Chapter 6
Delivery and Routing of IP Packets

Outline

- Connection
- Delivery
- Routing methods
- Static and dynamic routing
- Routing table and module
- Classless addressing

6.1

CONNECTION-ORIENTED VERSUS CONNECTIONLESS SERVICES

Introduction

- Delivery
  - The physical forwarding of the packets
    - Connectionless v.s. connection-oriented service
    - Direct v.s. indirect delivery
- Routing
  - Finding the route (next hop) for a datagram
    - Routing methods
    - Types of routing, routing tables and routing module

Connection-Oriented Versus Connectionless Services

- Delivery of a packet in the network layer
  - Connection-oriented
  - Connectionless
- Connection-oriented
  - the network layer protocol first makes a connection between source and destination before sending a packet
  - The decision about the route of a sequence of packets is made only one
    - When the connection is established

6.1 Connection-Oriented Versus Connectionless Services (Cont.)

- Connectionless
  - The network layer treat each packet independently
  - Each packet having no relationship to any other packet
- IP protocol is a connectionless protocol
  - IP is an internetwork protocol and the packets may be delivered through several heterogeneous networks
    - Some of the network may not be connection-oriented

6.2

DIRECT VERSUS INDIRECT DELIVERY

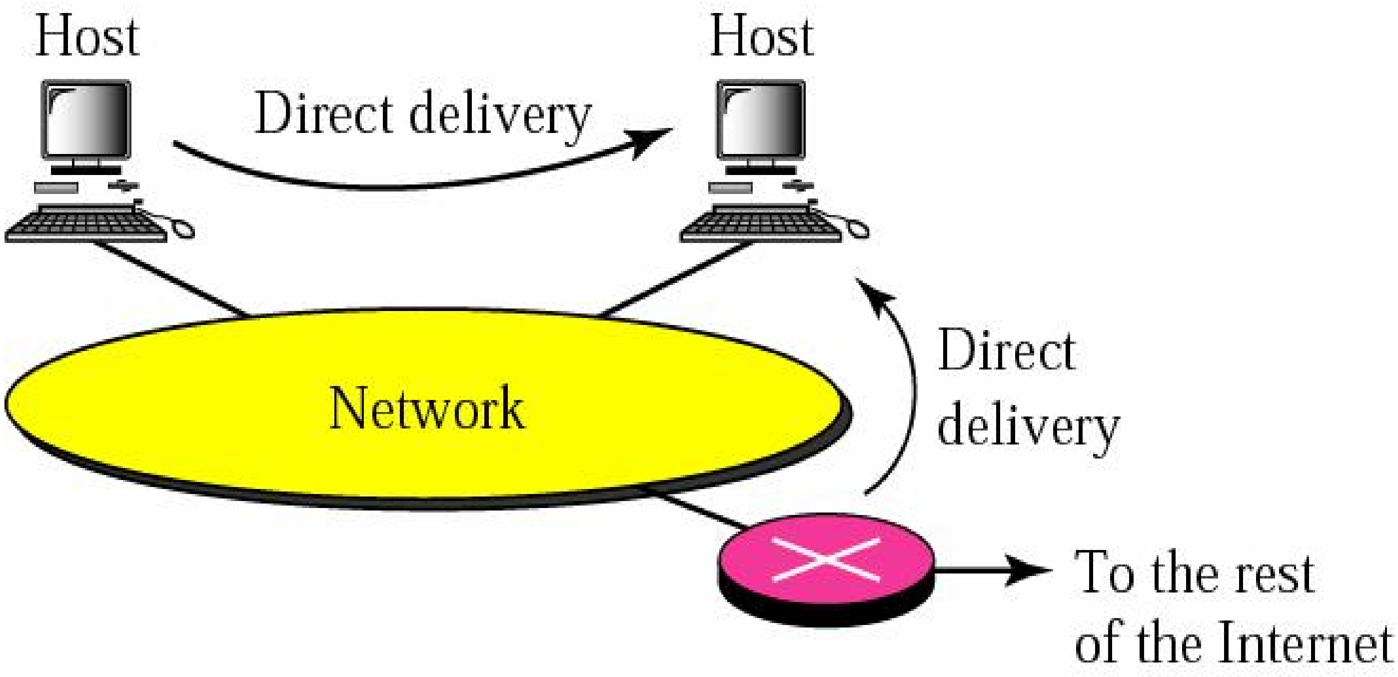
Direct Versus Indirect Delivery

- The delivery of a packet may be direct or indirect

Direct Delivery

- The final destination is a host in the same physical network as the deliverer
  - When the source and destination are located on the same physical network
  - Or the delivery is between the last router and the destination host

Direct Delivery



Direct Delivery (Cont.)

