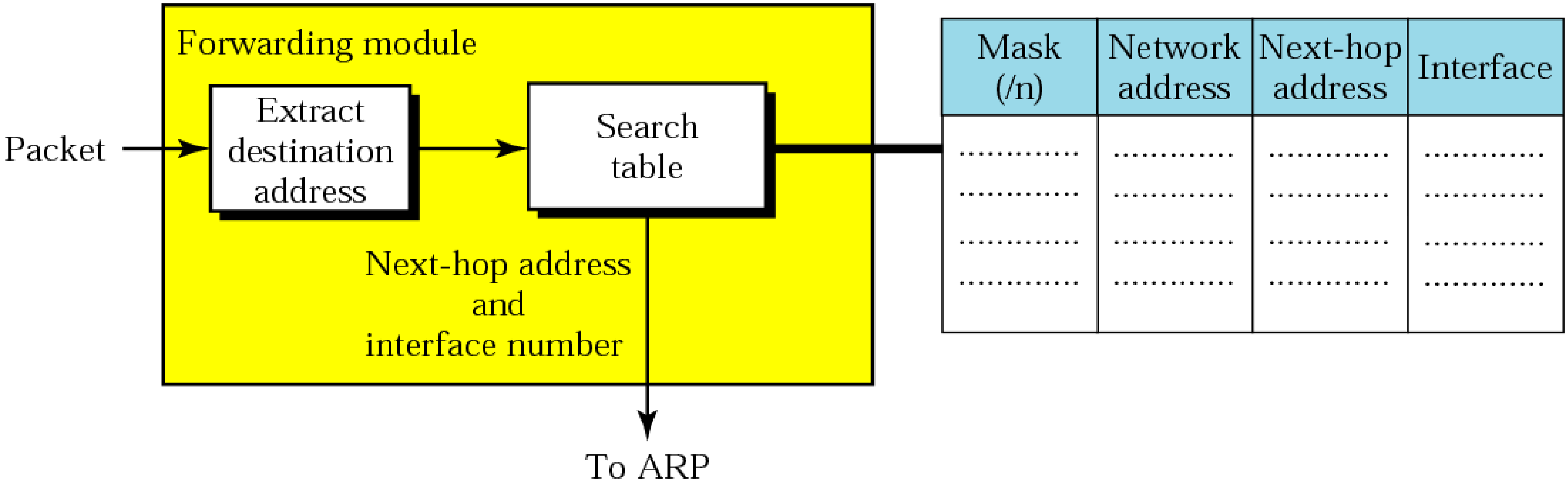
***In classful addressing we can have a routing table with three columns;***

***in classless addressing, we need at least four columns.***

## Forwarding with classless Addressing

- Whole address space is one entity; no classes.
- Table searched based on network address.
- Mask is included in the table.
- Fig. Shows simple forwarding module for classless addressing.

## Figure 6.12 *Simplified forwarding module in classless address*



## *Example 7*

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

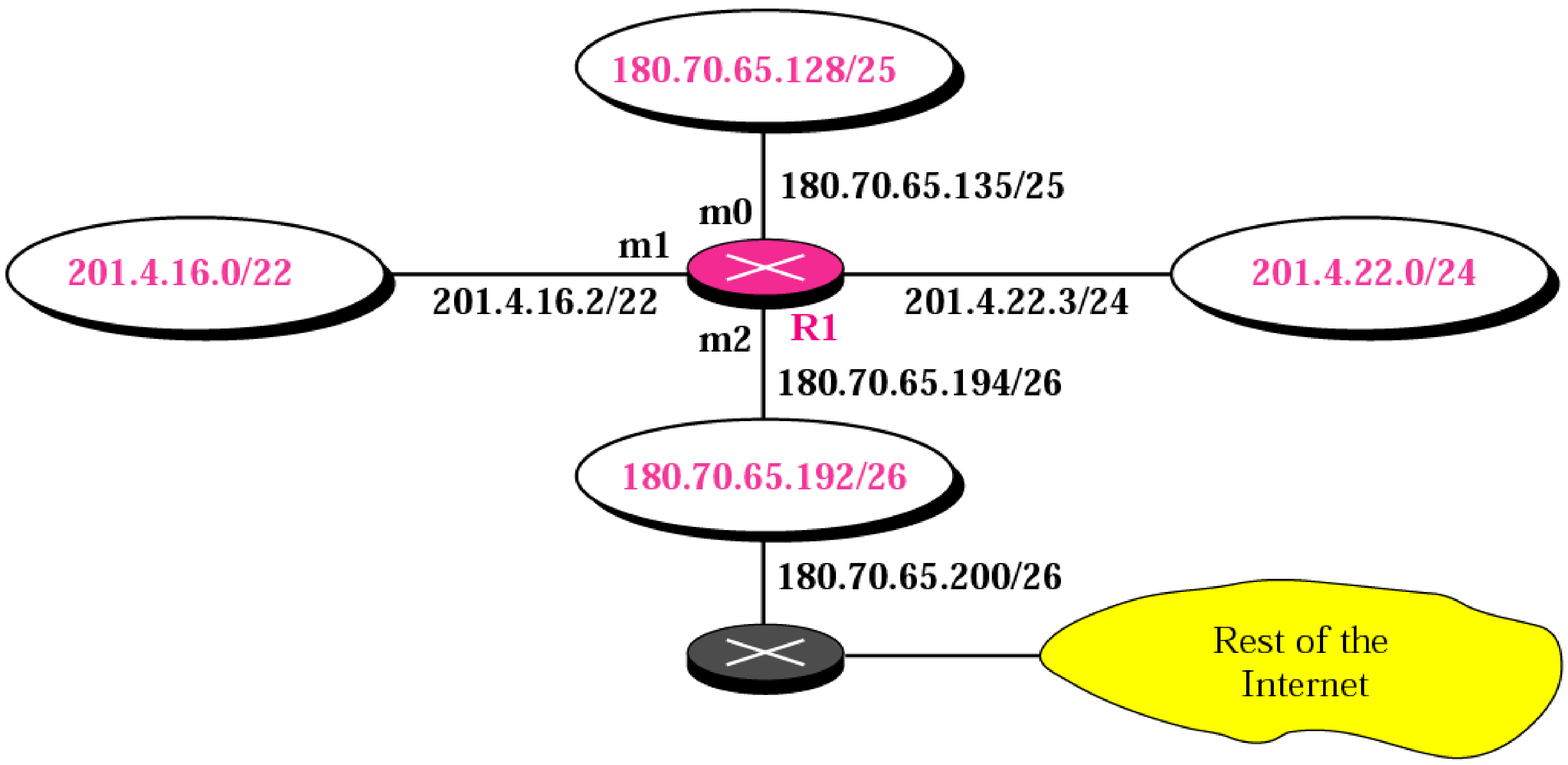
**See Next Slide**

***Solution***

***Table 6.1 shows the corresponding table.***

**See the table after the figure.**

## **Figure 6.13** *Configuration for Example 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 |

## *Example 8*

***Show the forwarding process if a packet arrives at R1 in Figure 6.13 with the destination address 180.70.65.140.***

## Example 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.***

## *Example 8 (Continued)*

***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 for further processing.***

## *Example 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:***

## *Example 9* *(Continued)*

*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. The destination address of the package and the interface number m3 are passed to ARP.*

