ROUTING

Learning outcome

- Understand the basics of routing protocols.
- Distinguish between routing and forwarding.
- Be familiar with the metrics used by routing protocols to determine path selection.
- Understand the basics of how data travels from end stations through intermediate stations and on to the destination end station.
- Understand the difference between routed protocols and routing protocols.

What Is Routing?

- التسيير هو عملية تحريك المعطيات عبر الشبكة من المصدر إلى الوجهة.
- ويتضمن التسيير:
  - تحديد ممر التسيير الأمثل.
  - توجيه المعطيات لتمر عبر هذا المسار.

التوجيه Forwarding

- نقصد بالتوجيه وضع الطرد في المسار المناسب للوصول إلى وجهته النهائية
- حتى يستطيع حاسب أو مسير توجيه طرد ما يجب أن يمتلك جدول تسيير Routing Table
- يوجد حالياً عدة طرق لتحقيق التوجيه:
  - منها ما يعتمد على وضع المسار كاملاً من المصدر إلى الوجهة ضمن جدول التسيير
  - ومنها ما يضع عنوان القفزة التالية Next hop فقط.
  - توجد أيضاً طرق تسمح بتحديد طريقاً لكل عنوان وجهة وهو ما يعرف بـ Host-specific أو طريقاً لكل عنوان شبكة الذي تقع عليه الوجهة وهو ما يعرف بـ Network-specific

Routing Principles

- يستخدم المسير آلية من أجل:
  - تحديد القفزة التالية الملائمة وفقاً لعنوان الرزمة
  - تحديد الانترفيس الملائم لنقل الرزمة عبر الوصلة بين مسيرين
- هنا يمكننا التمييز بين نوعين من التوجيه:
  - التوجيه المباشر حيث تكون الوجهة النهائية واقعة ضمن نفس الشبكة الفيزيائية للمرسل.
    - يستطيع المرسل أن يحدد كون التسليم مباشراً أو لا عن طريق مقارنة عنوان الشبكة التي يقع عليها مع عنوان الشبكة للوجهة وفي حال التطابق يكون التسليم مباشراً.
  - التوجيه غير المباشر ففيها لا يقع المرسل أو المستقبل ضمن نفس الشبكة الفيزيائية.

جدول التسيير Routing Table

- يمتلك كل حاسب مضيف Host أو مسير Router جدول تسيير يحتوي على مدخل لكل وجهة ممكنة أو مجموعة وجهات لمساعدته على تسيير الرزم
- يمكن أن يكون جدول التسيير ساكناً Static أو ديناميكياً Dynamic.

➢ جدول التسيير الساكن يحوي على مسارات يقوم مدير النظام بإدخالها يدوياً،

➢ جدول التسيير الديناميكي: يتم تحديثه آلياً باستخدام بروتوكولات التسيير الديناميكية

➢ صيغة جدول التسيير: يحوي جدول التسيير أربعة حقول على الأقل وهي:

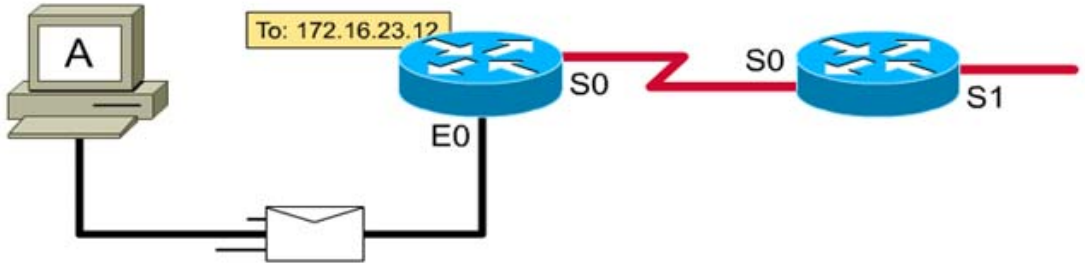
Mask (/n)	Network address	Next-hop address	Interface
.....	.....	.....	.....
.....	.....	.....	.....
.....	.....	.....	.....
.....	.....	.....	.....

- قناع الشبكة Mask
- عنوان الشبكة الوجهة
- عنوان القفزة التالية Next Hop
- بوابة الخرج Interface

IP Routing Table

- يحوي جدول التوجيه العناوين والقفزات التالية التي تناسبه
- يتم تسيير الرزمة قفزة إثر قفزة بين الموجهات عبر الشبكة.
- من أجل كل قفزة يتم تحديد الانترفيس المناسب "العنوان الفيزيائي"
- حين لا يستطيع الموجه تحديد القفزة التالية للرزمة يتم إرسالها إلى الوجهة الافتراضية.

Destination Network	Interface (Next Hop)
172.31.0.0	S0
172.19.0.0	--
192.168.1.0	--
10.0.0.0	E0



Routing Table (summary)

