Delivery and Forwarding of IP Packets

ICT 2255

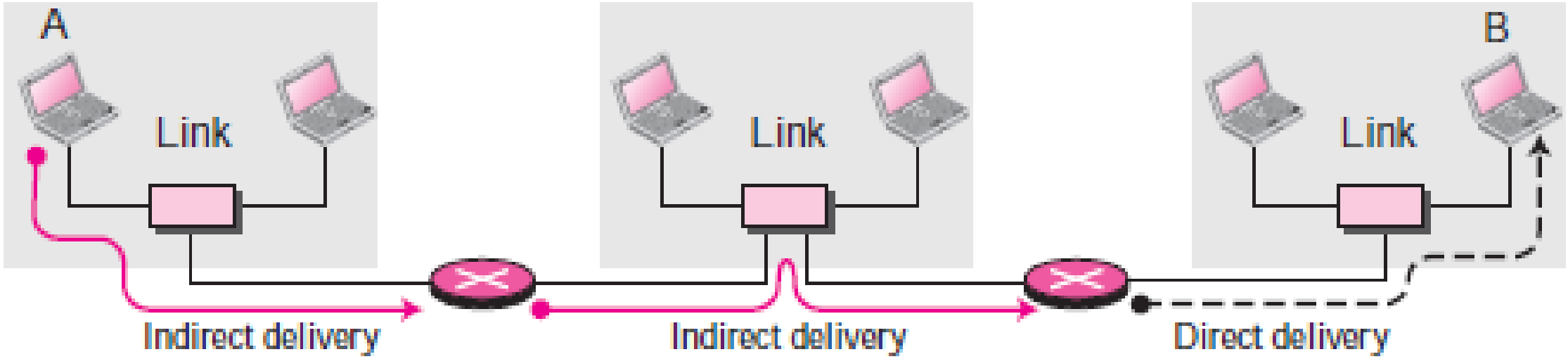
Delivery and Forwarding

- **Delivery:** The way a packet is handled by the underlying networks under the control of the network layer.
- **Forwarding:** Action applied by each router when a packet arrives at its interface.
  - Refers to placing a packet in its route to destination.
  - Deliver the packet to the next hop.

Delivery

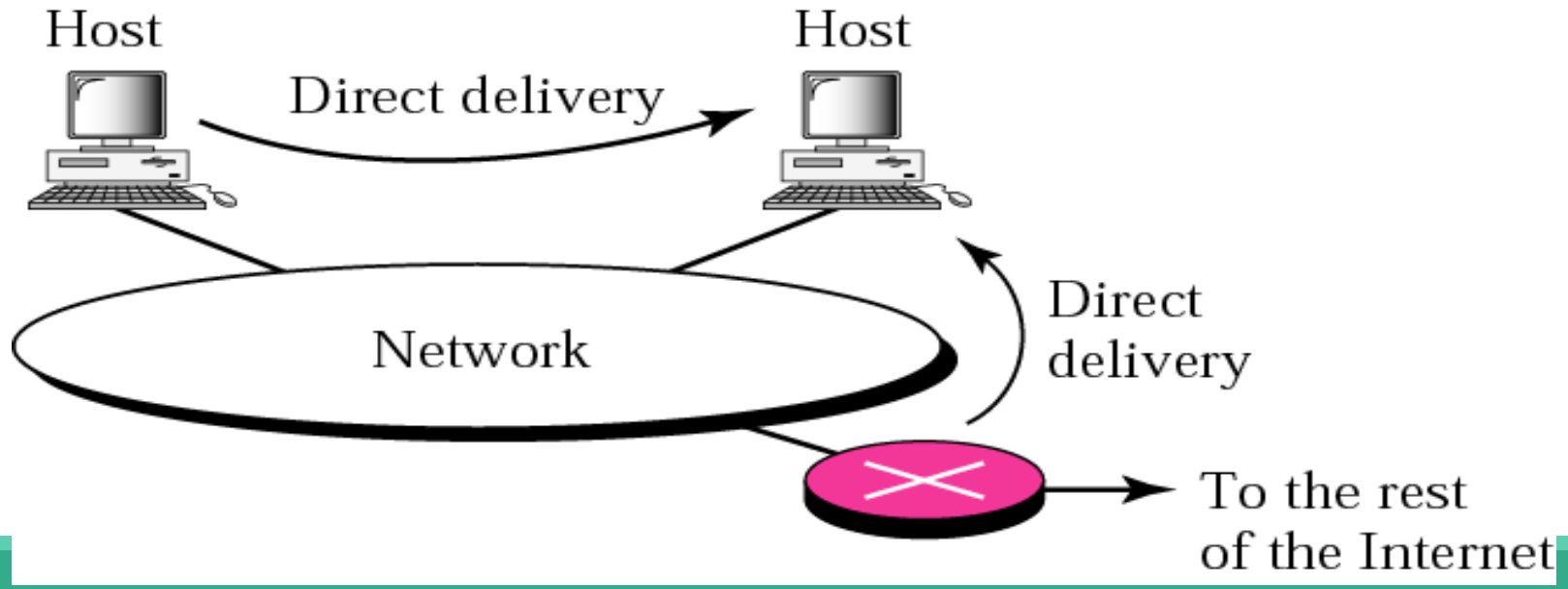
- The network layer supervises **delivery**: the handling of the packets by the underlying physical networks.
- Two important concepts :
  - Type of connection
  - Direct versus Indirect delivery.
- Type of Connection:
  - Connectionless: IP is a connectionless protocol.
  - Connection-oriented: IP can be used as a connection-oriented protocol-MPLS.