## *Example 10*

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

## *Example 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. This is probably an outgoing package that needs to be sent, via the default router, to some place else in the Internet.***

## *Example 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?***

## *Table 6.2 Routing table for Example 11*

| *Mask* | *Network Address* | *Next-Hop Address* | *Interface Number* |
|---|---|---|---|
| /26 | 140.6.12.64 | 180.14.2.5 | m2 |
| /24 | 130.4.8.0 | 190.17.6.2.0 | 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 |

## ***Example 11*** *(Continued)*

### *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 know to which networks these routers are connected by looking at their IP addresses. So we can put them at their appropriate place.***

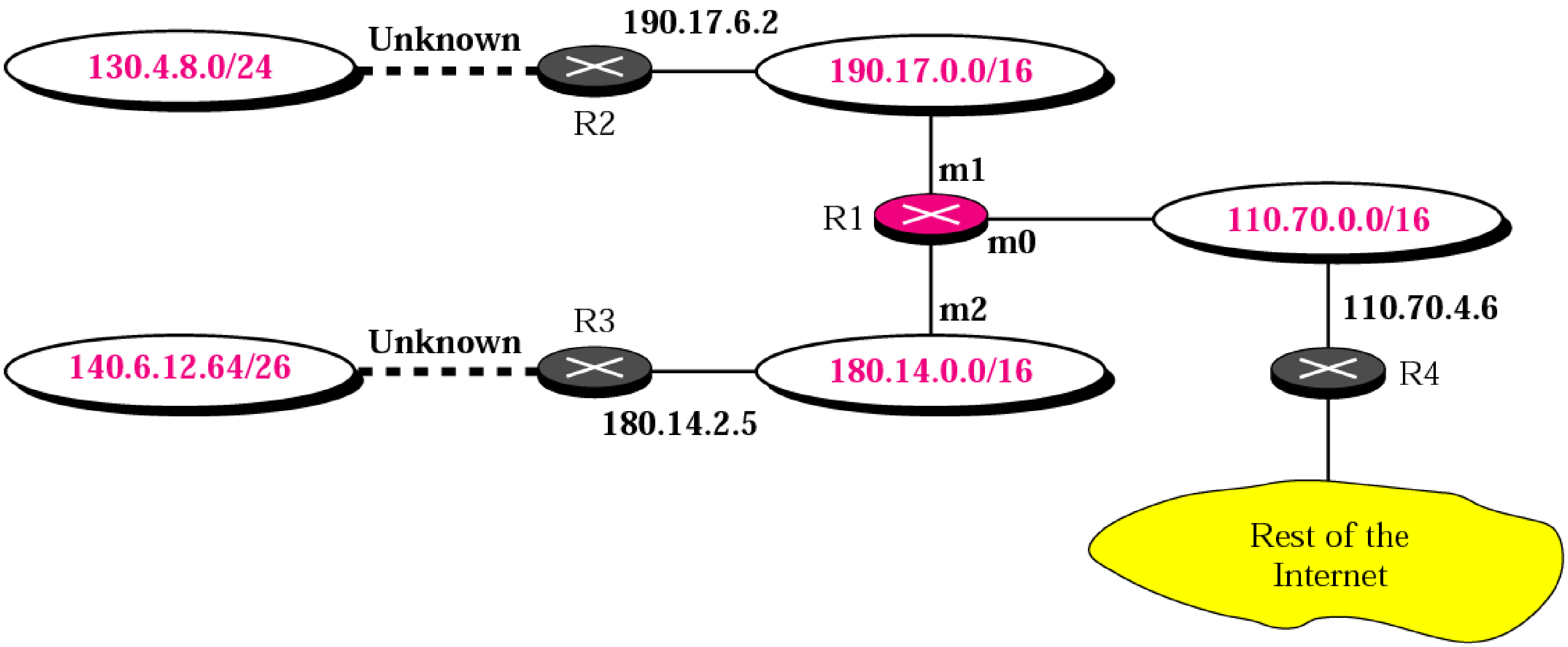
**See Next Slide**

## Example 11 *(Continued)*

***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 network140.6.12.64 is connected to router R3 directly or through a point-to-point network (WAN) 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.***