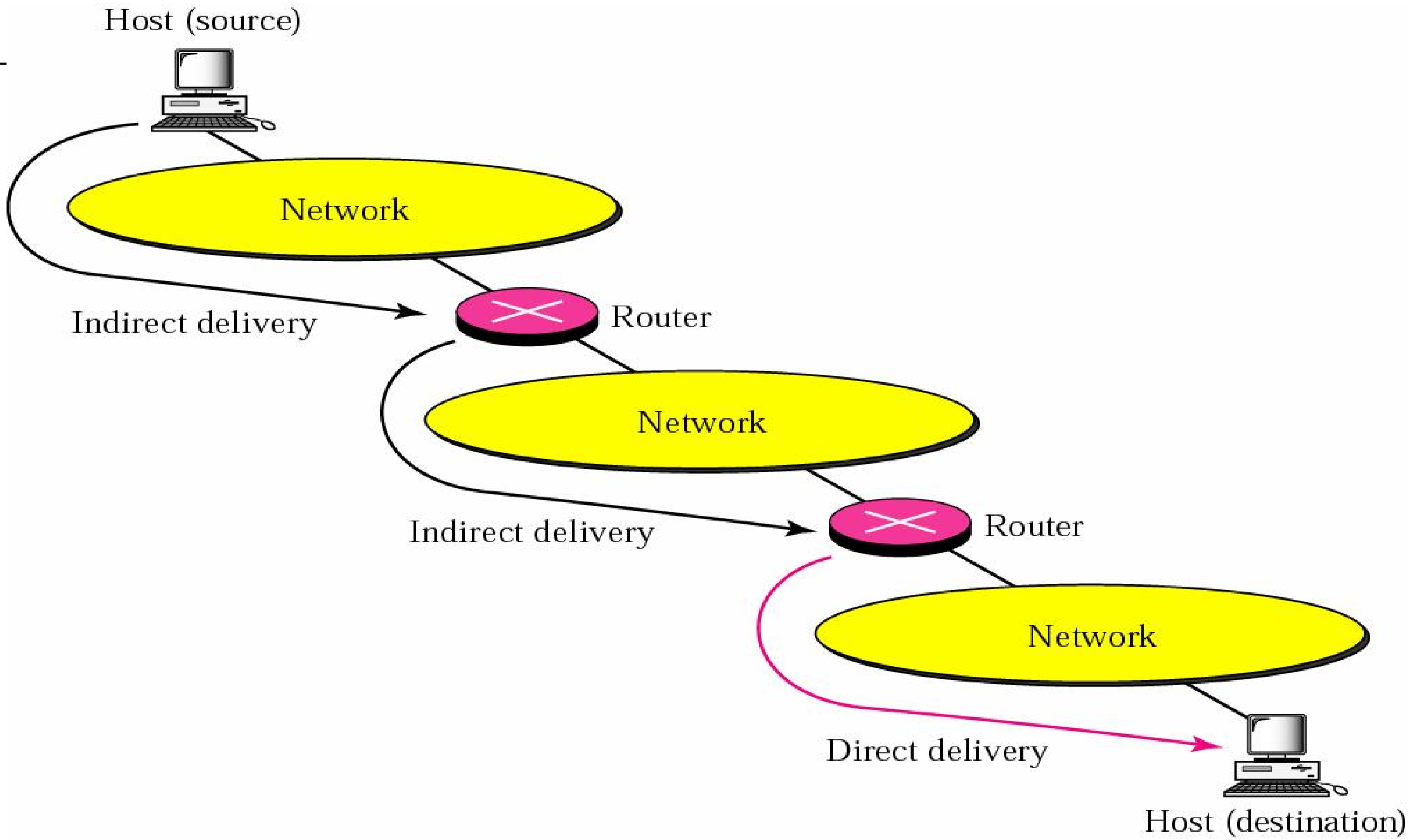
- How to determine if the delivery is direct
  - Compare the *network addresses* between *the destination* and *the current network*
- For direct delivery, the sender uses the destination *IP* address to find the destination *physical address*
  - Static method: finding a table
  - Dynamic method: use the address resolution protocol (ARP)

Indirect Delivery

- The destination host and the deliverer are not on the same network
  - Packet goes from routers to routers
- For indirect delivery
  - The sender uses *the destination IP address* and *a routing table* to find *the next router's IP address*
  - Then, the sender uses ARP protocol to find the next router's physical address

Figure 6-3

Indirect Delivery



Indirect Delivery (Cont.)

- A delivery always involves one direct delivery but zero or more indirect deliveries

- Besides, the last delivery is always a direct delivery

6.3

ROUTING METHODS

Routing Methods

- Routing requires a host/router to have a *routing table*
- However, with the increase of hosts,
  - The number of entries in the routing table also increase
- Look for ways to decrease the table size or handle issues such as security
  - *Next-hop routing*
  - *Network-specific routing*
  - *Host-specific routing*
  - *Default routing*

Next-Hop Routing

- Hold only the address of the next hop
  - Instead of holding information about the complete route

Next-Hop Routing

Routing table for host A

Destination	Route
Host B	R1, R2, Host B

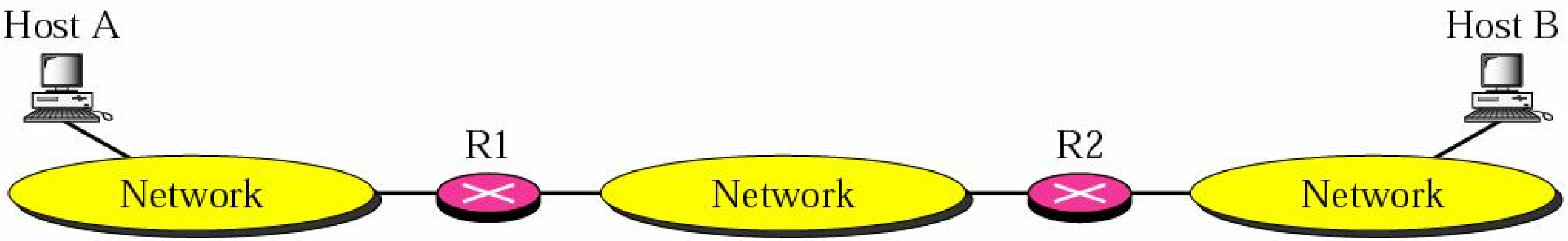
Routing table for R1

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	—

b. Routing tables based on next hop

Network-Specific Routing

- Use only one entry to define *the address of the network itself, i.e., network address*
  - Instead of having an entry for every host connected to the same physical network