Packet Delivery



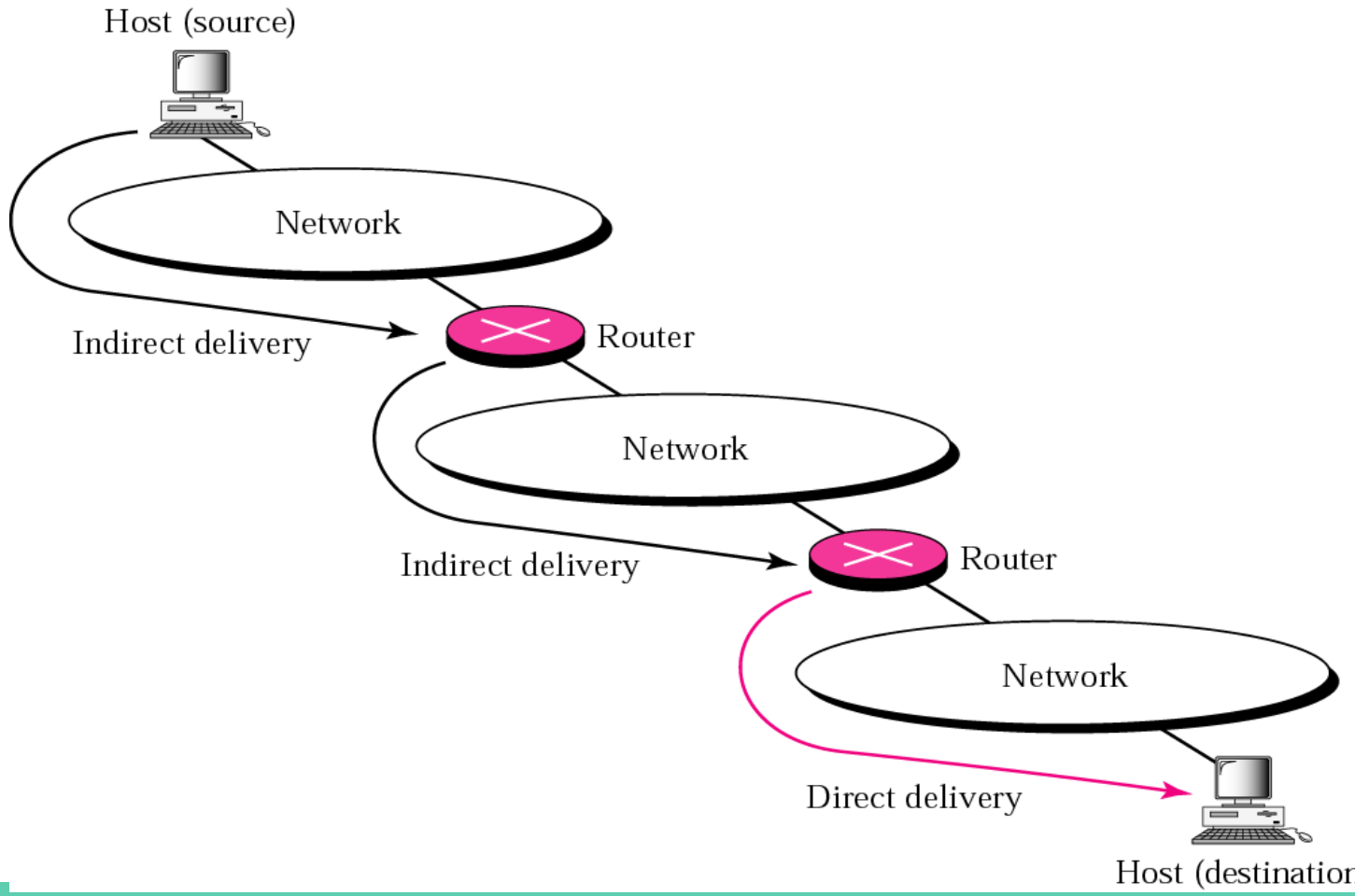
Direct Delivery

- Sender can determine if the delivery is direct. How?
- Get the network address using mask and compare it with the addresses of the network.
- The sender uses the destination IP address to find the destination physical address.



Indirect Delivery

- If the destination host is not on the same network as the deliverer, the packet is delivered indirectly.
- In an indirect delivery, the sender uses the destination IP address and a routing table to find the IP address of the next router to which the packet should be delivered.



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.
- When a host has a packet to send or when a router has received a packet to be forwarded, it looks at this table to find the route to the final destination.

Forwarding Techniques

- To make the size of the routing table manageable and also handle issues such as security.

1. **Next-Hop Method**
2. **Network-Specific Method**
3. **Host-Specific Method**
4. **Default Method**

Next-Hop Method

Routing table for host A

Destination	Route
Host B	R1, R2, Host B

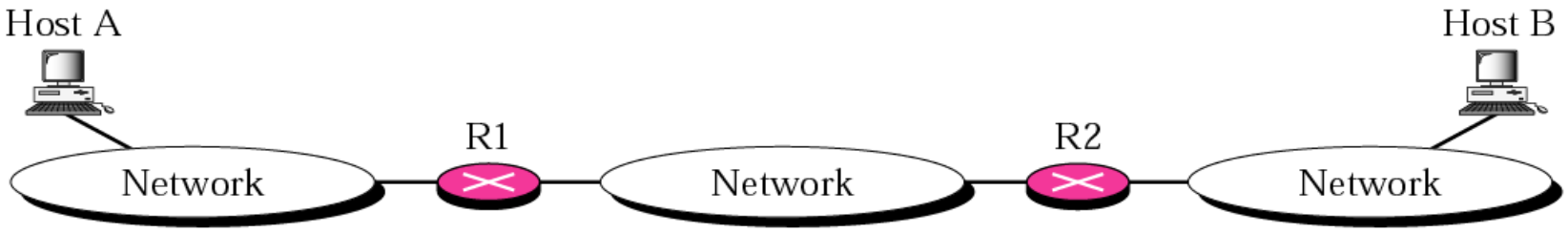
Routing table for R1

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

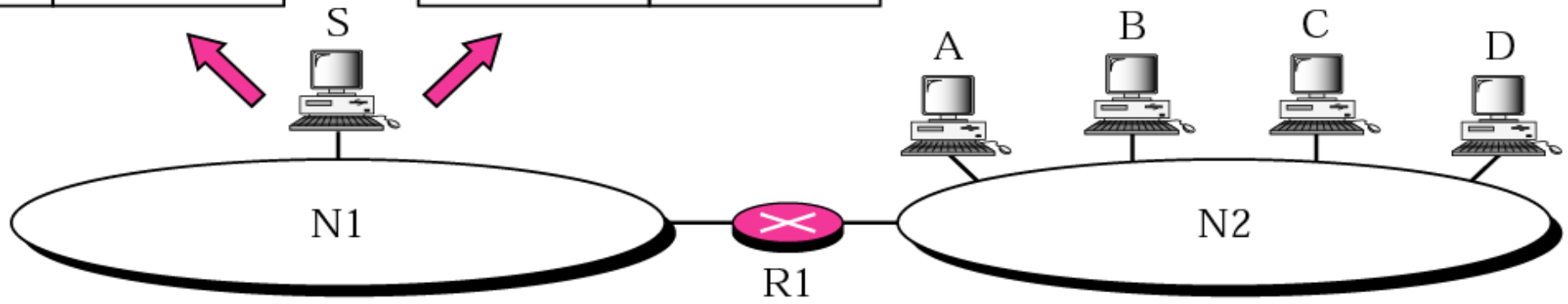
Network-Specific Method

Routing table for host S based on host-specific method

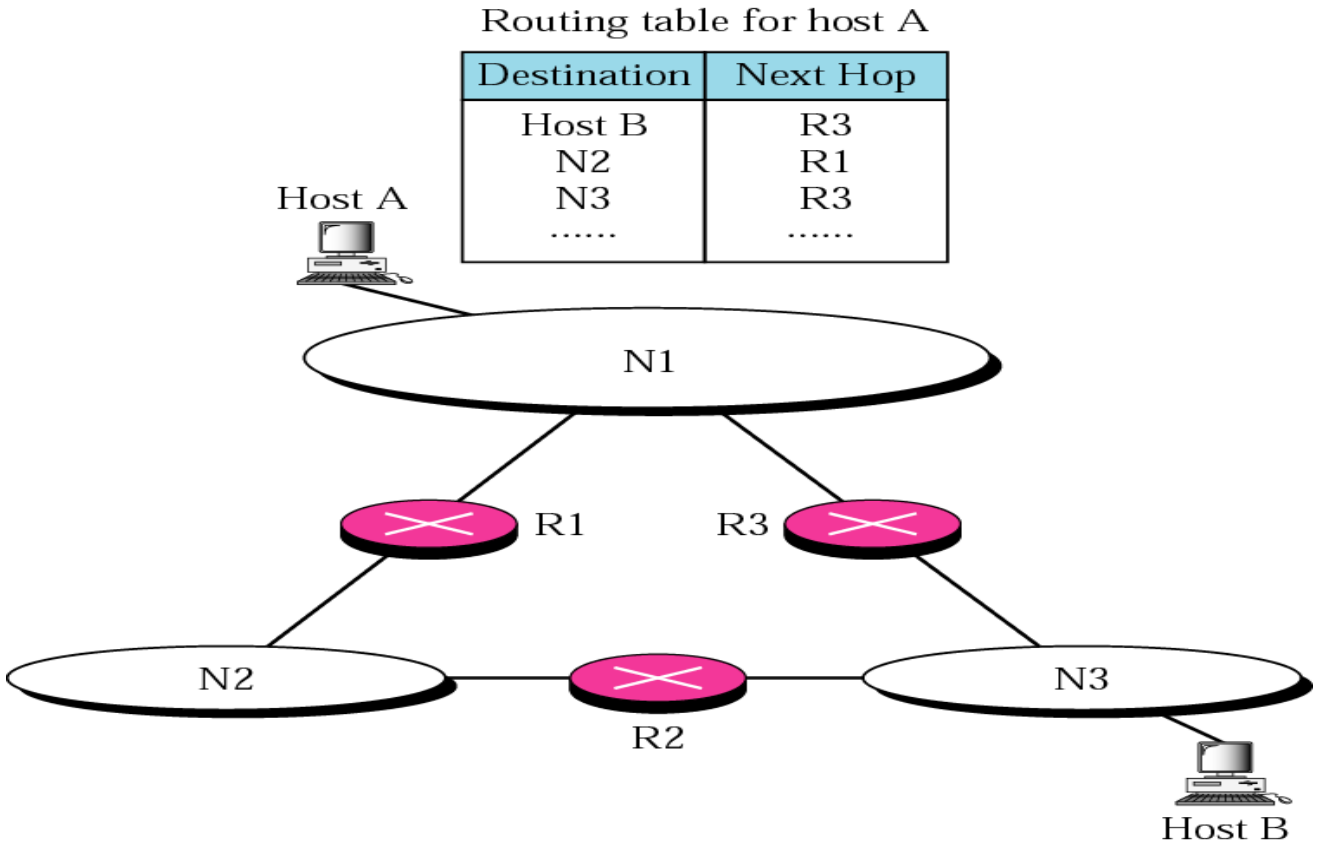
Destination	Next Hop
A	R1
B	R1
C	R1
D	R1