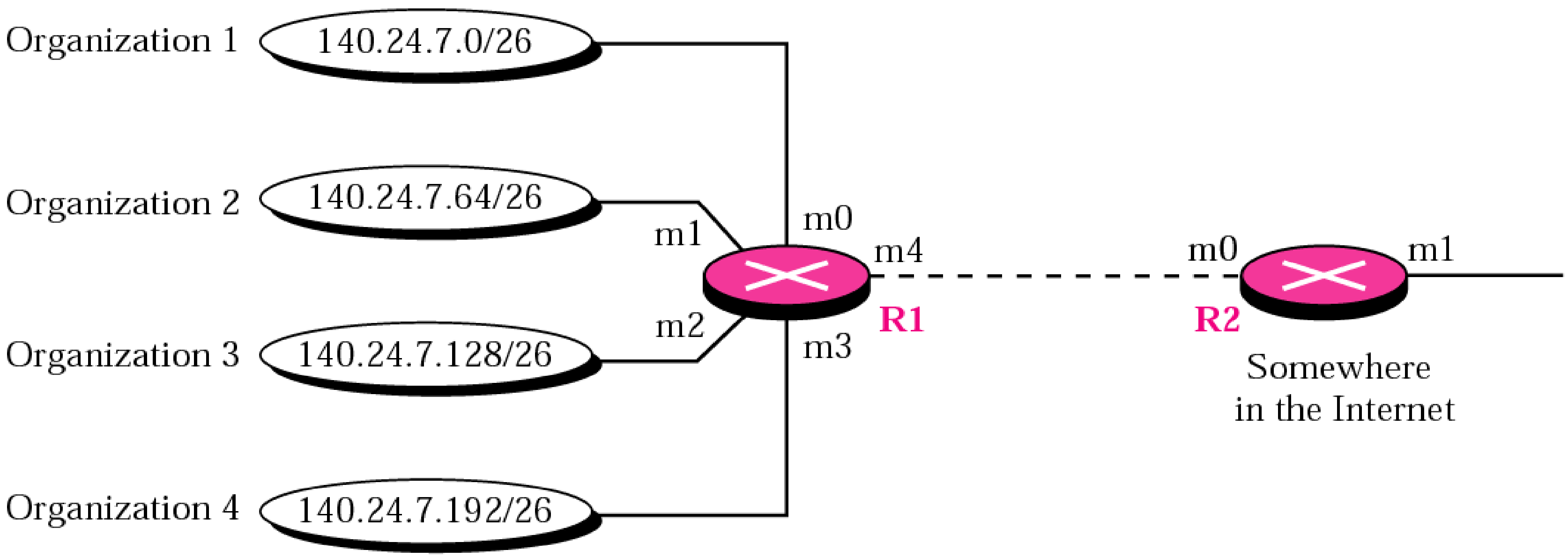
**See Next Slide**

## Figure 6.14 *Guessed topology for Example 6*



## Address Aggregation

# 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

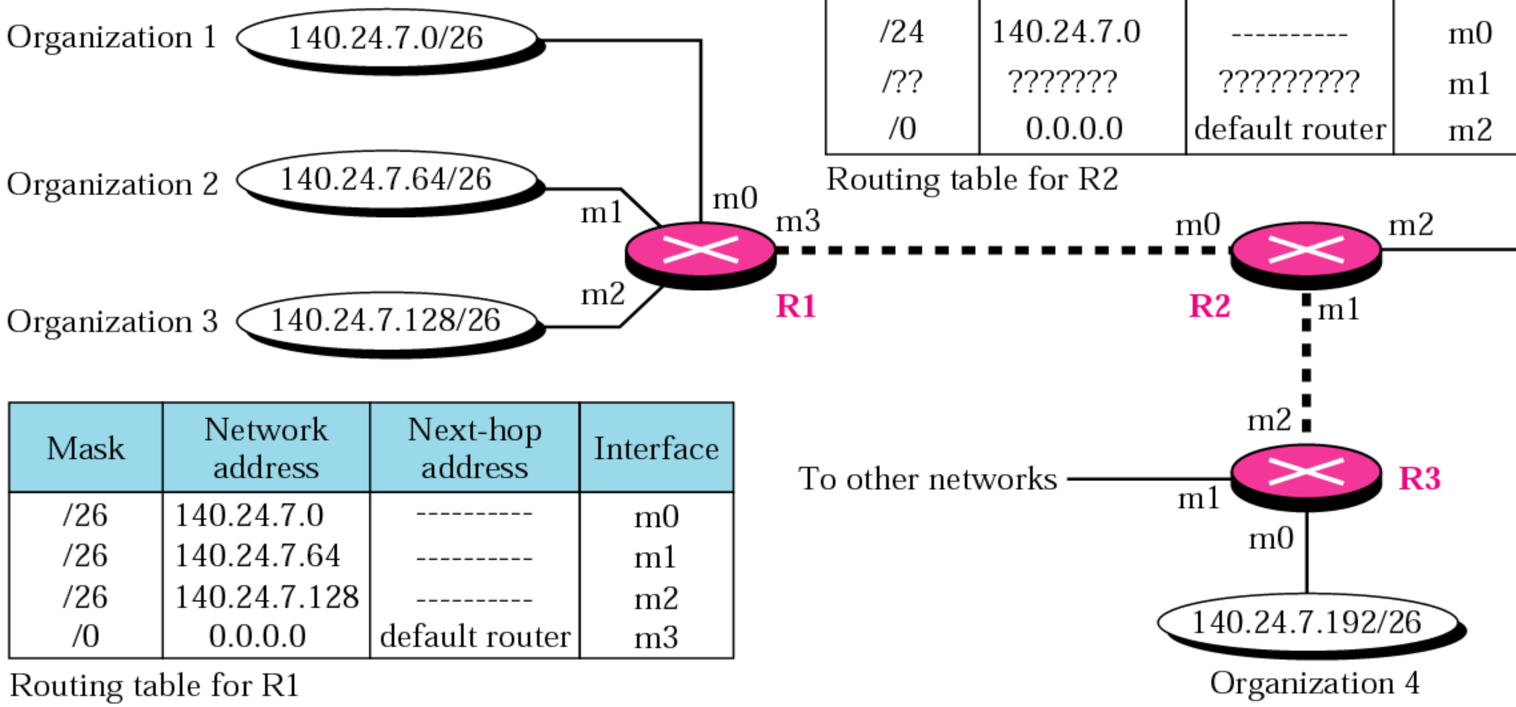
| Mask | Network address | Next-hop address | Interface |
|---|---|---|---|
| /24 | 140.24.7.0 | ---------- | m0 |
| /0 | 0.0.0.0 | default router | m1 |