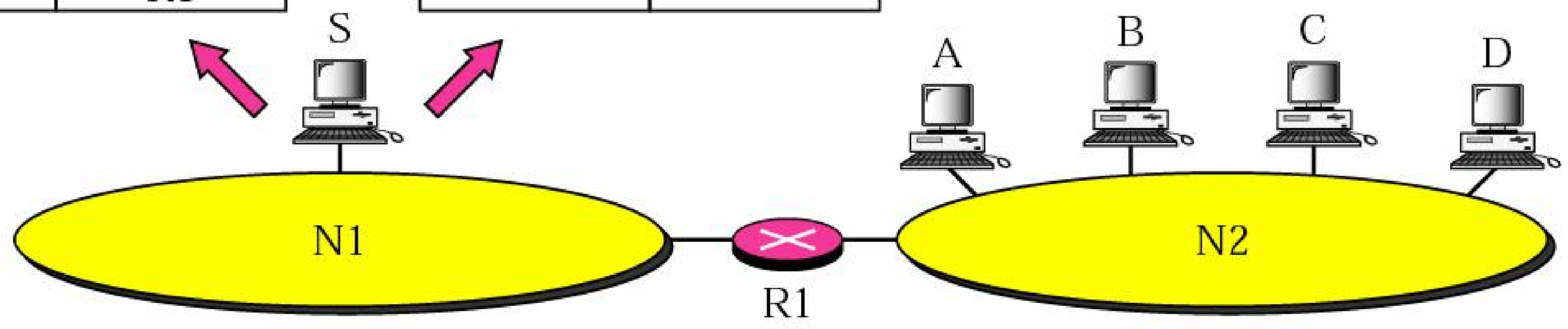
Network-Specific Routing

Routing table for host S based
on host-specific routing

Destination	Next Hop
A	R1
B	R1
C	R1
D	R1

Routing table for host S based
on network-specific routing

Destination	Next Hop
N2	R1



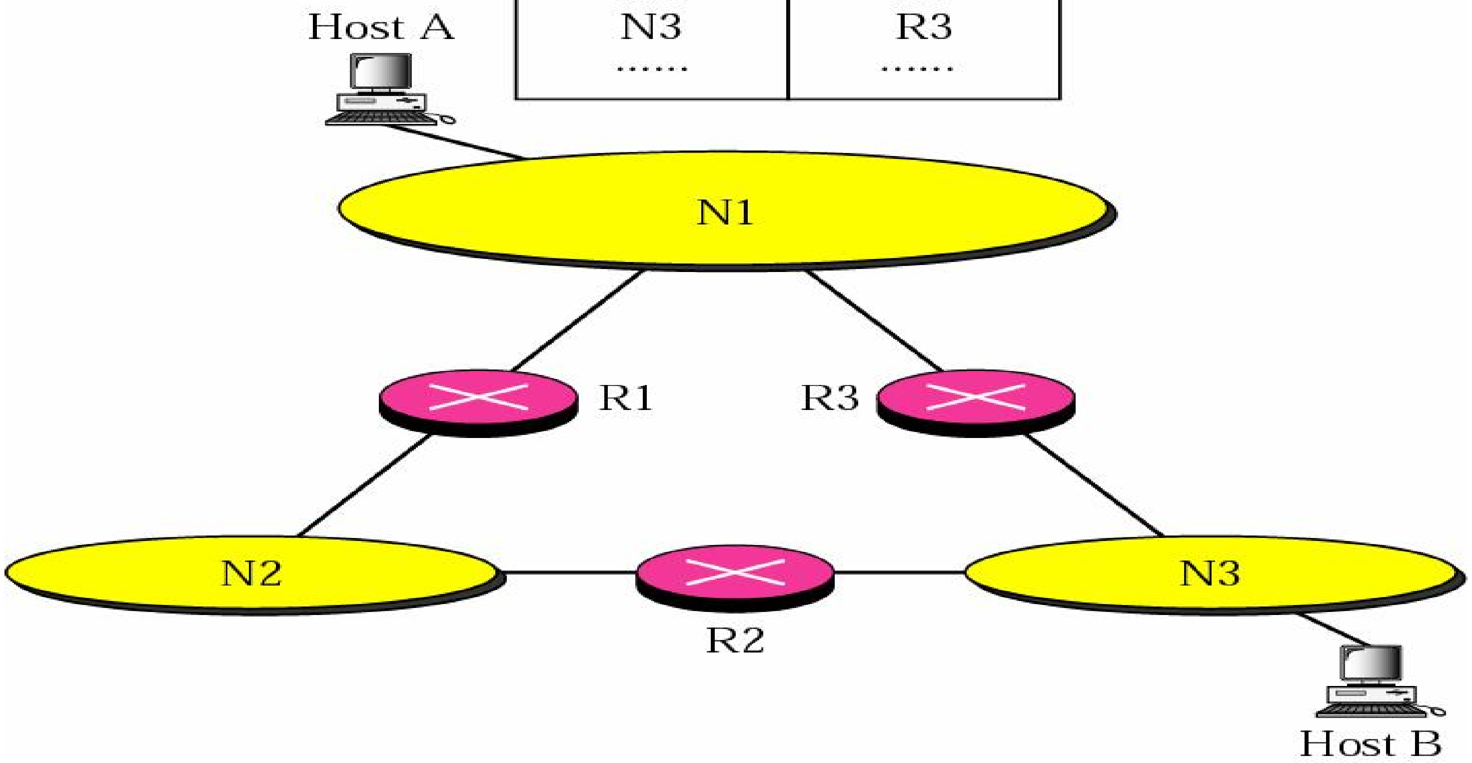
Host-Specific Routing

- The destination host address is given in the routing table
- The inverse of network-specific routing
- Not efficient for performance
  - But, in some occasions, the administrator wants to have more control over routing
    - Checking the route
    - Providing security