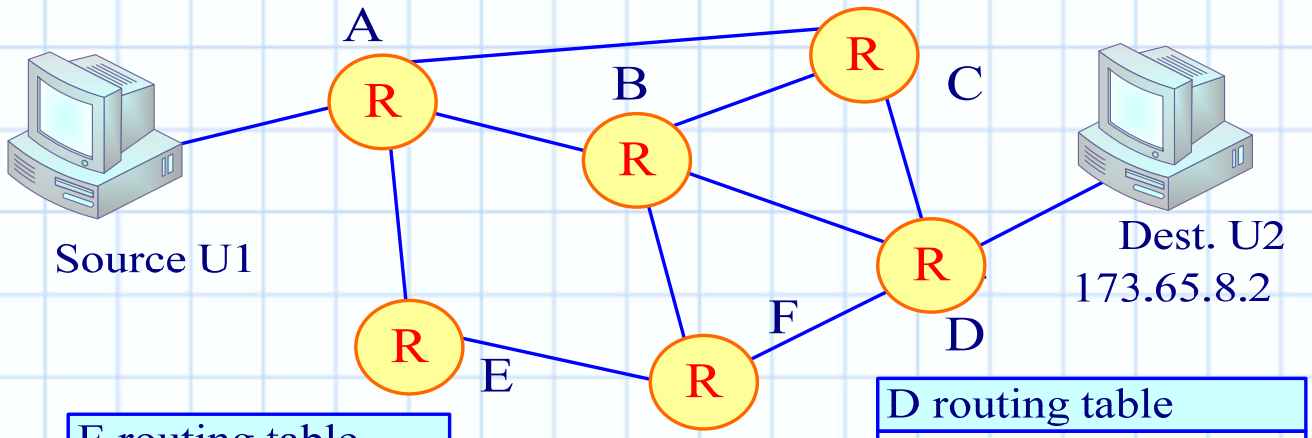
- هو عبارة عن جدول للبحث عن عناوين الوجهات وما يناسبها من منافذ
- يستخدم الموجه خوارزمية محددة من أجل تحقيق ذلك
- على الموجه أن يجيب على هذين السؤالين
  - عبر أي منفذ؟
  - القفزة التالية؟
- يتم اتخاذ القرار بناء على تقدير كلفة المسار حيث يتم احتساب هذه الكلف باستخدام خوارزميات محددة
- تأخذ هذه الخوارزميات في الحسبان عوامل متنوعة كالخطأ والتأخير وعدد القفزات وعرض الحزمة وغيرها
- تختلف طرقة احتساب القيمة باختلاف الموجه واختلاف الخوارزمية المطبقة.

Example of simple routing tables

A routing table
173.0.0.2 next hop B
173.65.8.2 next hop E
0.0.0.0 default rout C

B routing table
173.65.8.2 next hop D
173.65.7.3 next hop C
173.32.8.1 next hop A
0.0.0.0 default rout F

C routing table
173.65.8.2 next hop B
173.11.7.4 next hop A
0.0.0.0 default rout D



E routing table
173.65.8.2 next hop F
0.0.0.0 default rout A

F routing table
173.65.8.2 next hop B
173.58.0.2 next hop E
0.0.0.0 default rout B

D routing table
173.9.3.2 next hop C
173.65.8.2 next hop U1
173.3.33.5 next hop B
0.0.0.0 default rout F

Routing Table

Network Destination	Netmask	Gateway	Interface	Metric
0.0.0.0	0.0.0.0	10.100.55.1	10.100.55.102	25
5.0.0.0	255.0.0.0	5.187.250.135	5.187.250.135	20
5.187.250.135	255.255.255.255	127.0.0.1	127.0.0.1	20
5.255.255.255	255.255.255.255	5.187.250.135	5.187.250.135	20
10.100.55.0	255.255.255.0	10.100.55.102	10.100.55.102	25
10.100.55.1	255.255.255.255	10.100.55.102	10.100.55.102	1
10.100.55.102	255.255.255.255	127.0.0.1	127.0.0.1	25
10.255.255.255	255.255.255.255	10.100.55.102	10.100.55.102	25
70.91.253.33	255.255.255.255	10.100.55.1	10.100.55.102	1
127.0.0.0	255.0.0.0	127.0.0.1	127.0.0.1	1
169.254.0.0	255.255.0.0	5.187.250.135	5.187.250.135	20
192.168.1.0	255.255.255.0	192.168.100.4	192.168.100.4	1
192.168.100.0	255.255.255.0	192.168.100.4	192.168.100.4	25
192.168.100.4	255.255.255.255	127.0.0.1	127.0.0.1	25
192.168.100.255	255.255.255.255	192.168.100.4	192.168.100.4	25
224.0.0.0	240.0.0.0	5.187.250.135	5.187.250.135	20
224.0.0.0	240.0.0.0	10.100.55.102	10.100.55.102	25
224.0.0.0	240.0.0.0	192.168.100.4	192.168.100.4	25
255.255.255.255	255.255.255.255	5.187.250.135	5.187.250.135	1
255.255.255.255	255.255.255.255	10.100.55.102	10.100.55.102	1
255.255.255.255	255.255.255.255	192.168.100.4	2	1
255.255.255.255	255.255.255.255	192.168.100.4	192.168.100.4	1