Routing table for R2

# Figure 6.16 *Longest mask matching*

| 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 R2




| 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 R1

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

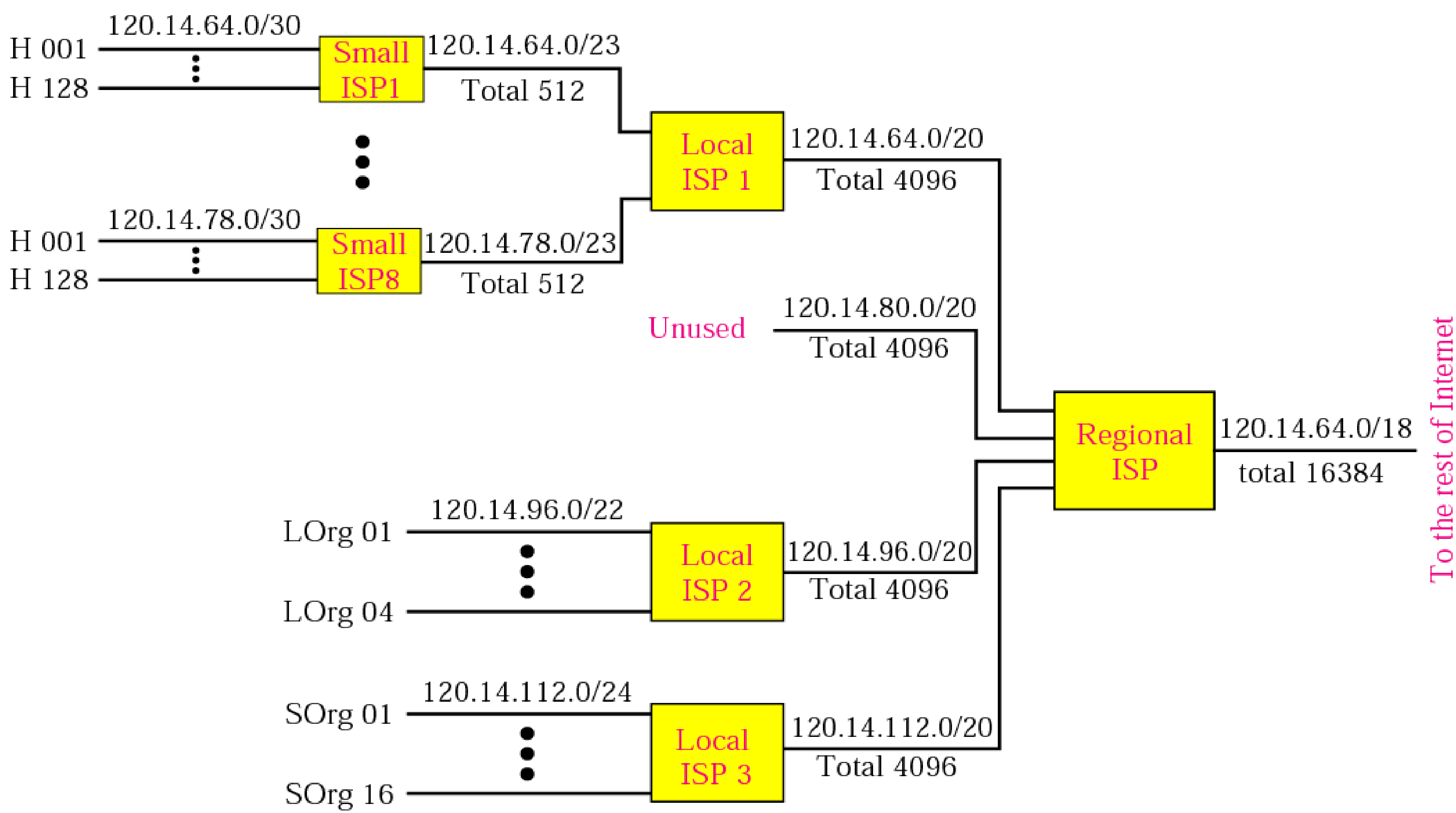
Routing table for R3

## *Example 12*

***As an example of hierarchical routing, let us consider Figure 6.17. A regional ISP is granted 16384 addresses starting from 120.14.64.0. The regional ISP has decided to divide this block into four 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.***

**See Next Slide**

## Figure 6.17 *Hierarchical routing with ISPs*



## Example 12 *(Continued)*

***The first local ISP has divided its assigned subblock into 8 smaller blocks and assigned each to a small ISP. Each small ISP provides services to 128 households (H001 to H128), each using four addresses. Note that the mask for each small ISP is now /23 because the block is further divided into 8 blocks. Each household has a mask of /30, because a household has only 4 addresses ($2^{32-30}$ is 4).***

***The second local ISP has divided its block into 4 blocks and has assigned the addresses to 4 large organizations (LOrg01 to LOrg04). Note that each large organization has 1024 addresses and the mask is /22.***

**See Next Slide**

# *Example 12* *(Continued)*

***The third local ISP has divided its block into 16 blocks and assigned each block to a small organization (SOrg01 to SOrg15). Each small organization has 256 addresses and the mask is /24.***

***There is a sense of hierarchy in this configuration. All routers in the Internet send a packet with destination address 120.14.64.0 to 120.14.127.255 to the regional ISP. The regional ISP sends every packet with destination address 120.14.64.0 to 120.14.79.255 to Local ISP1. Local ISP1 sends every packet with destination address 120.14.64.0 to 120.14.64.3 to H001.***

# 6.3 ROUTING

***Routing deals with the issues of creating and maintaining routing tables.***

***The topics discussed in this section include:***

***Static Versus Dynamic Routing Tables***
***Routing Table***

## Figure 6.18 *Common fields in a routing table*

| Mask | Network address | Next-hop address | Interface | Flags | Reference count | Use |
|---|---|---|---|---|---|---|
| ............... | ............... | ............... | ............... | ............... | ............... | ............... |

## *Example 13*

***One utility that can be used to find the contents of a routing table for a host or router is netstat in UNIX or LINUX. The following shows the listing of the contents of the default server. We have used two options, r and n. The option r indicates that we are interested in the routing table and the option n indicates that we are looking for numeric addresses. Note that this is a routing table for a host, not a router. Although we discussed the routing table for a router throughout the chapter, a host also needs a routing table.***

**See Next Slide**

## Example 13 *(continued)*

*$ netstat -rn*

***Kernel IP routing table***

| *Destination* | *Gateway* | *Mask* | *Flags* | *Iface* |
|---|---|---|---|---|
| 153.18.16.0 | 0.0.0.0 | 255.255.240.0 | U | eth0 |
| 127.0.0.0 | 0.0.0.0 | 255.0.0.0 | U | lo |
| 0.0.0.0 | 153.18.31. 254 | 0.0.0.0 | UG | eth0. |