Host-Specific Routing

Routing table for host A

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



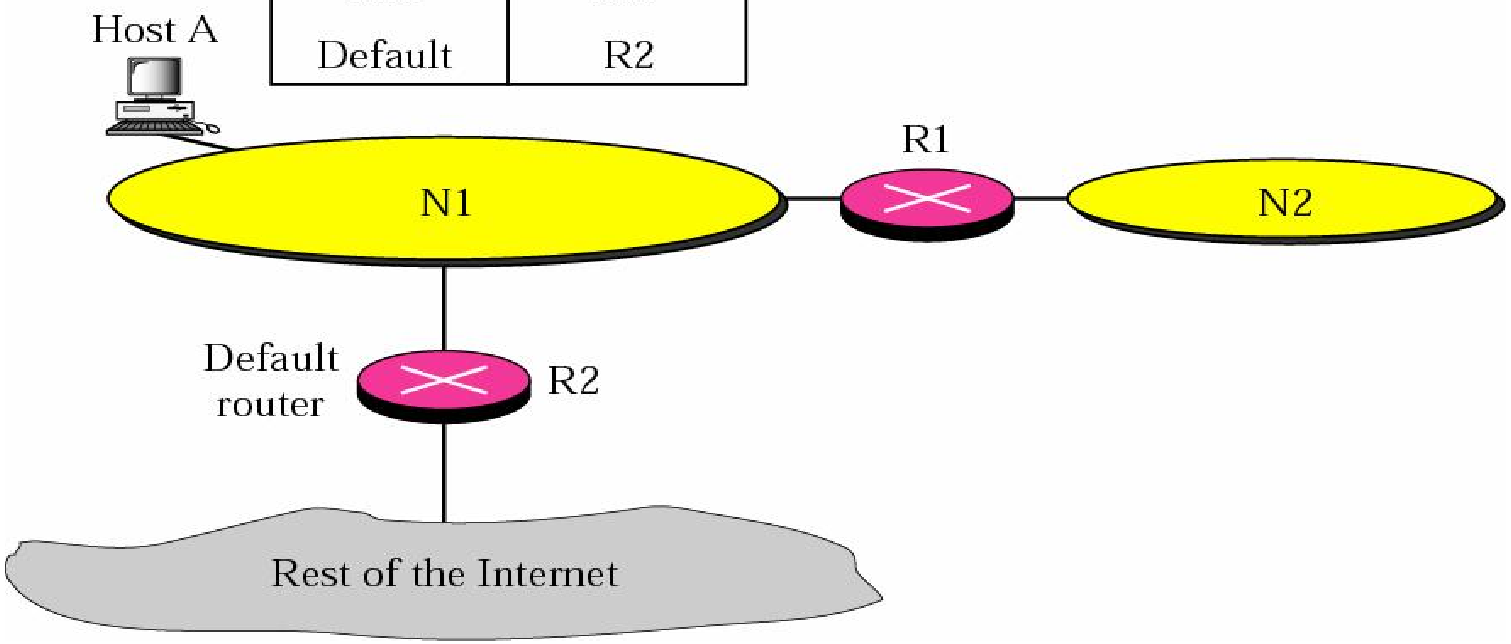
Default Routing

- Instead of listing all networks in the routing table
  - Just use one entry called *default*
  - Network address is 0.0.0.0

Default Routing

Routing table for host A

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



6.4

STATIC VERSUS DYNAMIC ROUTING

Static Versus Dynamic Routing Table

- Static Routing Table
  - The entries are entered *manually*
  - Cannot be updated unless manually altered by administrator
- Dynamic Routing Table
  - Update periodically using dynamic routing protocol
    - RIP, OSPF, or BGP
  - If a router shutdown or a link is broken
    - Update the tables accordingly