Routing table for host S based on network-specific method

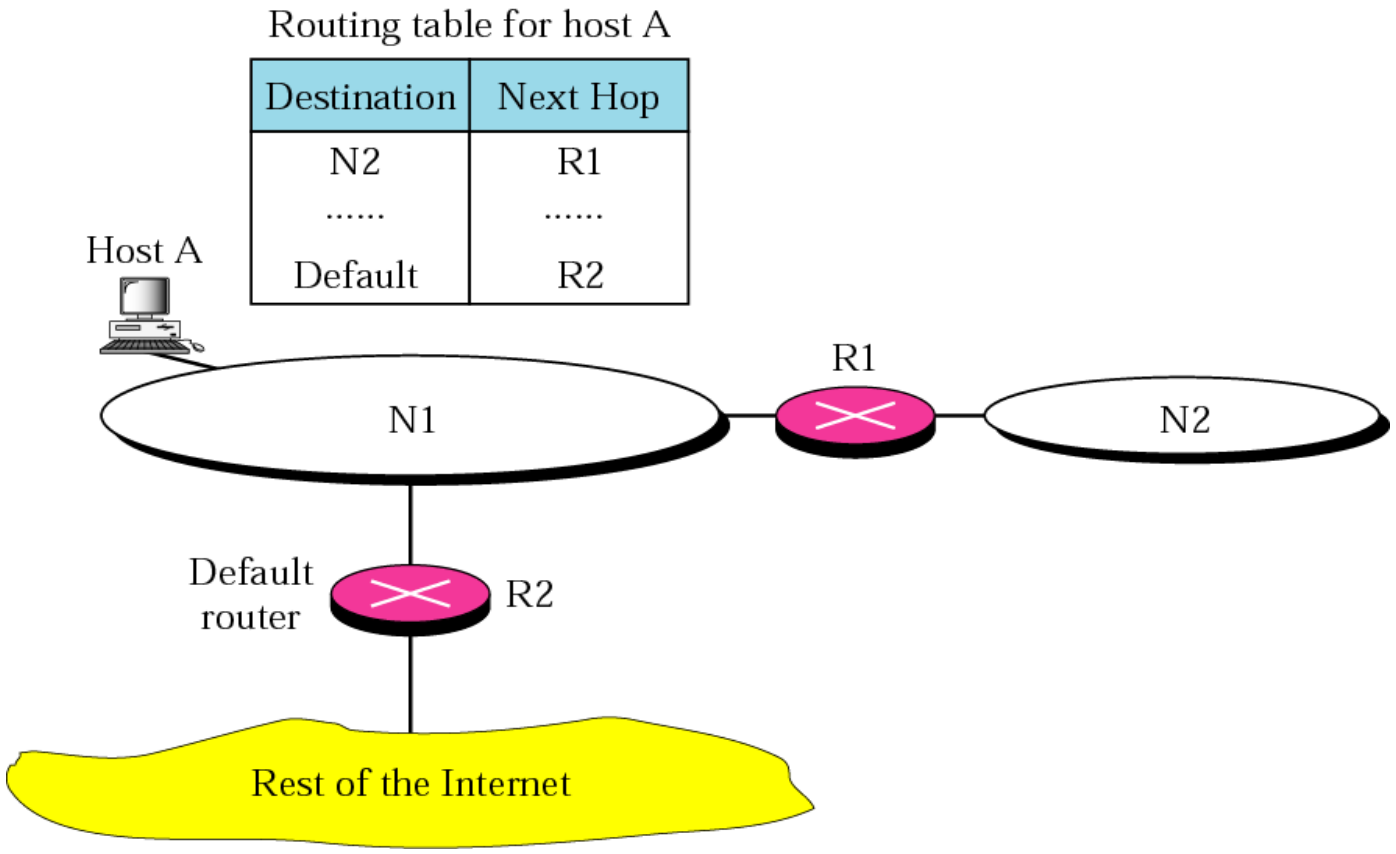
Destination	Next Hop
N2	R1



Host-Specific Method



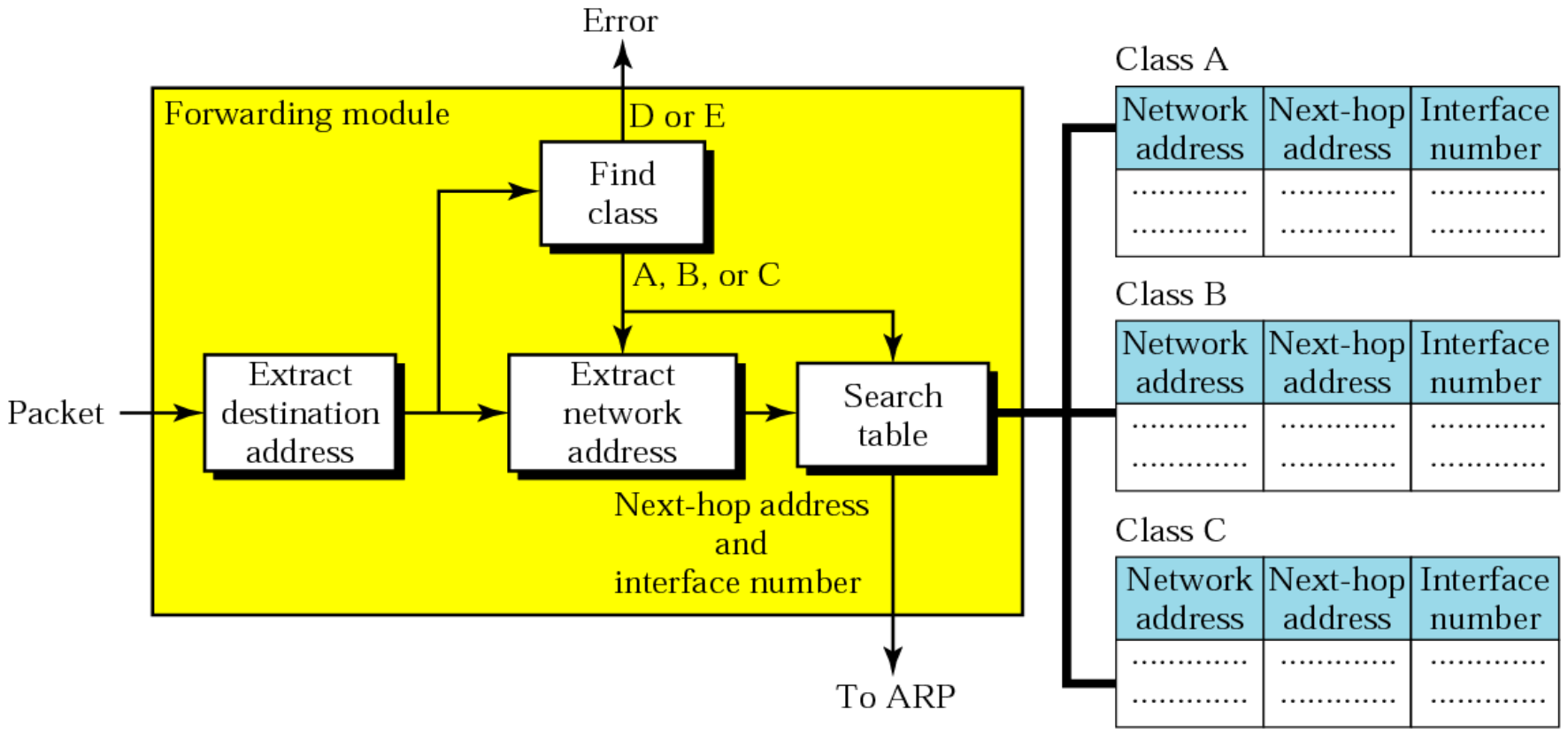
Default Method



The existence of a default mask in a classful address makes the forwarding process simple