Default Gateway: 10.100.55.1

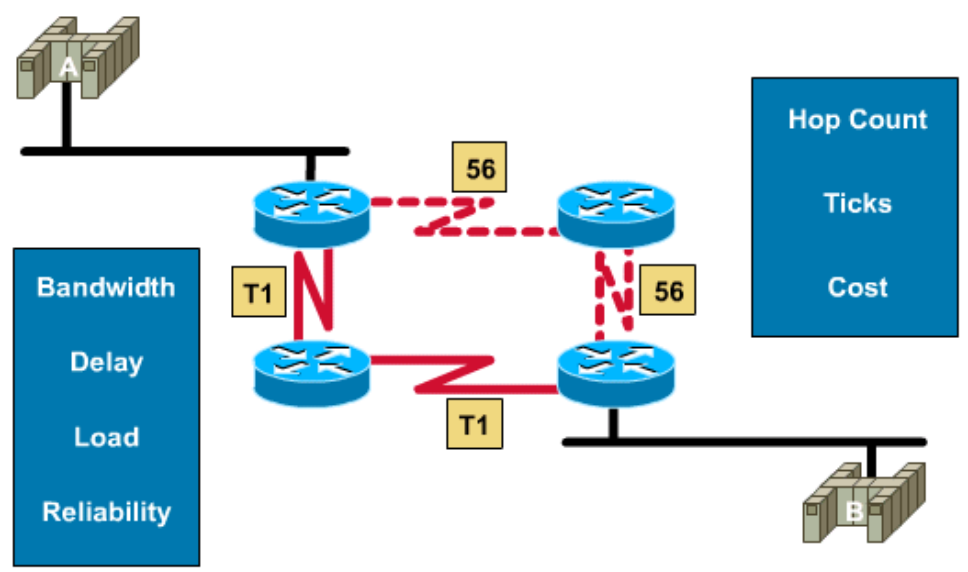
Routing table entries

Network ID	Forwarding address	Interface	Metric	Net Mask	Life time

- **Network Destination:** The network ID corresponding to the route. The network destination can be class-based, subnet, or super-net, or an IP address for a host route.
- **Forwarding address or Gateway:** The forwarding or next-hop IP address for the network destination.
- **Interface:** The IP address corresponding to the network interface that is used to forward the IP datagram.
- **Metric:** A number used to indicate the cost of the route.
- **Net-mask:** The mask used to match a destination IP address to the network destination.
- **Lifetime**: The Lifetime field indicates the lifetime that the route is considered valid. If a learned route's lifetime expires, it is removed from the routing table.

Routing Metrics

- Metrics may be determined by a single characteristic or by several complex characteristics.



- Examples of common routing metrics are:
  - Bandwidth
  - Delay
  - Load
  - Reliability
  - Hop Count
  - Ticks
  - Cost

Routing Metrics

- الهدف الأساسي لخوارزمية التوجه هو أن تحدد المعلومات الأفضل لوضعها في حقول جدول التوجيه، وحساب قيم مناسبة لهذه الحقول ومنها القيمة القياسية metric value من أجل كل ممر.
- يتم احتساب هذه القيمة بناء على واحد او اكثر من الخصائص التي تسم المسار.
- عادة تكون القيمة الأقل هي القيمة الأفضل.

بعض القيم القياسية

Definition of some Routing metrics

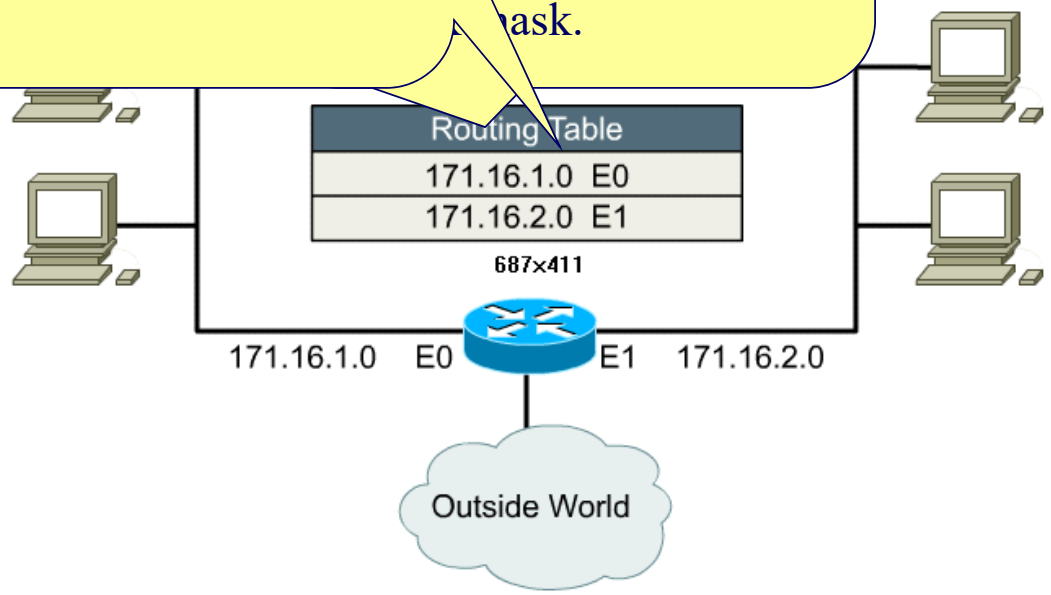
Routing metrics can include the following:

- Hops: The number of intermediate routers between a given network and the local router
- Latency: The time delay in processing a packet through the router or over a given route
- Congestion: The length of the packet queue at the incoming port of the router
- Load: The processor use at the router or the number of packets per second that it is currently processing
- Bandwidth: The available capacity of a route to support network traffic.
- Reliability: The relative amount of downtime that a particular router might experience because of malfunctions
- Maximum Transmission Unit (MTU): The largest packet size that the router can forward without needing to fragment the packet