**See Next Slide**

# *Example 13* *(continued)*

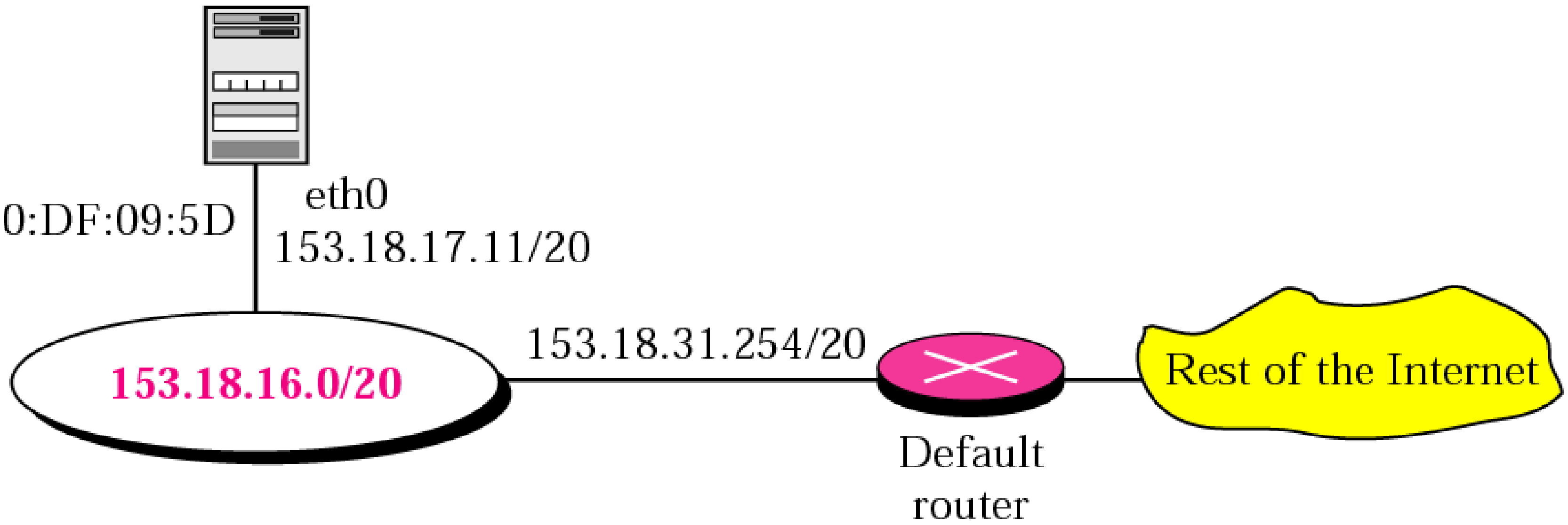
***More information about the IP address and physical address of the server can be found using the ifconfig command on the given interface (eth0).***

```
$ ifconfig eth0
eth0 Link   encap:Ethernet    HWaddr 00:B0:D0:DF:09:5D
inet addr:153.18.17.11          Bcast:153.18.31.255        Mask:255.255.240.0
....
```

***From the above information, we can deduce the configuration of the server as shown in Figure 6.19.***

**See Next Slide**

## Figure 6.19 *Configuration of the server for Example 13*



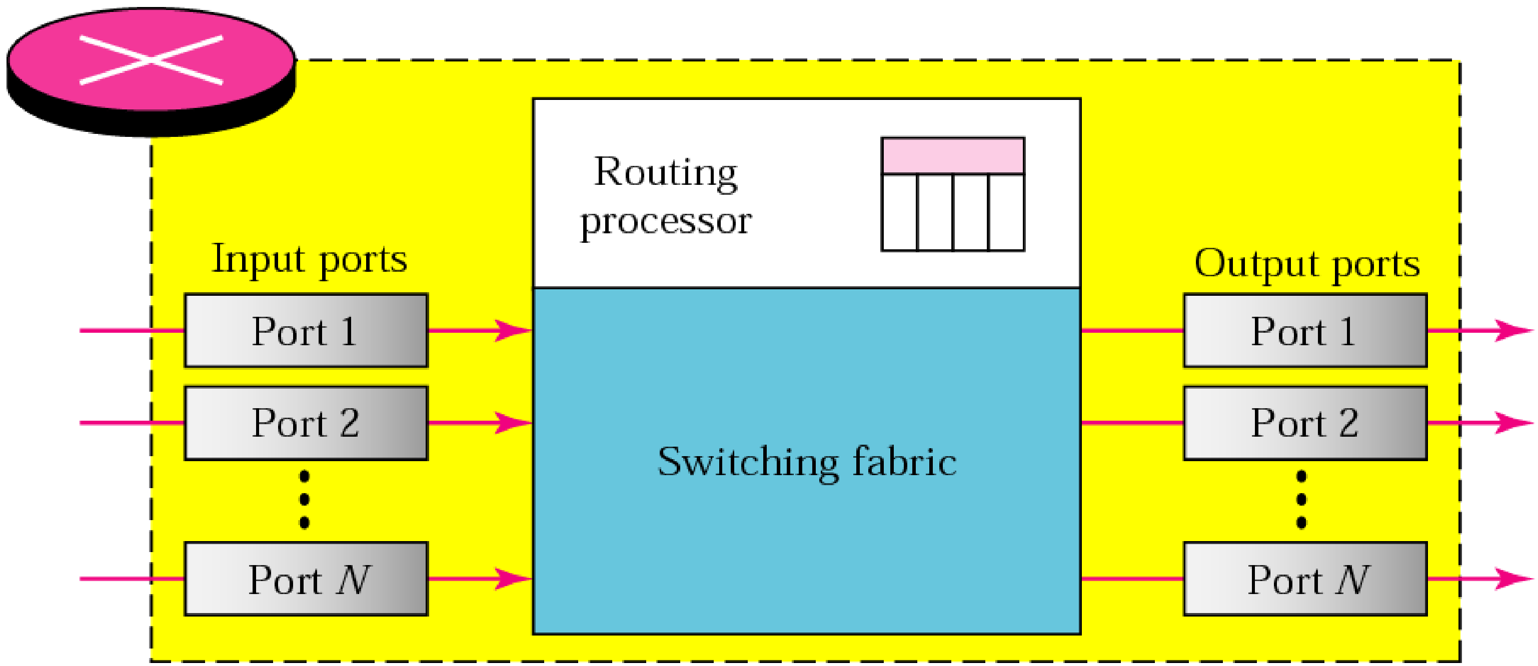
# 6.4 STRUCTURE OF A ROUTER

***We represent a router as a black box that accepts incoming packets from one of the input ports (interfaces), uses a routing table to find the departing output port, and sends the packet from this output port.***

***The topics discussed in this section include:***

***Components***

## Figure 6.20 *Router components*



# *Components of Router*

Input Ports – Performs physical and Data Link layer functions.
Bits constructed from Received signal.
Buffer

Output Ports – same as Input port in reverse order.

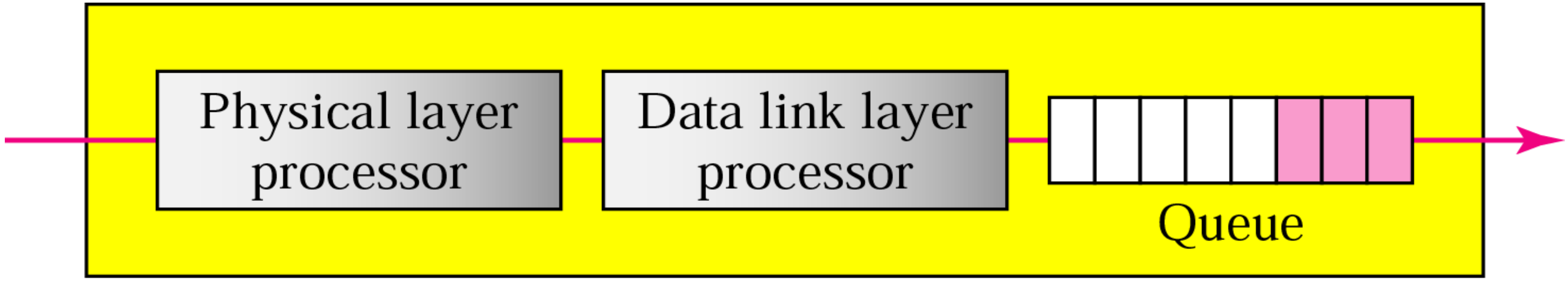
Routing processor – Performs functions of Network layer.
Finds address of next hop and o/p port number.
Performs Table Lookup

Switching Fabric – Speed affects the delivery.