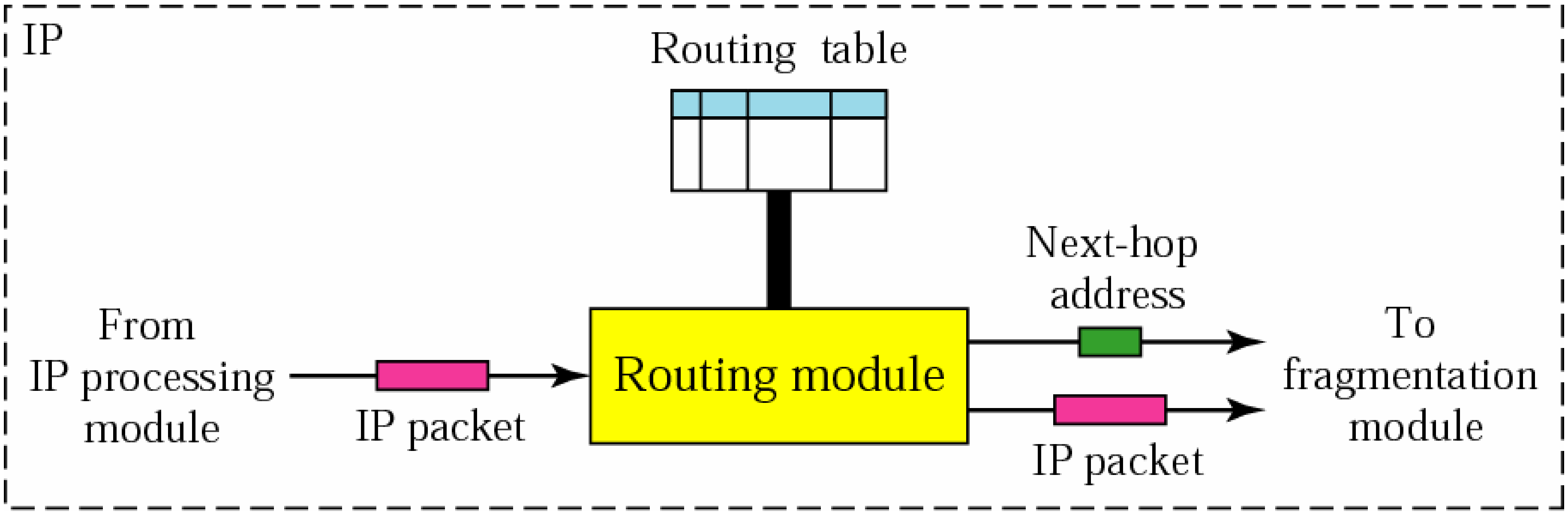
6.5

ROUTING TABLE AND ROUTING MODULE

Routing Table and Routing Module

- When look for the route
  - First check for *direct delivery*
  - Then *host-specific delivery*
  - Then *network-specific delivery*
  - Finally *default delivery*
- This hierarchical strategy can be implemented in the *routing module* or in the *routing table*

Routing Module and Routing Table



Routing Table

- Routing table usually has seven fields
  - Mask, destination address, next-hop address, flags, reference count, use, and interface
- Mask: applies to the destination IP address to find the network/subnetwork address of the destination
  - In host-specific routing: mask = 255.255.255.255
  - In default routing: mask = 0.0.0.0
  - In an unsubnetted network: mask = default mask

Routing Table (Cont.)

- Destination address: can be either
  - Destination *host address* (host-specific address)
  - Destination *network address* (network-specific address)
- Next-hop address
  - The address of the next-hop router

Routing Table (Cont.)

- Flags
  - U (Up): the router is up and running.
    - If not present, cannot forward packet to this router
  - G (Gateway): destination is in another network and use *indirect delivery*
    - If not present, use direct delivery
  - H (Host-specific): the entry in the destination field is host-specific address
    - If not present, destination field is network-specific address

Routing Table (Cont.)

- Flags
  - D (Added by redirection): routing information for this destination has been *added* by a ***redirection message*** from ICMP.
  - M (Modified by redirection): routing information for this destination has been *modified* by a ***redirection message*** from ICMP.
    - Discuss in Chapter 9

Routing Table (Cont.)

- Reference count
  - The number of *users* that are using this route at any moment
- Use
  - The number of *packets* transmitted through this router for the corresponding destination
- Interface
  - The name of interface

Routing Table

Mask	Destination address	Next-hop address	Flags	Reference count	Use	Interface
255.0.0.0	124.0.0.0	145.6.7.23	UG	4	20	m2
....	....		....	....	....	....
....	....	....	....	....	....	....

Flags

U The router is up and running.

G The destination is in another network.

H Host-specific address.

D Added by redirection.