Determining Network Address

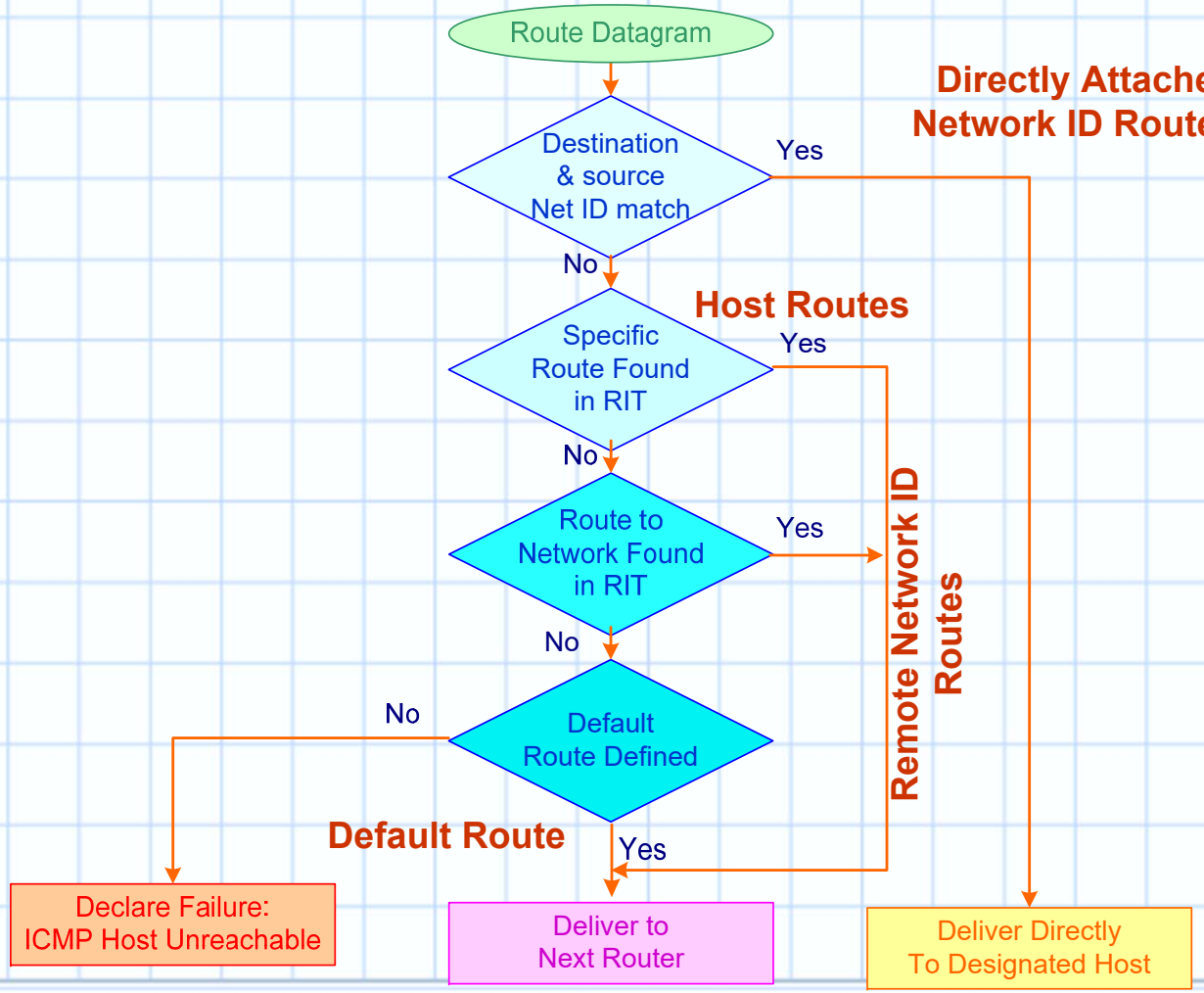
The router then performs the logical AND
twork number.
host portion of the
oved.
packet
eves the internal
ask.

Finally, router looks up the destination network number, matches it with an outgoing interface and forwards the frame to the destination IP address.

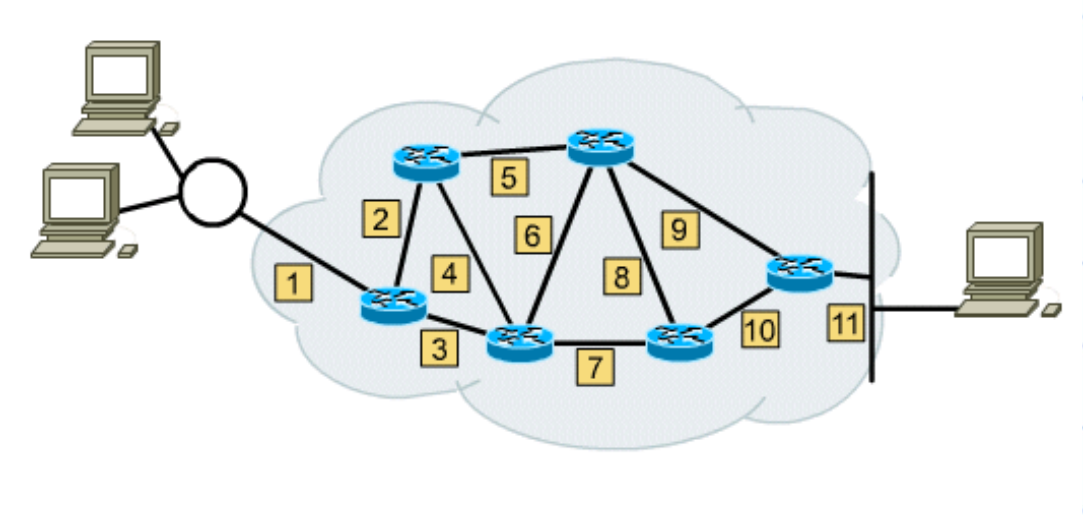


Types of routes

- **Directly Attached Network ID Routes:** For network IDs that are directly attached (the Gateway IP address is the IP address of the interface on that network).
- **Remote Network ID Routes:** For network IDs that are not directly attached but are available across other routers (the Gateway IP address is the IP address of a local router in between the forwarding node and the remote network).
- **Host Routes:** A route to a specific IP address. (the Network Destination is the IP address of the specified host and the subnet mask is 255.255.255.255).
- **Default Route:** Is designed to be used when a more specific network ID or host route is not found (the default route Network Destination is 0.0.0.0 with the subnet mask of 0.0.0.0).