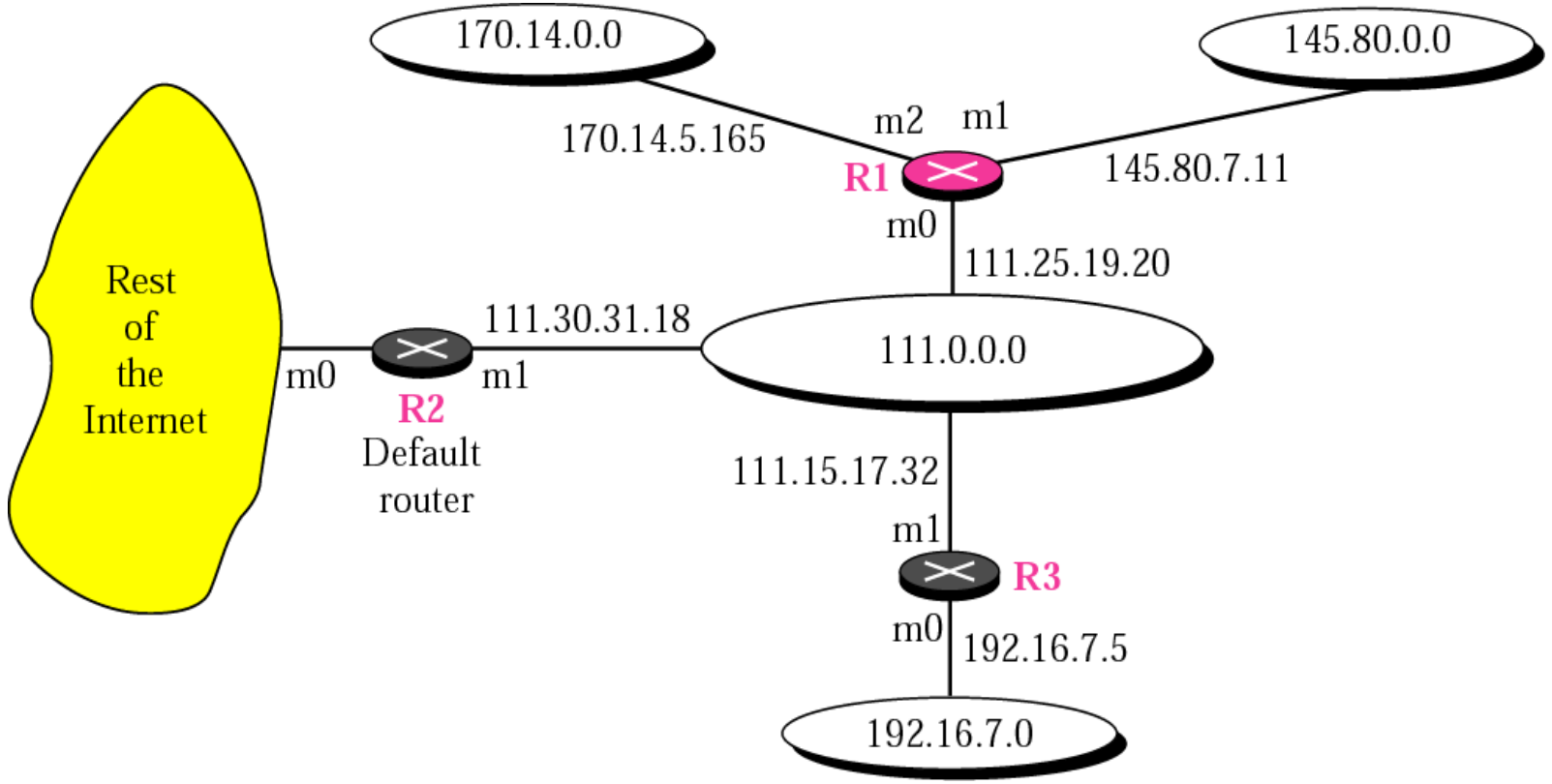
Forwarding with Classful Addressing

Without Subnetting



Example

- Show the routing table for router R1.



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

- Router R1 receives a packet with destination address 192.16.7.14. Show how the packet is forwarded.
- Destination Address in binary: *11000000 00010000 00000111 00001110*
- >>**28 bits:** *00000000 00000000 00000000 00001100 :* ***12*** **=>** ***Class C***
- Extract network address: *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.

Class C

Network address	Next-hop address	Interface
192.16.7.0	111.15.17.32	m0

Example

Q> Router R1 receives a packet with destination address 167.24.160.5. Show how the packet is forwarded.

Class A

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

Class C

Network address	Next-hop address	Interface
192.16.7.0	111.15.17.32	m0

Class B

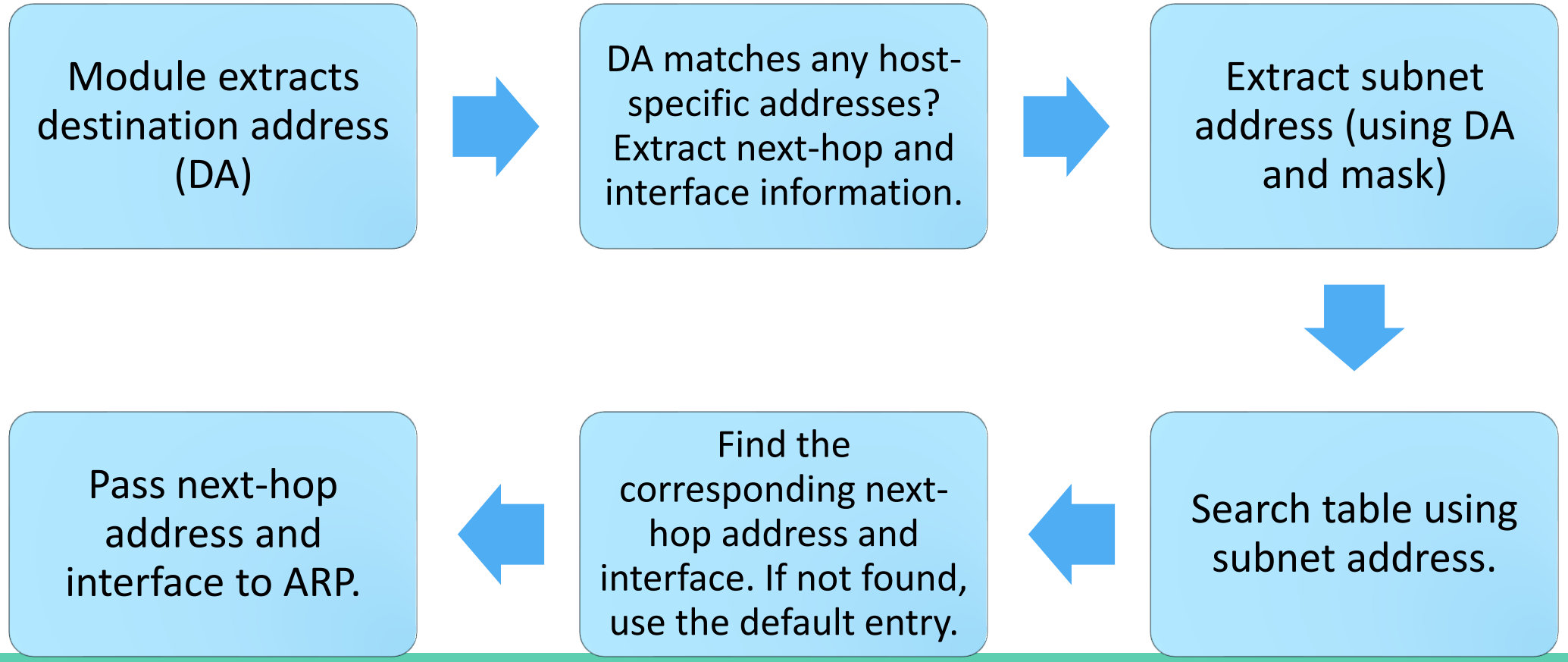
Network address	Next-hop address	Interface
145.80.0.0	----------	m1
170.14.0.0	----------	m2

Default: 111.30.31.18, m0

What is the significance of each of the columns in the routing table?