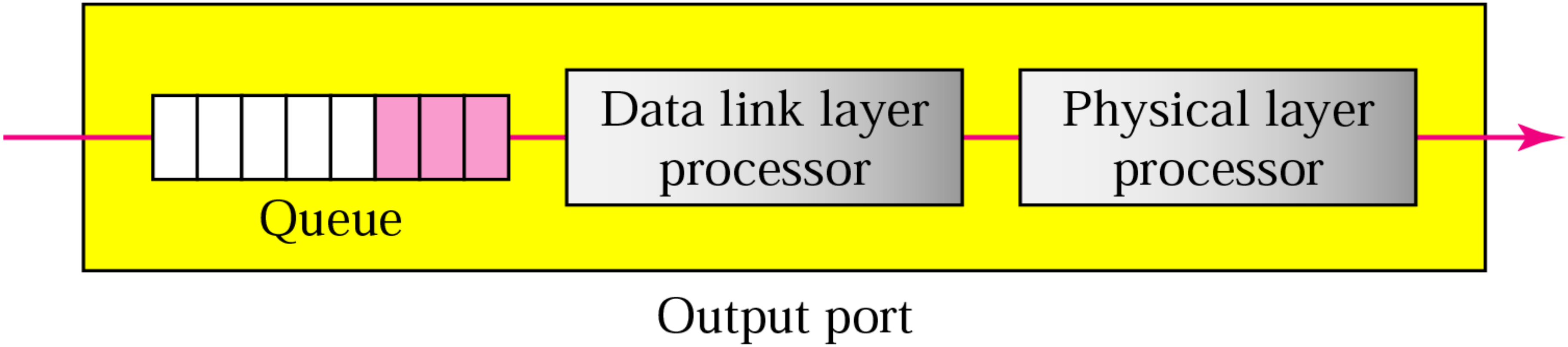
**Figure 6.1** ***Direct delivery***

# Input port




Input port

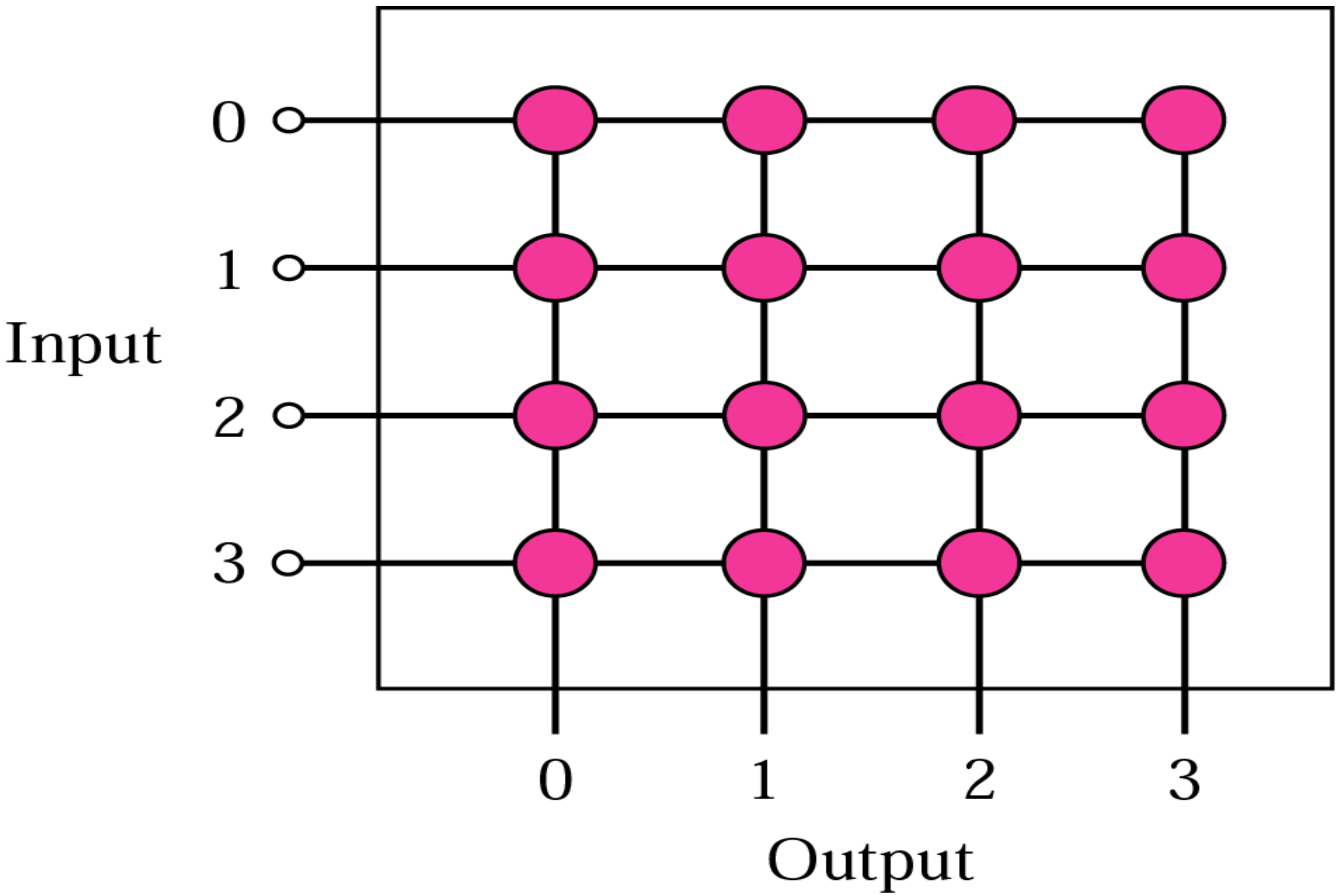