Route Datagram
Destination & source Net ID match
Yes
Directly Attached Network ID Routes
No
Host Routes
Specific Route Found in RIT
Yes
No
Route to Network Found in RIT
Yes
Remote Network ID Routes
No
Default Route Defined
No
Default Route
Yes
Declare Failure: ICMP Host Unreachable
Deliver to Next Router
Deliver Directly To Designated Host

End-to-End communications



- Network addresses represent the various paths between routers.
- By learning consistent paths between end stations, routers can reduce broadcasts and increase efficiency.

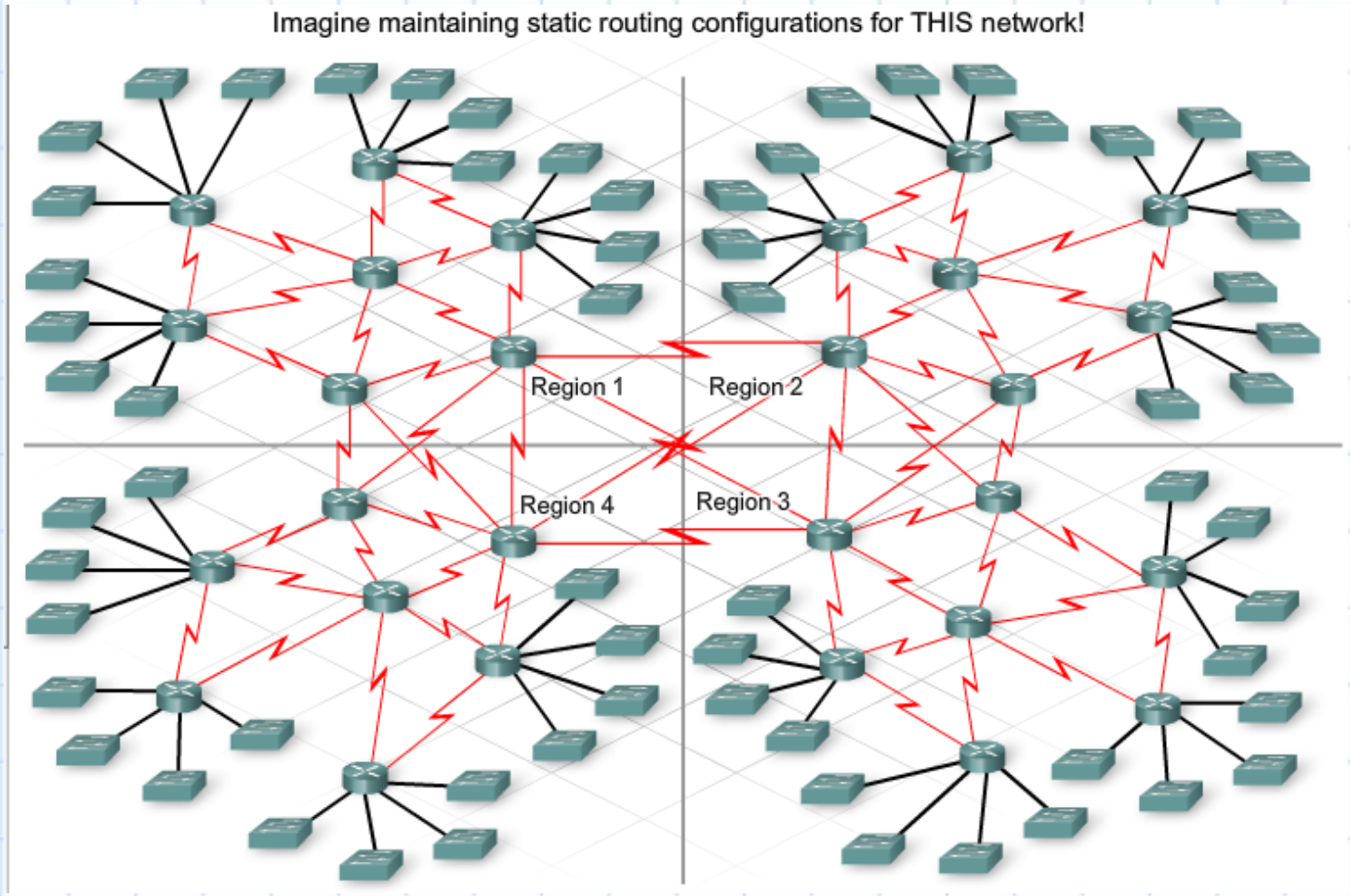
Static Routing

- Configuring the routing tables prior to operation
- Is mainly used in small networks
- The benefits of using static routing are as follows:
  - It is simple'
  - It has lower overheads (no run-time updates are necessary).
  - It is easy to troubleshoot.
- The problems are:
  - As network grows, more effort is required to implement the static definitions.
  - Any changes means having to configure most, if not all, routers.
  - It lacks the ability to adapt to any changes in the operating environment.
  - Traffic is not diverted if there is a link failure.