Forwarding with Classful Addressing

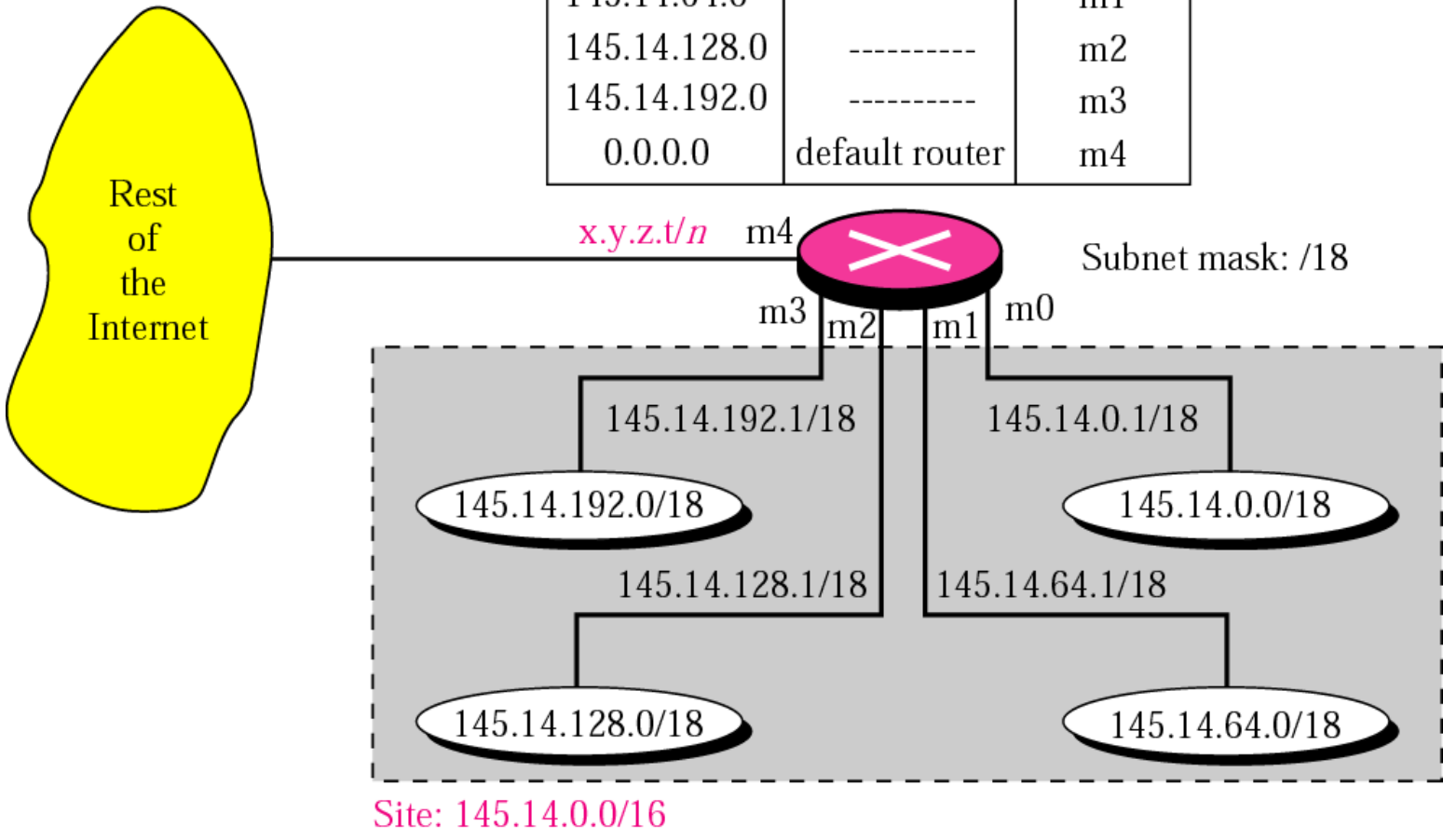
- With fixed-length subnetting



Important Points:

1. 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.
2. 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.
3. 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.

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

- The router receives a packet with destination address 145.14.32.78. Show how the packet is forwarded.

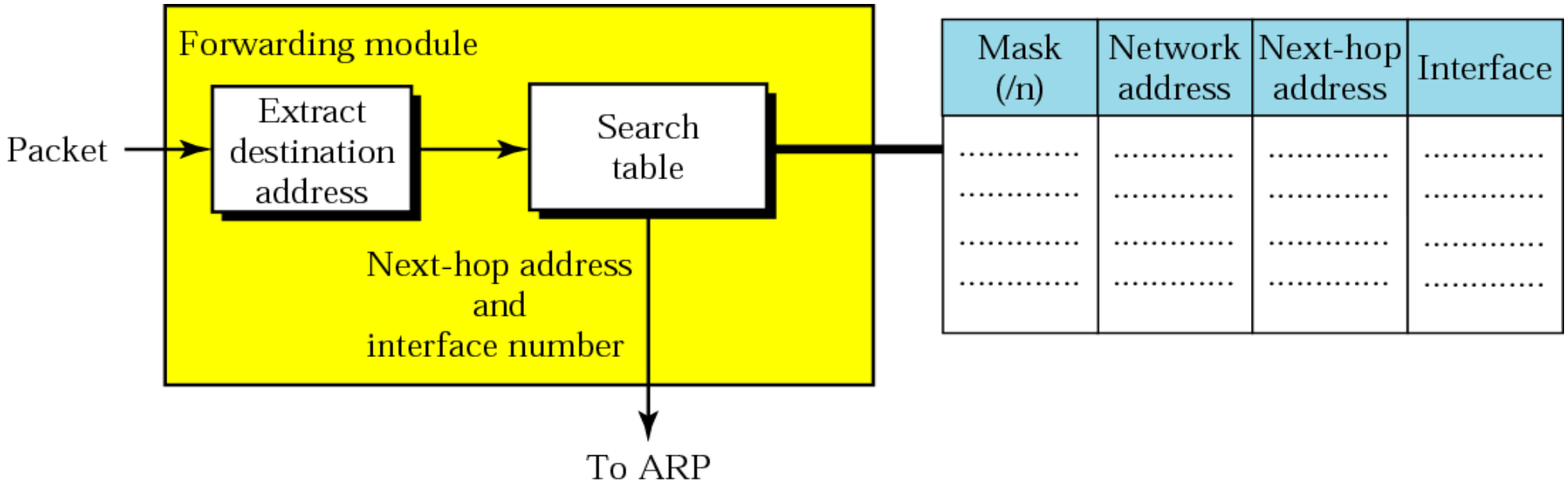
1. Apply mask /18 to get subnet address: 145.14.0.0
2. The packet is delivered to ARP with the next-hop address 145.14.32.78 and the outgoing interface m0.

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

1. Apply mask /18 to get subnet address: 7.22.64.0
2. The table is searched and the address is not found.
3. The router uses the address of the default router and sends the packet to that router.

