Chapter 22

Network Layer: Delivery, Forwarding, and Routing

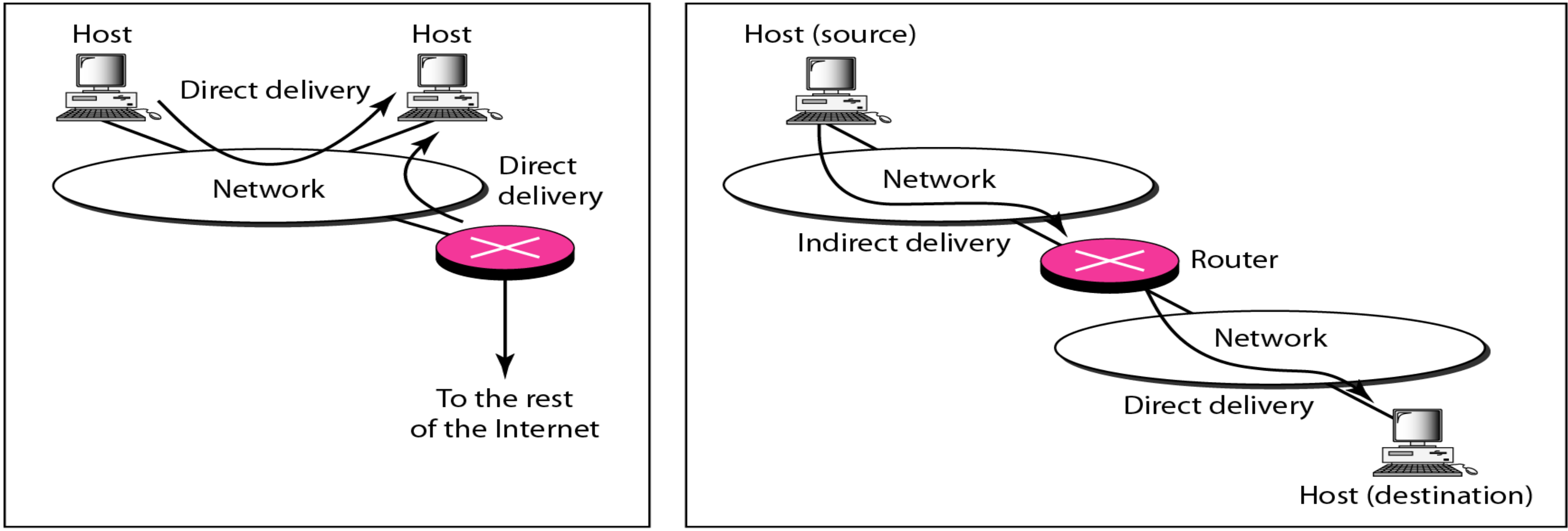
22-1 DELIVERY

The network layer supervises the handling of the packets by the underlying physical networks. We define this handling as the delivery of a packet.

Topics discussed in this section:

Direct Versus Indirect Delivery

Figure 22.1 *Direct and indirect delivery*



a. Direct delivery

b. Indirect and direct delivery

22-2 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. 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.

Topics discussed in this section:

Forwarding Techniques
Forwarding Process
Routing Table

Figure 22.2 *Route method versus next-hop method*

a. Routing tables based on route

b. Routing tables based on next hop

Routing table for host A

Destination	Route
Host B	R1, R2, host B

Destination	Next hop
Host B	R1

Routing table for R1

Destination	Route
Host B	R2, host B

Destination	Next hop
Host B	R2

Routing table for R2

Destination	Route
Host B	Host B

Destination	Next hop
Host B	---

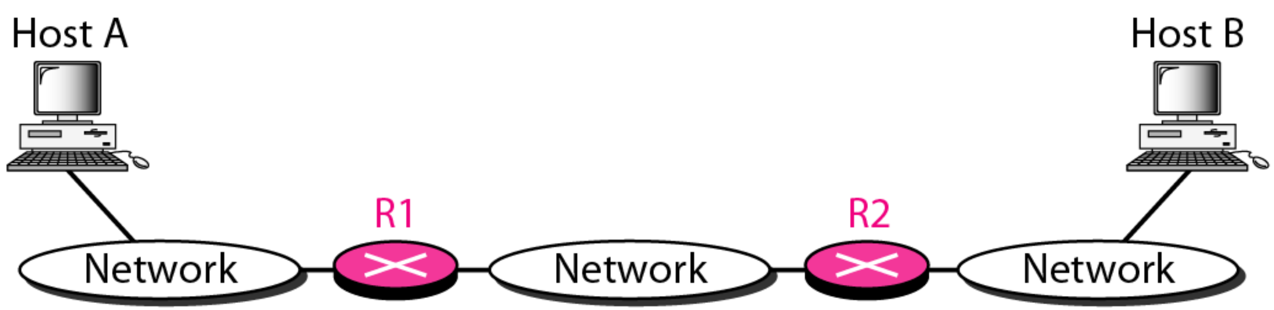


Figure 22.3 *Host-specific versus network-specific method*

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