Dynamic Routing

- Routers build their routing table through information exchanged with each other during run time.
- The network adjusts its routing to all reachable destination addresses on an up-to-the-minute basis.
- Dynamic routing reacting dynamically to:
  - addition of new devices or addresses to the network;
  - removal of devices or addresses from the network;
  - moving of devices or address from one location in the network to another
  - re-adjustment of routes when links between routers fail.
- The challenges faced when creating routing tables :
  - determining the full list of reachable addresses and keeping this permanently up-to-date;
  - creating a routing algorithm (calculation procedure)
  - avoiding network instability.

Static routing? Dynamic Routing?..

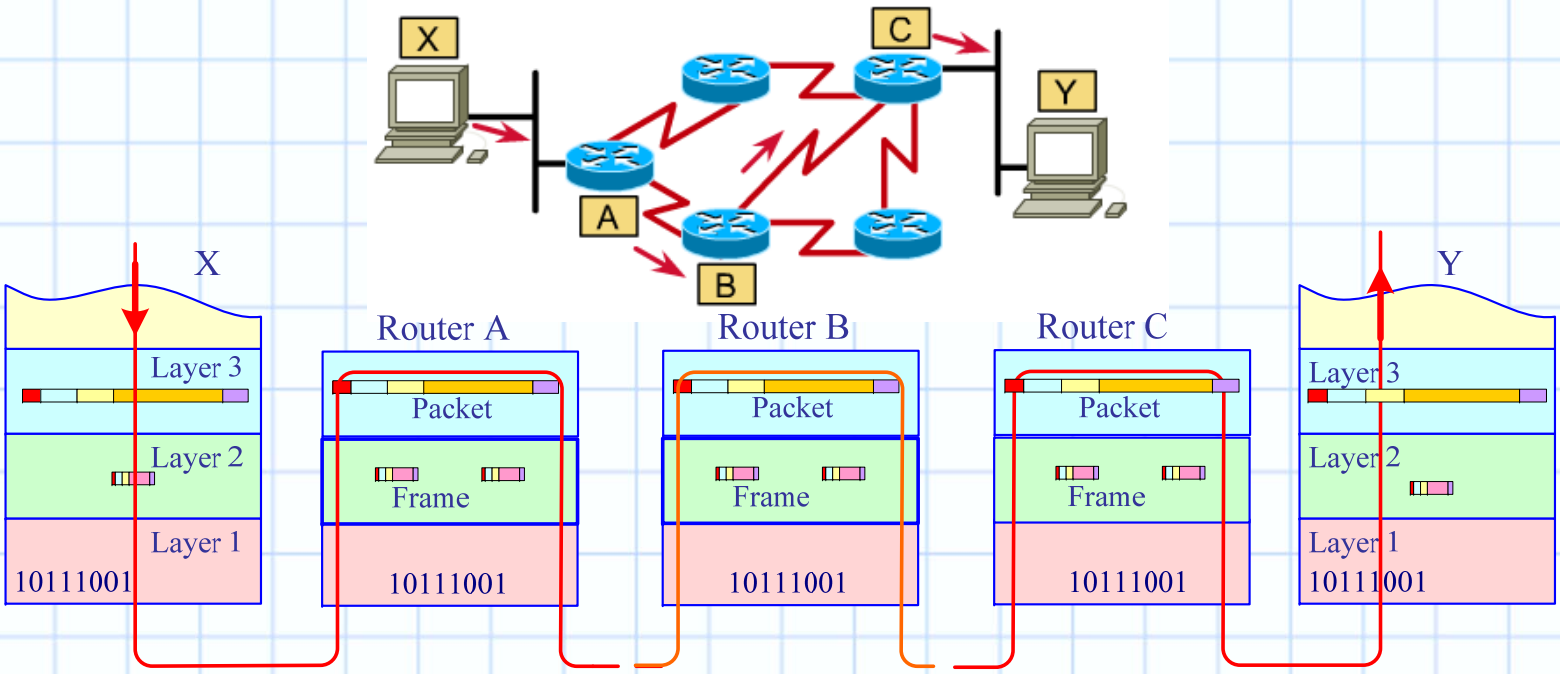


Routing Algorithms and Routing Protocols

- **Routing protocols** determine the path from a sending host to the destination host.
- **Routing algorithms** the heart of any routing protocol.
- **The Route Determination Process:**
  - Calculate the net ID.
  - determines the route that matches the most bits to the Destination IP address (finding the longest or closest matching route).
    - If multiple closest matching routes are found, IP uses the route with the lowest metric.
    - If multiple closest matching routes with the lowest metric are found, IP randomly chooses the route to use.
- **The route chosen yields**
  - a forwarding IP address (the Gateway IP address or the Destination IP address of the IP datagram)
  - an interface (identified through the Interface IP address).
  - If the route determination process fails to find a route, IP declares a routing error.
  - the IP datagram is discarded and ICMP "Destination Unreachable-Host Unreachable" message is sent to the source host.

Routing algorithms key characteristics

- **Accuracy:** find the destination in an appropriate amount of time.
- **Simplicity:** Low complexity of algorithms is particularly important where routers with limited physical resources involve software.
- **Optimality:** the ability to select the best route.
- **Stability:** correct performance in unforeseen circumstances (node failure and routing table corruptions).
- **Adaptability:** When a failure happens in a network, an algorithm should be able to adapt load increases or decreases.
- **Convergence:** converge rapidly when a network distributes routing update messages.
- **Load balancing:** balances over eligible links to avoid having a heavily and temporarily congested link.