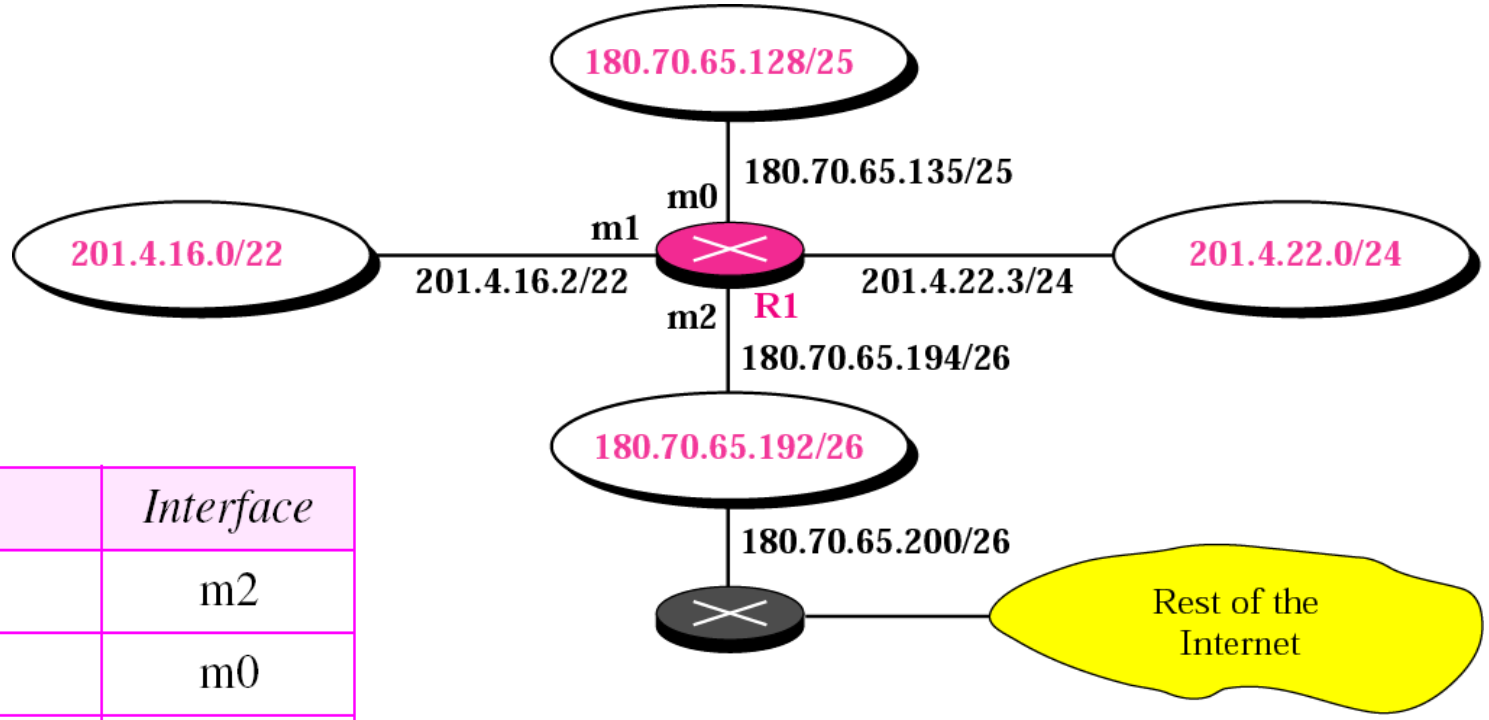
Forwarding with Classless Addressing

- In classless addressing, we need a routing table with at least four columns. Why?



Example

- Make a routing table for router R1



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

- Show the forwarding process if a packet arrives at R1 with the destination address 180.70.65.140.

Example

- Show the forwarding process if a packet arrives at R1 with the destination address 201.4.22.35.

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

- Show the forwarding process if a packet arrives at R1 with the destination address 18.24.32.78.

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

- Can we find the configuration of a router, if we know only its routing table? The routing table for router R1 is given. Can we draw its topology?

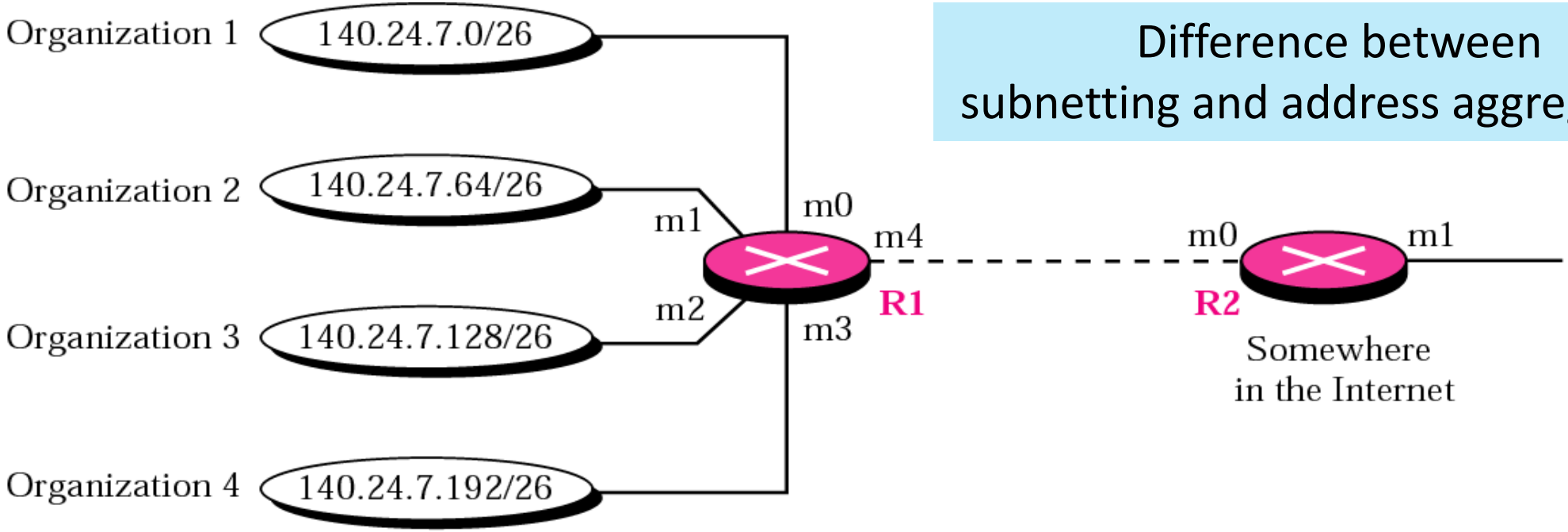
Mask	Network Address	Next hop Address	Interface Number
/24	192.16.7.0	111.15.17.32	m0
/16	145.80.0.0	----------	m1
/16	170.14.0.0	----------	m2
/8	111.0.0.0	----------	m0
default	default	111.30.31.18	m0

Question

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

Address Aggregation

- When we use **classful addressing**, there is only one entry in the routing table for each site outside the organization.
- The entry defines the site even if that site is subnetted. When a packet arrives at the router, the router checks the corresponding entry and forwards the packet accordingly.
- When we use **classless addressing**, it is likely that the number of routing table entries will increase. Why?
- This is because the intent of classless addressing is to divide up the whole address space into manageable blocks.
- The increased size of the table results in an increase in the amount of time needed to search the table.
- To alleviate the problem, the idea of **address aggregation** was designed.



Difference between subnetting and 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