# Output port



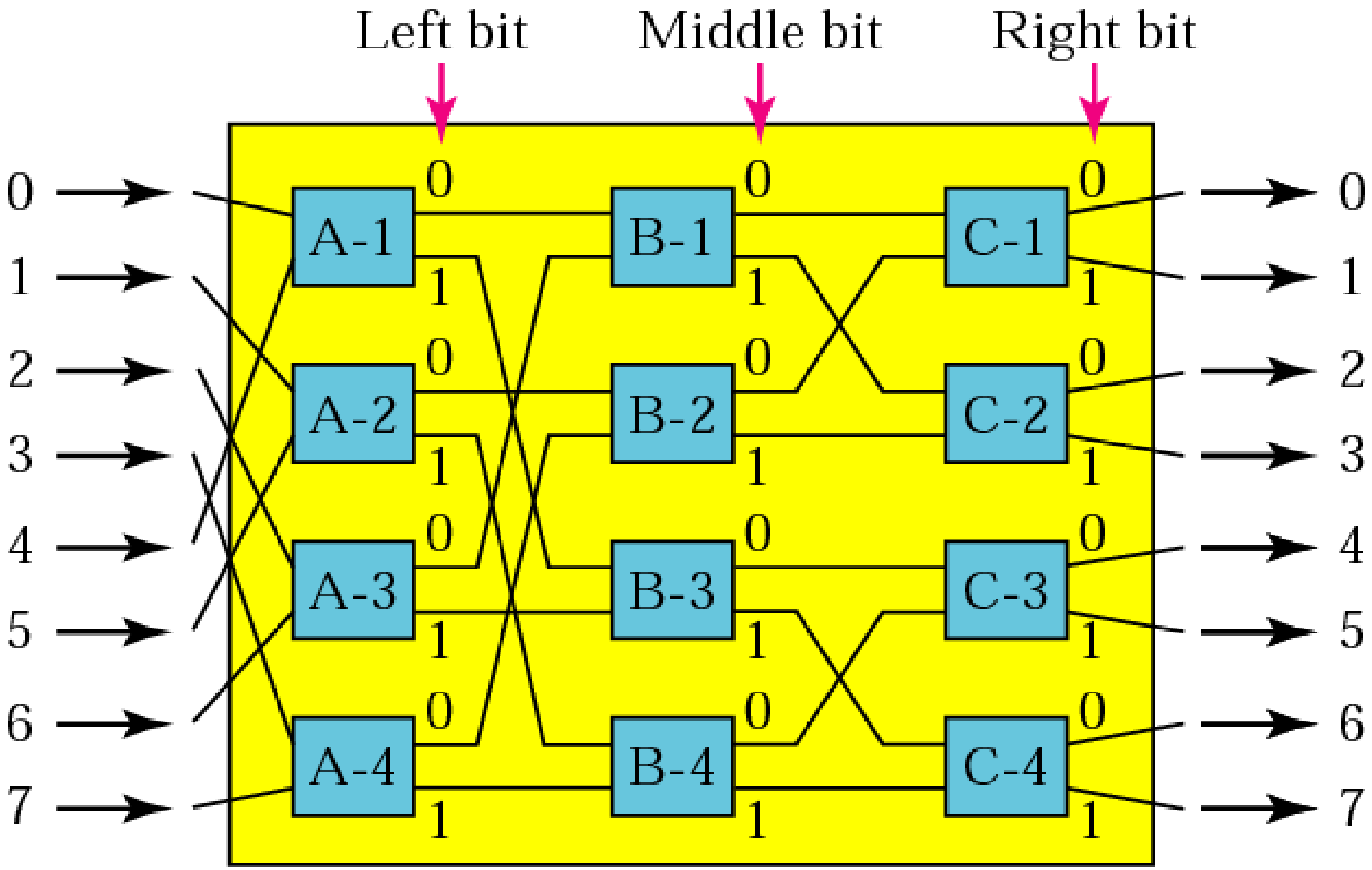
Data link layer processor
Physical layer processor
Queue
Output port

# Crossbar switch

Connects *n* inputs to *n* outputs in a grid.