- Typical Layer 3 Routing: Router only processes layers 1, 2, and 3, with the routing process using layer 3.
- Router does have upper-layer protocols so you can telnet into the router, etc., however layer 3 routing does not use the upper-layer protocols to make its routing decisions – only layer 3.

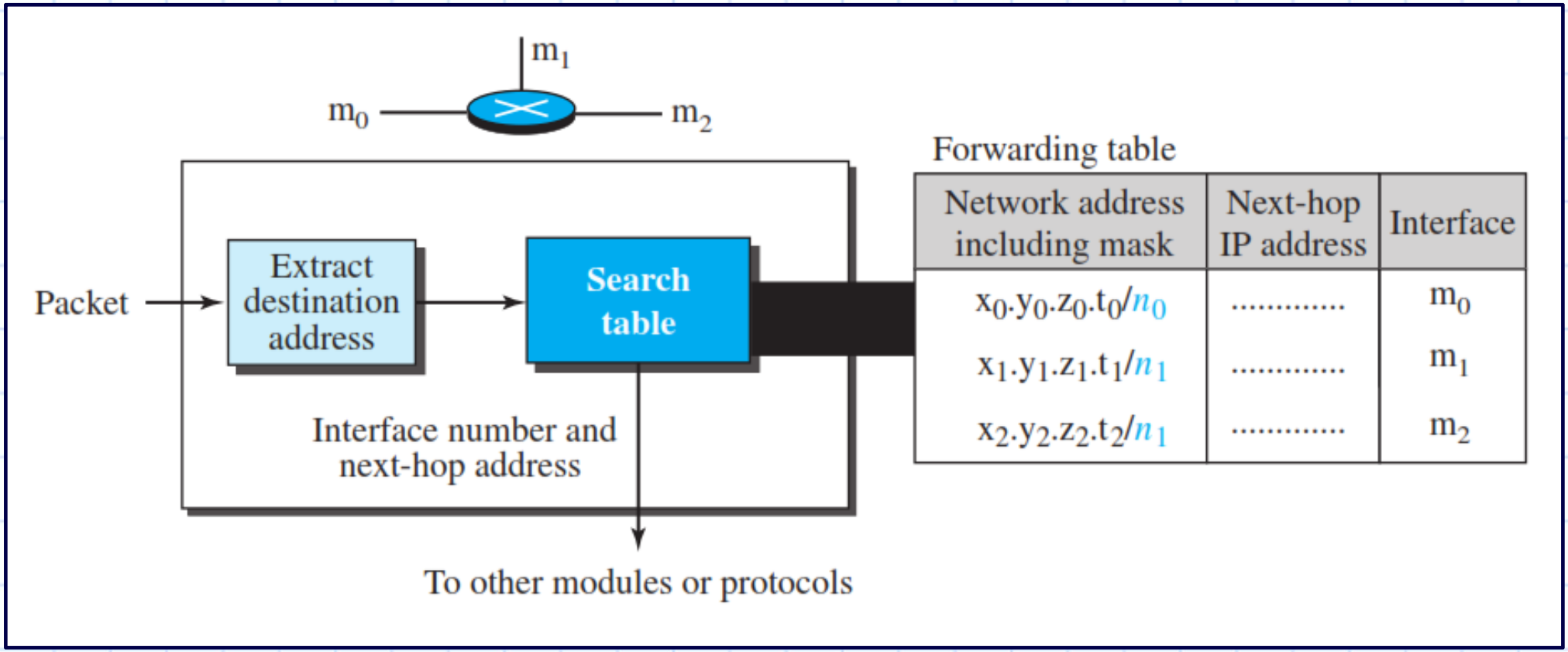
Routed Protocols

- A *routed* protocol is any network protocol that provides enough information in its network layer address to allow a packet to be forwarded from one host to another host based on the addressing scheme.
- Examples of routed protocols
  - IP
  - IPX
  - Apple Talk

Routing Protocols

- *Routing* protocols support a routed protocol by providing mechanisms for sharing routing information. Routing protocol messages move between the routers. A routing protocol allows the routers to communicate with other routers to update and maintain tables. TCP/IP examples of routing protocols are:
  - RIP (Routing Information Protocol)
  - IGRP (Interior Gateway Routing Protocol)
  - EIGRP (Enhanced Interior Gateway Routing Protocol)
  - OSPF (Open Shortest Path First)