Question

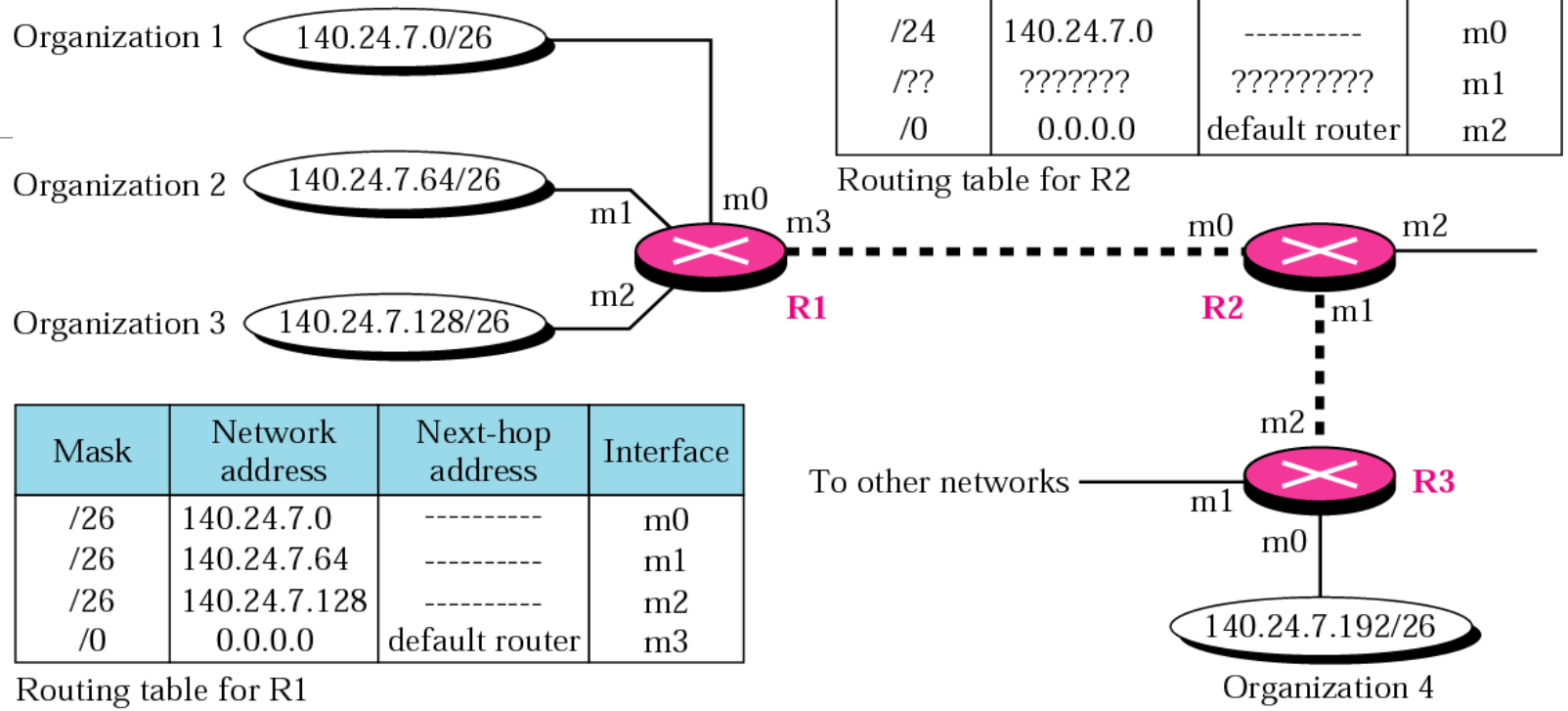
- A router can reach four different organizations via the same interface. The IP prefixes used by the different organizations are 108.25.224.0/21, 108.25.232.0/21, 108.25.240.0/21 and 108.25.248.0/21. Can the router aggregate the prefixes? If so to what?

Answer

Hence the router can aggregate the prefixes to 108.25.224.0/19

Longest Mask Matching

- This principle states that the routing table is sorted from the longest mask to the shortest mask.
- In other words, if there are three masks, /27, /26, and /24, the mask /27 must be the first entry and /24 must be last.



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

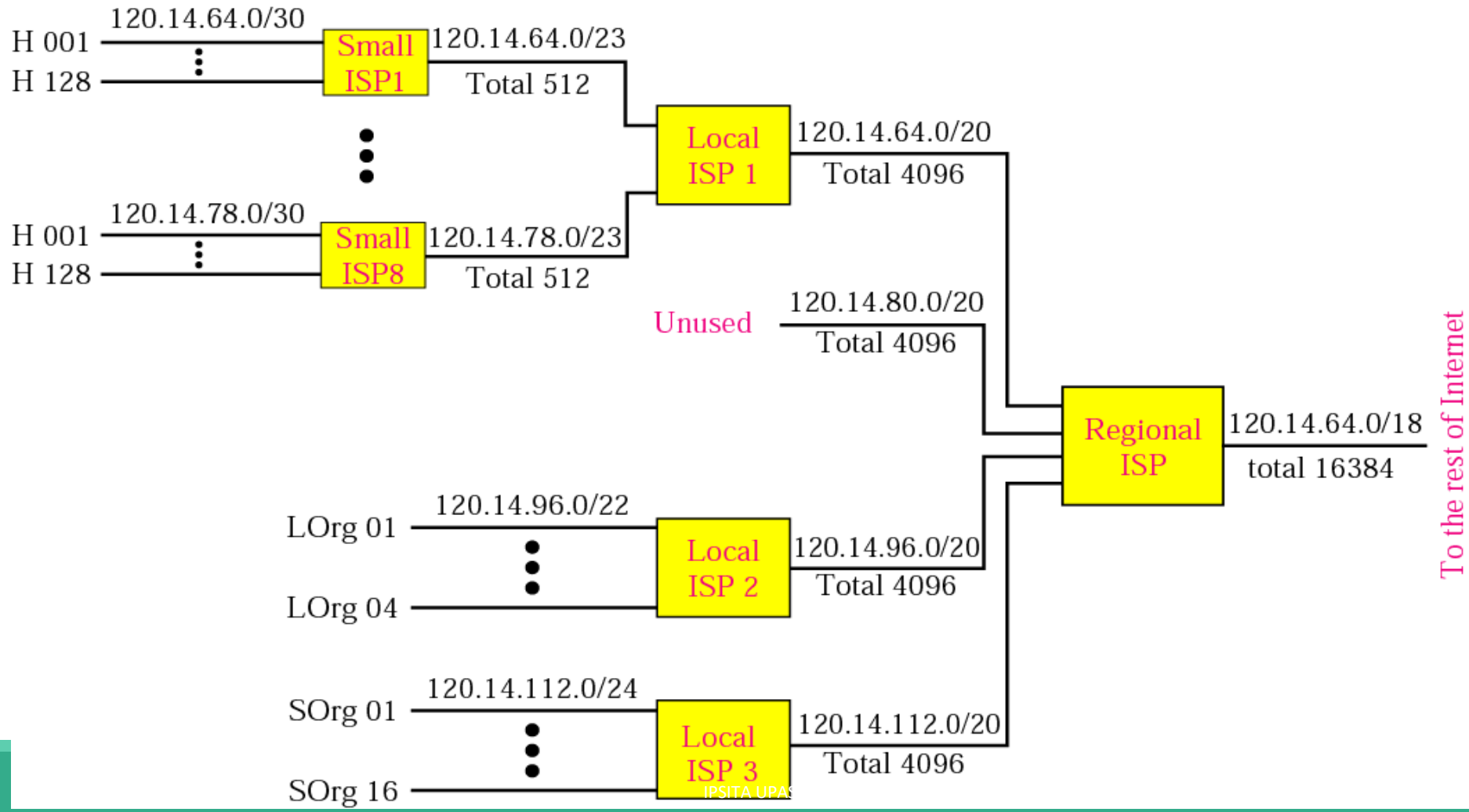
Routing table for R1

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

Hierarchical Routing

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.



Geographical Routing

- To decrease the size of the routing table even further, we need to extend hierarchical routing to include geographical routing.
- We must divide the entire address space into a few large blocks based on geography.

Routing Table Search Algorithms

- Searching in Classful Addressing
  - Divide into 3 buckets, one for each class.
  - 8 buckets for Class A, 4 buckets for Class B, 2 buckets for Class C.
- Searching in Classless Addressing
  - Divide into buckets, one for each prefix.
  - Change DS for searching: use tree or a trie (in place of list).