# *A banyan switch*

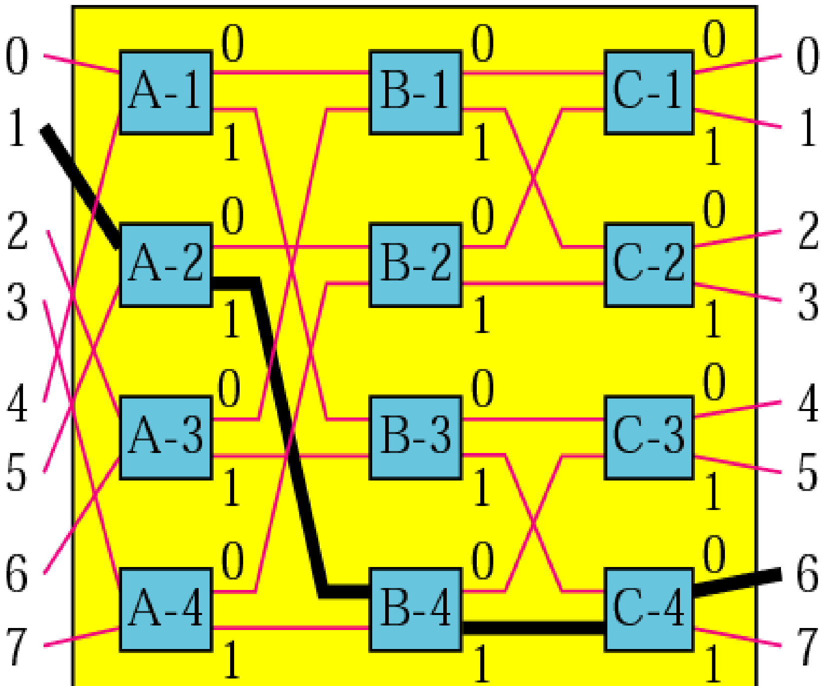


# *A banyan switch*

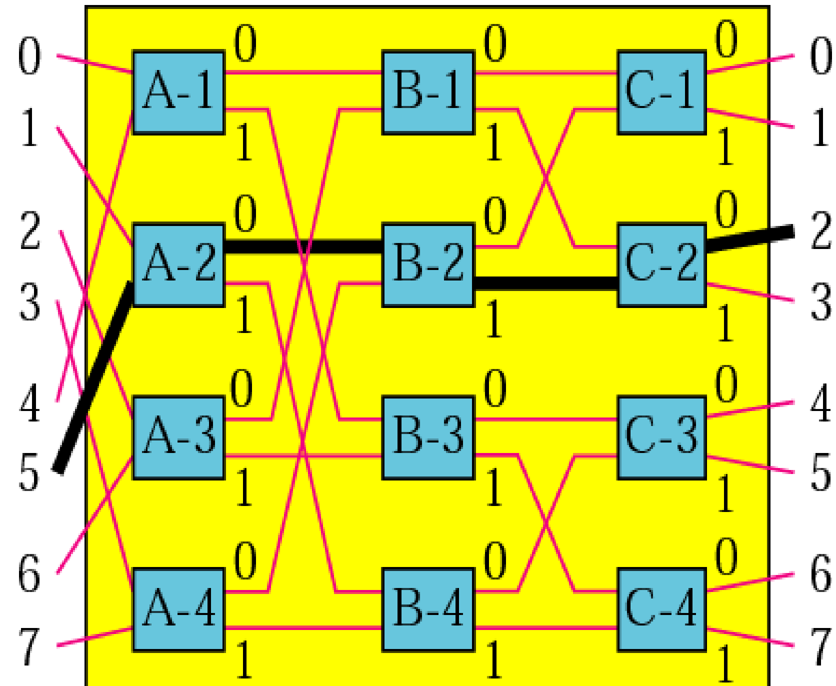
Multistage switch with microswitches at each stage.

For n inputs and n outputs we have $\log_2(n)$ stages with n/2 microswitches.

# *Examples of routing in a banyan switch*




a. Input 1 sending to output 6 (110)



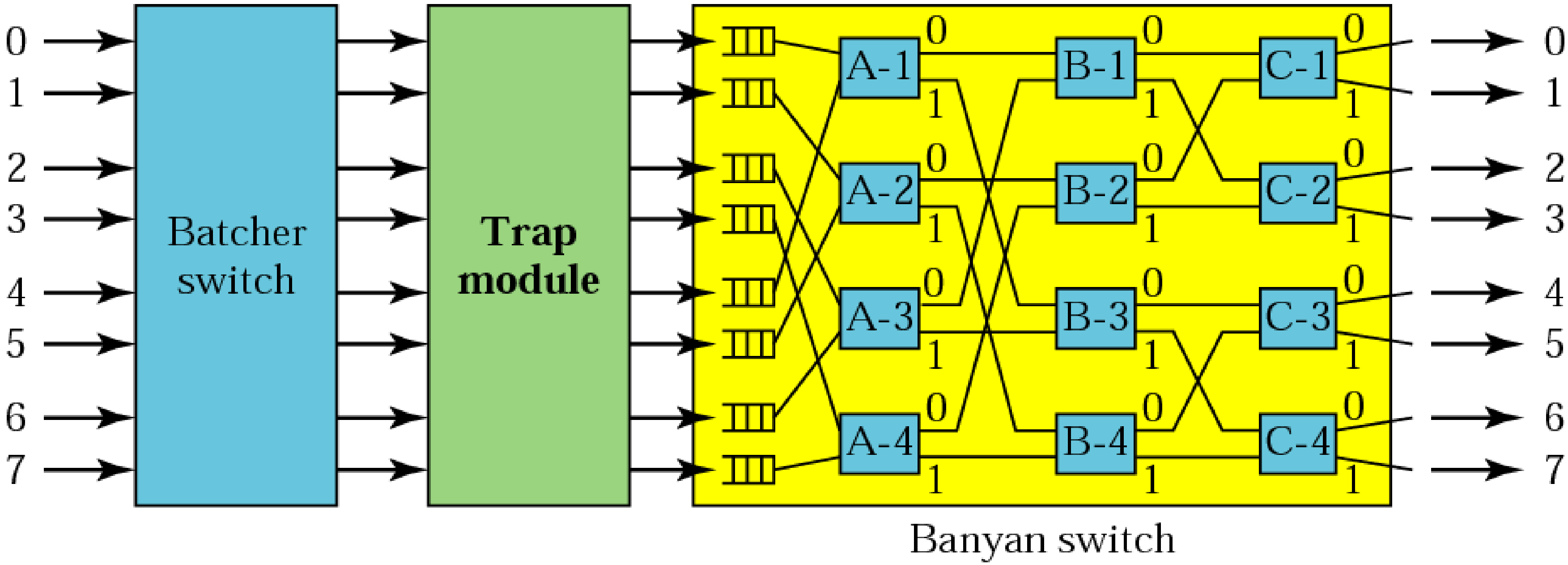

b. Input 5 sending to output 2 (010)

# *Batcher-banyan switch*

Possibility of internal collision.

Sort arriving packets based on their destination port.

Trap module prevents duplicate packets from passing to the banyan switch simultaneously.



THE END...!

```
[ns@gkpserver ~]$ netstat -rn
Kernel IP routing table
Destination     Gateway         Genmask         Flags   MSS Window  irtt Iface
192.168.6.0     0.0.0.0         255.255.255.0   U         0 0          0 eth0
192.168.122.0   0.0.0.0         255.255.255.0   U         0 0          0 virbr0
169.254.0.0     0.0.0.0         255.255.0.0     U         0 0          0 eth0
0.0.0.0         192.168.6.254   0.0.0.0         UG        0 0          0 eth0
```

```
[root@gkpserver ~]# ifconfig
eth0      Link encap:Ethernet  HWaddr 00:0F:FE:0D:DE:74
          inet addr:192.168.6.201  Bcast:192.168.6.255  Mask:255.255.255.0
          inet6 addr: fe80::20f:feff:fe0d:de74/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:4839 errors:0 dropped:0 overruns:0 frame:0
          TX packets:45 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:453698 (443.0 KiB)  TX bytes:7432 (7.2 KiB)
          Interrupt:16

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:16436  Metric:1
          RX packets:5768 errors:0 dropped:0 overruns:0 frame:0
          TX packets:5768 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:3576476 (3.4 MiB)  TX bytes:3576476 (3.4 MiB)
```

```
[root@gkpserver ~]# ifconfig
eth0      Link encap:Ethernet  HWaddr 00:0F:FE:0D:DE:74
          inet addr:192.168.6.201  Bcast:192.168.6.255  Mask:255.255.255.0
          inet6 addr: fe80::20f:feff:fe0d:de74/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:4839 errors:0 dropped:0 overruns:0 frame:0
          TX packets:45 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:453698 (443.0 KiB)  TX bytes:7432 (7.2 KiB)
          Interrupt:16

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:16436  Metric:1
          RX packets:5768 errors:0 dropped:0 overruns:0 frame:0
          TX packets:5768 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:3576476 (3.4 MiB)  TX bytes:3576476 (3.4 MiB)
```