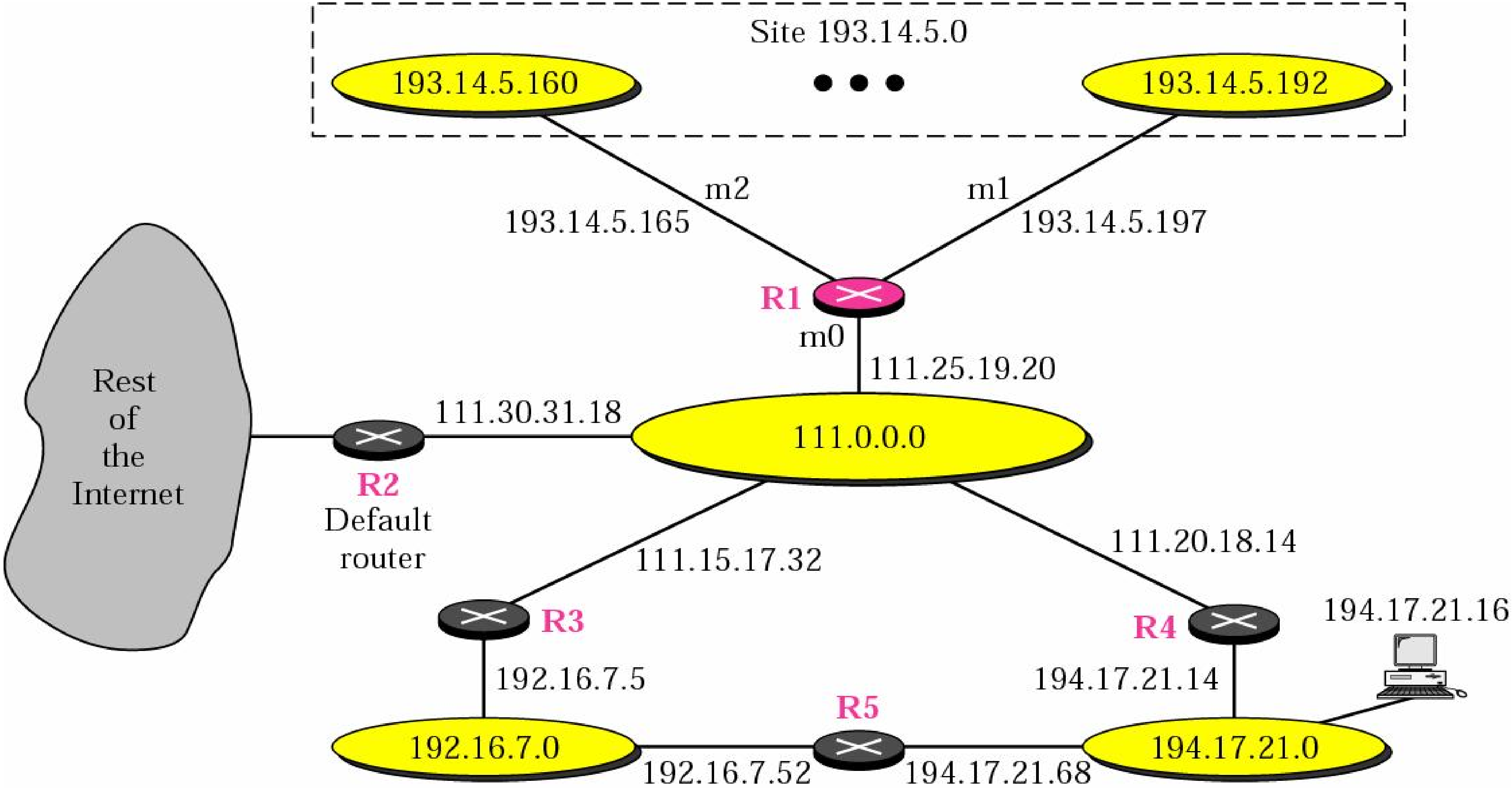
M Modified by redirection.

Routing Module

1. For each entry in the routing table
    1. Apply the mask to the packet dest. Address
    2. If (the result match the value in the dest. field)
        1. If (the G flag is present)   // indirect delivery
            1. Use the next-hop entry in the table as next-hop address
        2. If (the G flag is missing)
            1. Use packet destination address (direct delivery)
        3. Send packet to fragmentation module with next-hop address
        4. Stop
2. If no match is found, send an ICMP error message
3. Stop

Figure 6-9

Configuration for Routing Example



Routing Table of R1 Used for Example

Mask	Dest.	Next Hop	F	I.
255.0.0.0	111.0.0.0	--	U	m0
255.255.255.224	193.14.5.160	-	U	m2
255.255.255.224	193.14.5.192	-	U	m1
255.255.255.255	194.17.21.16	111.20.18.14	UGH	m0
255.255.255.0	192.16.7.0	111.15.17.32	UG	m0
255.255.255.0	194.17.21.0	111.20.18.14	UG	m0
0.0.0.0	0.0.0.0	111.30.31.18	UG	m0

Example 1

Router R1 receives 500 packets for destination 192.16.7.14; the algorithm applies the masks row by row to the destination address until a match (with the value in the second column: *Destination* field) is found:

Solution

Direct delivery

192.16.7.14	&	255.0.0.0	è	192.0.0.0	no match
192.16.7.14	&	255.255.255.224	è	192.16.7.0	no match
192.16.7.14	&	255.255.255.224	è	192.16.7.	no match

Host-specific

192.16.7.14 & 255.255.255.255 è 192.16.7.14 no match

Network-specific

192.16.7.14 & 255.255.255.0 è 192.16.7.0 **match**

Solution

- The router send the packet through interface m0
- Increment the *use* field by 500
- Increase the *reference count* field by 1

Example 2

Router R1 receives 100 packets for destination 193.14.5.176; the algorithm applies the masks row by row to the destination address until a match is found:

Solution

Direct delivery

193.14.5.176 & 255.0.0.0 è 193.0.0.0 no match

193.14.5.176 & 255.255.255.224 è 193.14.5.160 **match**

- The router send the packet through interface m2 along with the next-hop IP address
- Increment the *use* field by 100
- Increase the *reference count* field by 1

Example 3

Router R1 receives 20 packets for destination 200.34.12.34; the algorithm applies the masks row by row to the destination address until a match is found:

Solution

Direct delivery

200.34.12.34	&	255.0.0.0	è	200.0.0.0	no match
200.34.12.34	&	255.255.255.224	è	200.34.12.32	no match
200.34.12.34	&	255.255.255.224	è	200.34.12.32	no match