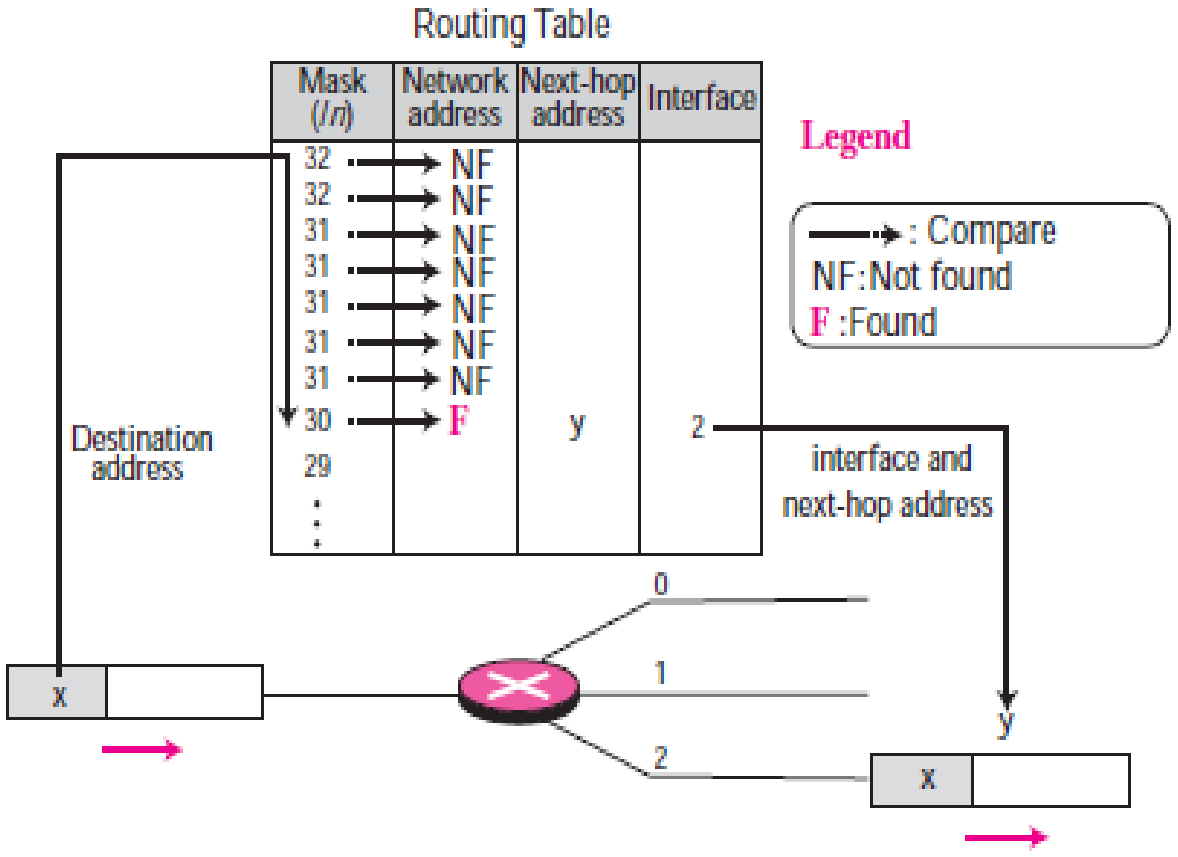
Forwarding based on Label

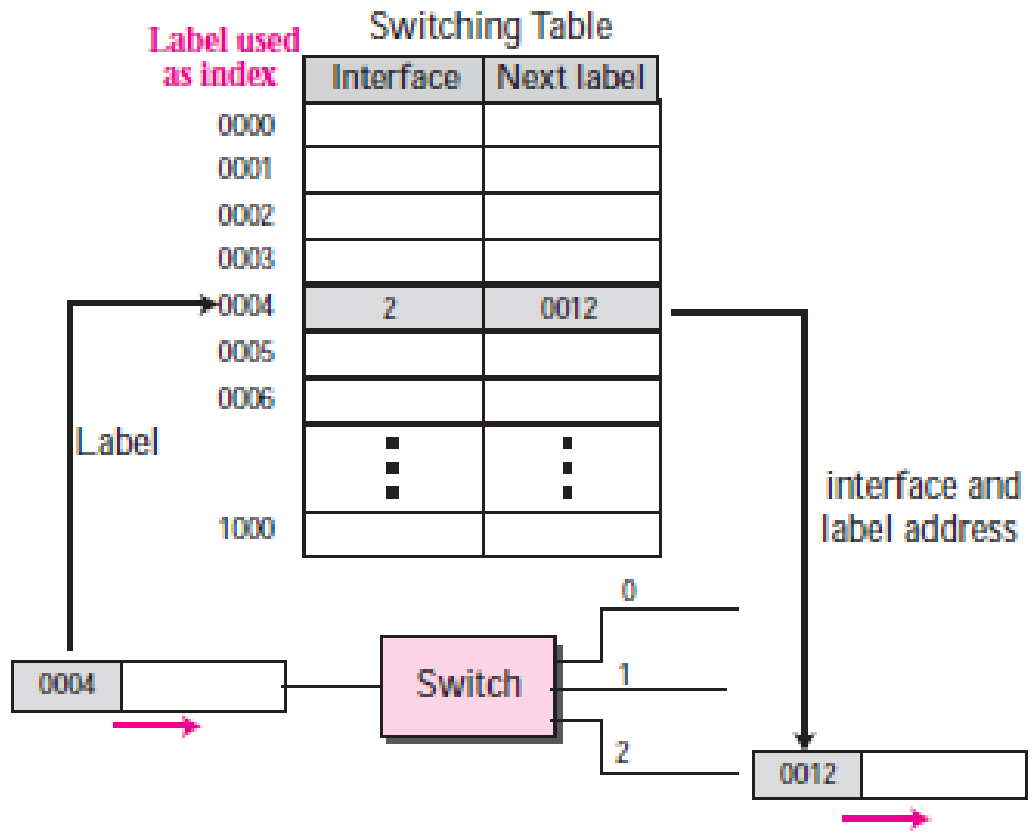
Connectionless network	Connection-oriented network
Datagram Approach	Virtual-Circuit Approach
Router forwards packet based on Destination Address in the header.	Switch forwards a packet based on the label attached to a packet.

Routing Replaced by **Switching**

- Routing: **searching** the contents of a table.
- Switching: **accessing** a table using an index.

Forwarding based on
Destination Address vs Label





Using MPLS

- Conventional routers in the Internet can be replaced by MPLS routers that can behave like **a router** and **a switch**.

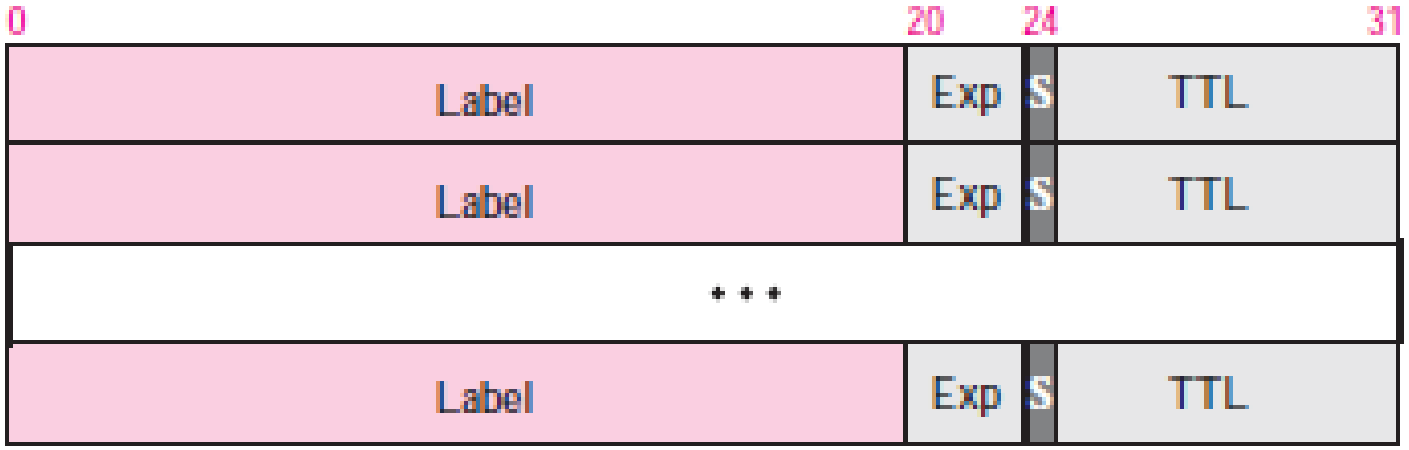
Forward the packet based on the destination address.

Forward a packet based on the label.

- How to simulate connection-oriented switching using IP?
- We need to add a field to carry the label.
- Encapsulate IPv4 packet in an MPLS packet. (MPLS behaving like a pseudo-layer.)

MPLS Header

- Stack of subheaders; used for multilevel hierarchical switching.



Books

- Forouzan B.A., “TCP/IP Protocol Suite”, 4th edition. Chapter 6.