Simplified forwarding module in classless address



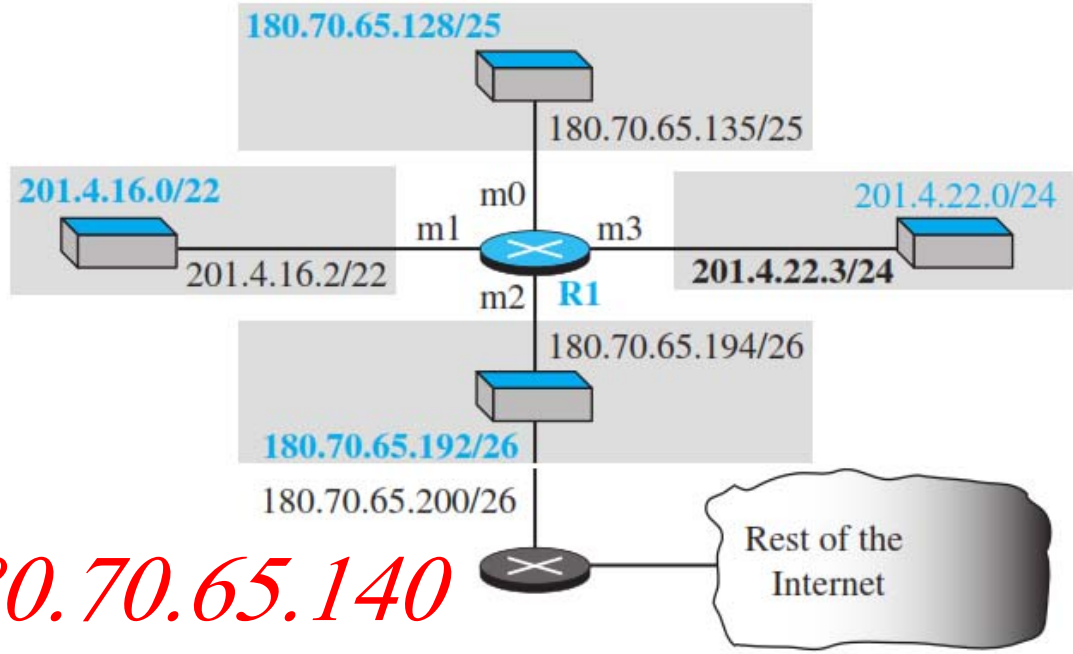
Longest mask matching

IP Packet Destination	172.16.0.10	10101100.00010000.00000000.00001010
Route 1	172.16.0.0/12	10101100.00010000.00000000.00000000
Route 2	172.16.0.0/18	10101100.00010000.00000000.00000000
Route 3	172.16.0.0/26	10101100.00010000.00000000.00000000

Longest Match to IP Packet Destination

Longest mask matching

Net address/mask	Next hop	Interface
180.70.65.192/26	—	m2
180.70.65.128/25	—	m0
201.4.22.0/24	—	m3
201.4.16.0/22	—	m1
Default	180.70.65.200	m2



180.70.65.140

Leftmost bits in the destination address	Next hop	Interface
10110100 01000110 01000001 11	—	m2
10110100 01000110 01000001 1	—	m0
11001001 00000100 00011100	—	m3
11001001 00000100 000100	—	m1
Default	180.70.65.200	m2

201.4.22.35

18.24.32.78

Example 2

Show the forwarding process if a packet arrives at R1 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 and the interface number m0 are passed to ARP for further processing.

Example 3

Show the forwarding process if a packet arrives at R1 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.*
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.*

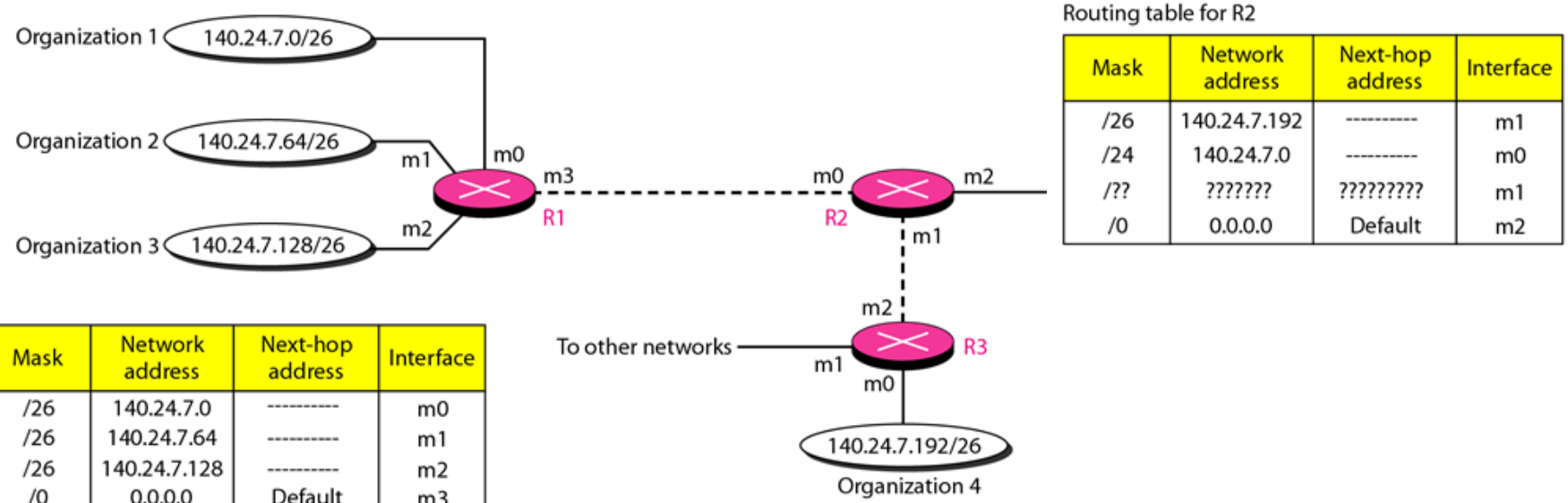
Example 4

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

Solution

This time all masks are applied, one by one, 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 someplace else in the Internet.

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	m2

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	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	m2

Routing table for R3

Example 5 example of hierarchical routing

A regional ISP is granted 16,384 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.

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, each using four addresses.

Example 22.5 (continued)

The second local ISP has divided its block into 4 blocks and has assigned the addresses to four large organizations.

The third local ISP has divided its block into 16 blocks and assigned each block to a small organization. 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.

Hierarchical routing with ISPs