Host-specific

200.34.12.34	&	255.255.255.255	è	200.34.12.34	no match

Solution

Network-specific

200.34.12.34 & 255.255.255.0 è 200.34.12.0 no match

200.34.12.34 & 255.255.255.0 è 200.34.12.0 no match

Default

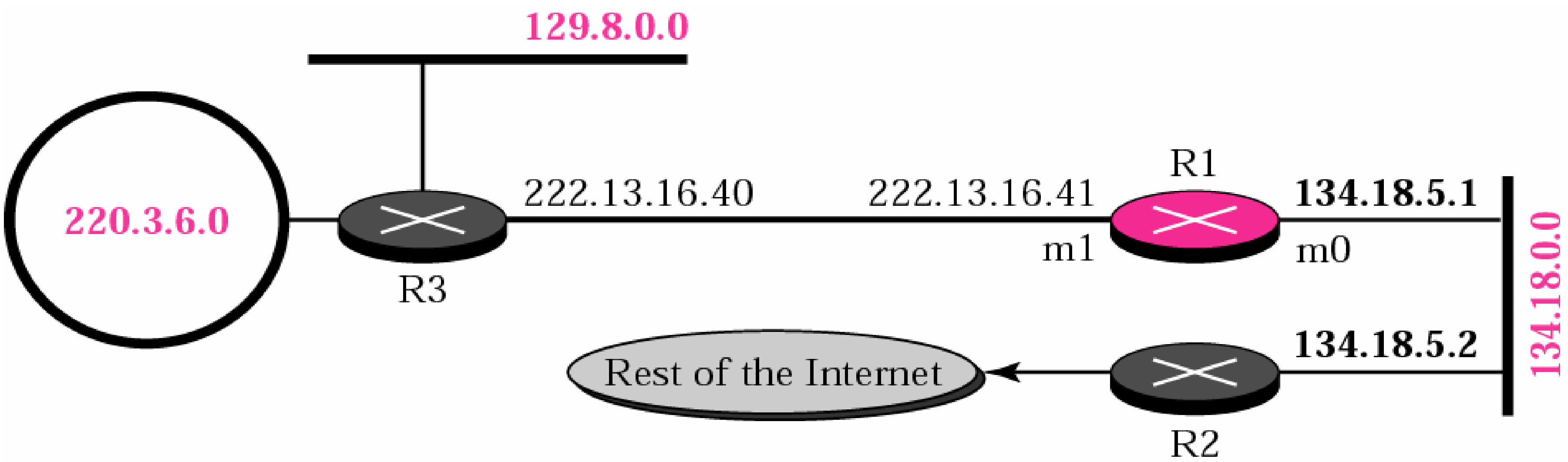
200.34.12.34 & 0.0.0.0 è 0.0.0.0. **match**

- The router send the packet through interface m0 along with the next-hop IP address
- Increment the *use* field by 20
- Increase the *reference count* field by 1

Example 4

Make the routing table for router R1 in the following Figure

Example 4



- There are three explicit destination networks and one default access to the rest of the Internet (default route)
- The network 134.18.0.0 is *direct routing*
  - G is not present and Next Hop is blank
- Another three networks are *indirect routing*
  - G = 1 and Next Hop given the IP address of next hop

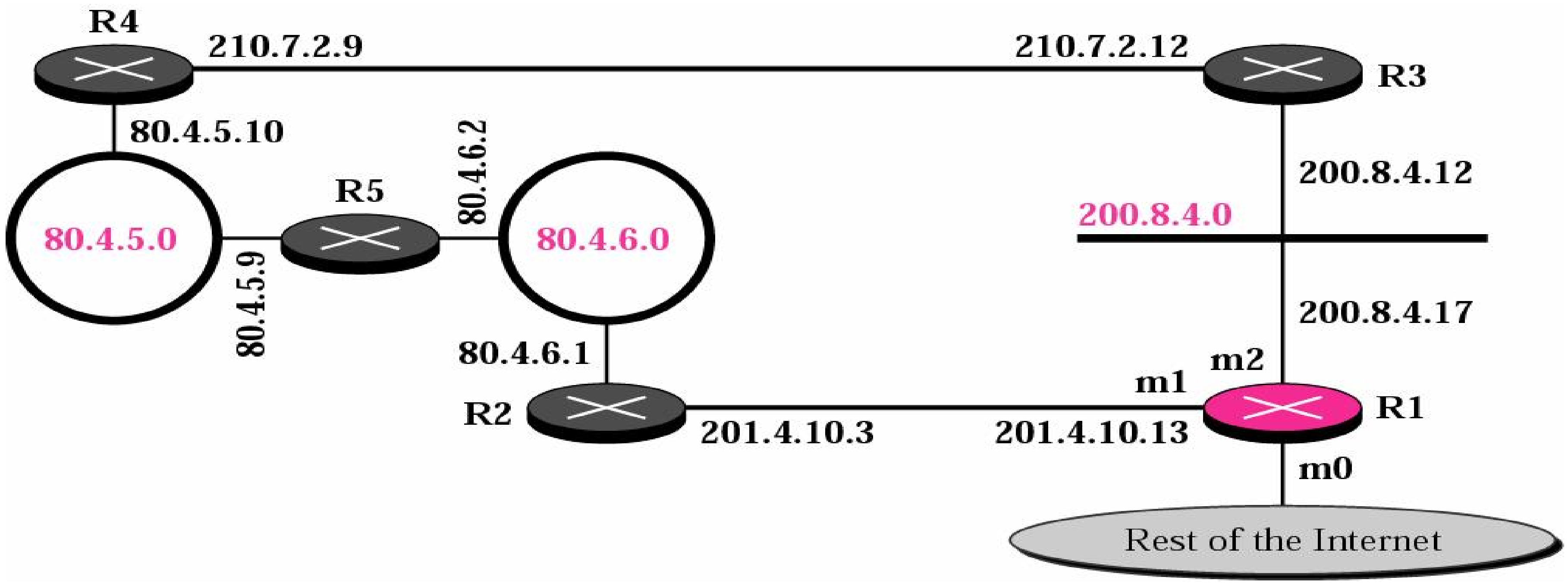
Solution

Mask	Destination	Next Hop	I.
255.255.0.0	134.18.0.0	--	m0
255.255.0.0	129.8.0.0	222.13.16.40	m1
255.255.255.0	220.3.6.0	222.13.16.40	m1
0.0.0.0	0.0.0.0	134.18.5.2	m0

Example 5

Make the routing table for router R1 in Figure 6.11

Example 5



- There are five network, but two of them are point-to-point with no hosts and need not be in the routing table
- There is also an entry for the default route
  - But we do not know the IP address to the default route.

Solution

Mask	Destination	Next Hop	I.
255.255.255.0	200.8.4.0	----	m2
255.255.255.0	80.4.5.0	201.4.10.3 or 200.8.4.12	m1 or m2
255.255.255.0	80.4.6.0	201.4.10.3 or 200.8.4.12	m1 or m2
0.0.0.0	0.0.0.0	????????????	m0

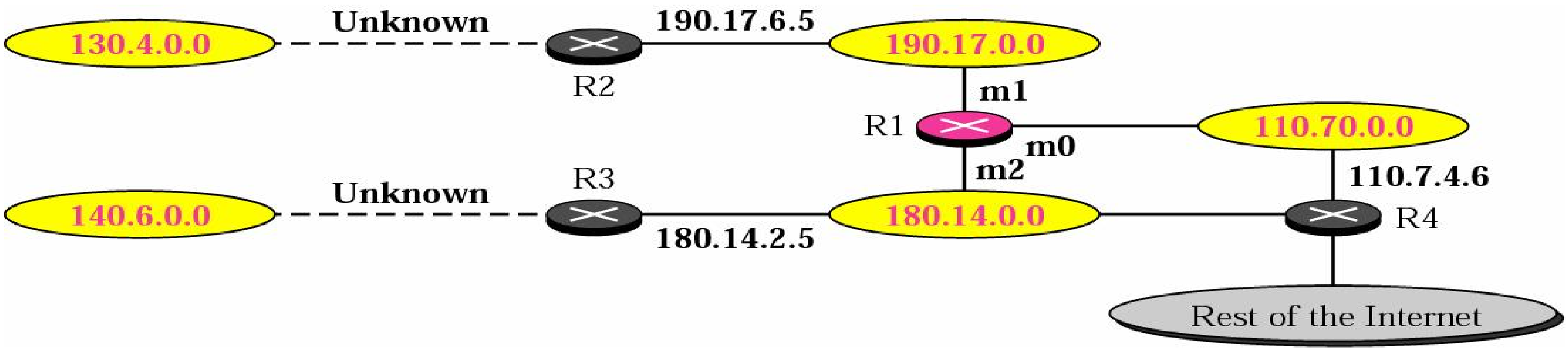
Example 6

The routing table for router R1 is given below.

Draw its topology

Mask	Destination	Next Hop	I.
255.255.0.0	110.70.0.0	-	m0
255.255.0.0	180.14.0.0	-	m2
255.255.0.0	190.17.0.0	-	m1
255.255.0.0	130.4.0.0	190.17.6.5	m1
255.255.0.0	140.6.0.0	180.14.2.5	m2
0.0.0.0	0.0.0.0	110.70.4.6	m0

Example 6: Solution



- From the table:
  - There are three networks directly connected to R1
  - There are two networks indirectly connected to R1
  - One default router to the rest of network
- However, we do not know whether the network 130.4.0.0 and 140.6.0.0 are
  - Directly connected to the router R2
  - Or through a point-to-point network and another router

6.6

CLASSLESS ADDRESSING: CIDR

Classless Addressing

- Requires changes as compared to the classful addressing
  - Routing Table Size
  - Hierarchical Routing
  - Geographical Routing
  - Routing Table Search Algorithms

Routing Table Size

- In classful address
  - There is only one entry for each site
  - Even this site is subnetted

- In classless address
  - The number of entries can either decrease or increase

Routing Table Size (Cont.)

- Decrease
  - In classful addressing
    - Four entries in the routing table for an organization that creates a supernet from four class C blocks
  - In classless addressing
    - Only one entry in the routing table
- Increase: more likely occur
  - Class A and B blocks are divided into smaller blocks in classless addressing

Hierarchical Routing

- To solve the problem of vast routing tables
  - Create a sense of hierarchy in the Internet architecture and routing tables
- Internet is divided into international and national ISP
  - National ISP are divided into regional ISPs
  - Regional ISP are divided into local ISPs
- Routing table decrease its size by this hierarchical structure

Geographical Routing

- To decrease the size of the routing table even further, we need to extend hierarchical routing to include geographical routing
- Divide the entire address space into a few large blocks
  - A block to North America
  - A block to Europe
  - A block to Asia
  - A block to Africa

Routing Table Search Algorithm

- Previous, the routing table is organized as a list
  - However, to make search easier, the routing table can be divided into three buckets (areas)
  - When a packet arrives, applies the *default mask* to find the corresponding bucket (class A, B, or C)
    - Notably, from a address, we can derive which class it belongs to

Routing Table Search Algorithm (Cont.)

- In classless routing, we can also use buckets
  - However, 32 buckets are used instead of three
    - Each buckets corresponding to each prefix length
  - When a packet arrives, try the longest prefix (/32), then the next prefix (/31) and so on until matched
    - *Longest match method*
- However, this search method would also take quite a long time
  - Use other data structures such as tree or binary tree

Note

***In classful addressing,
each address has self-contained
information that facilitates
routing table searching.***

Note

In classless addressing, there is no self-contained information in the destination address to facilitate routing table searching.