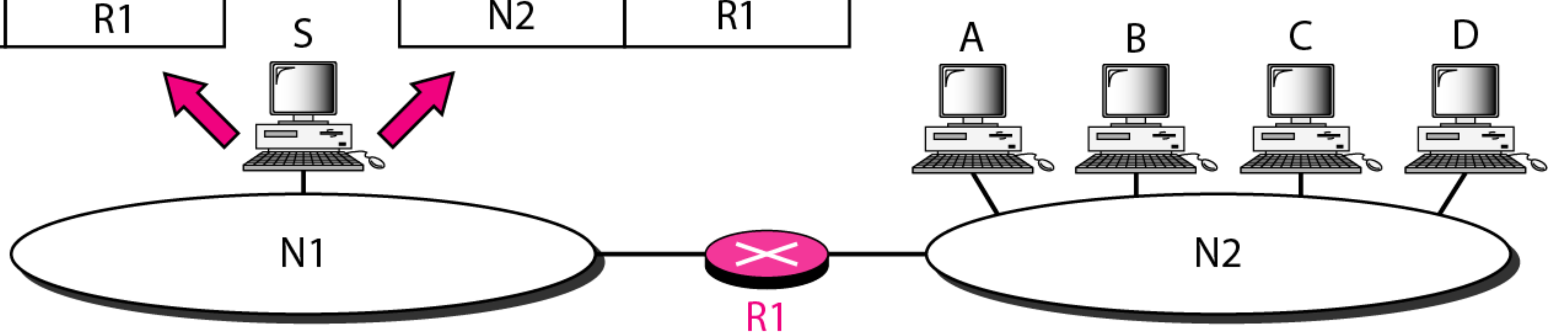


Figure 22.4 *Default method*

Destination	Next hop
N2	R1
Any other	R2

Routing table for host A

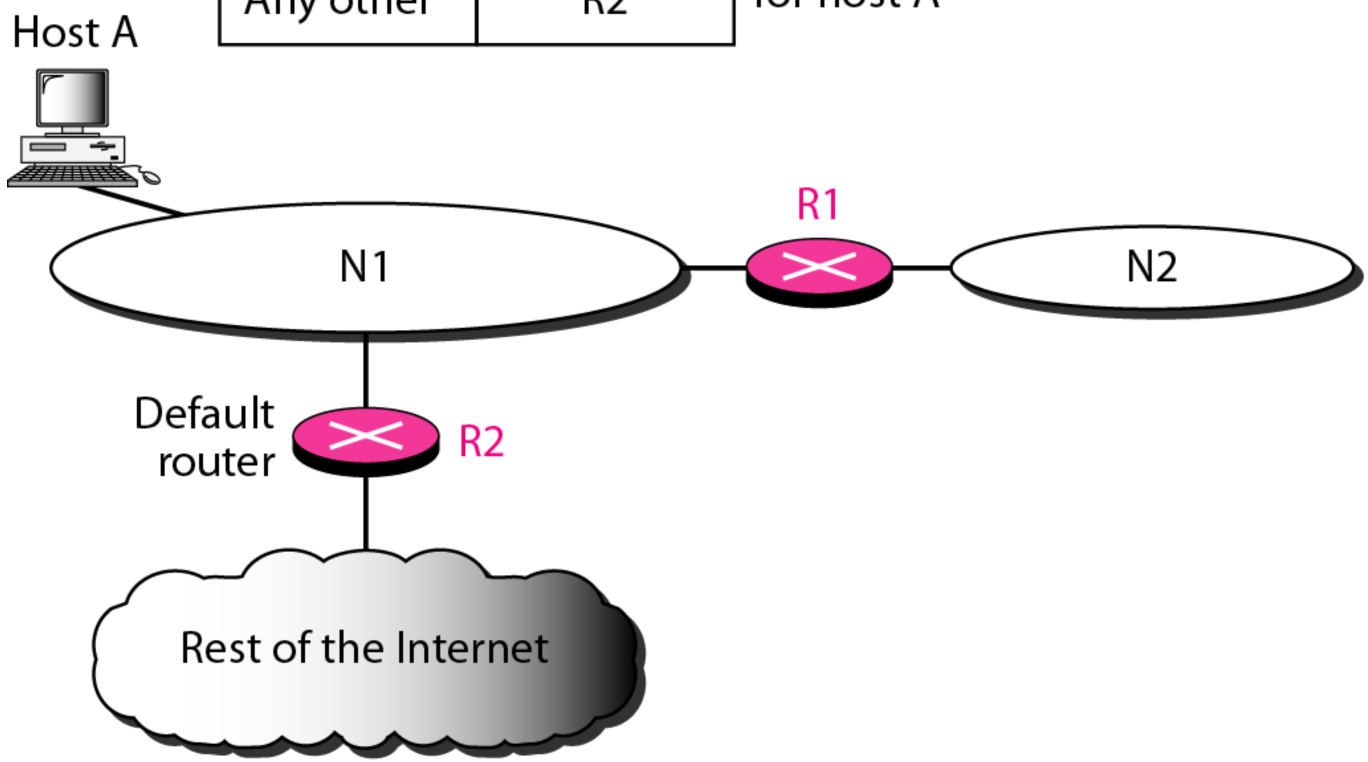
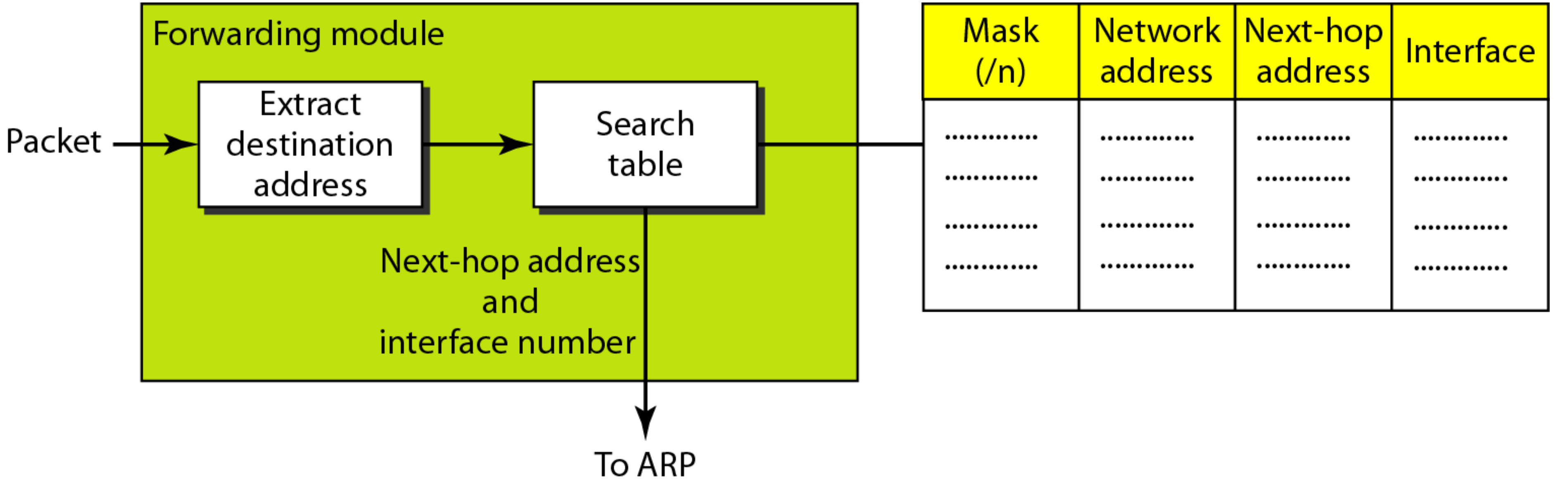


Figure 22.5 *Simplified forwarding module in classless address*



Note

In classless addressing, we need at least four columns in a routing table.

Example 22.1

Make a routing table for router R1, using the configuration in Figure 22.6.

Solution

Table 22.1 shows the corresponding table.

Figure 22.6 *Configuration for Example 22.1*

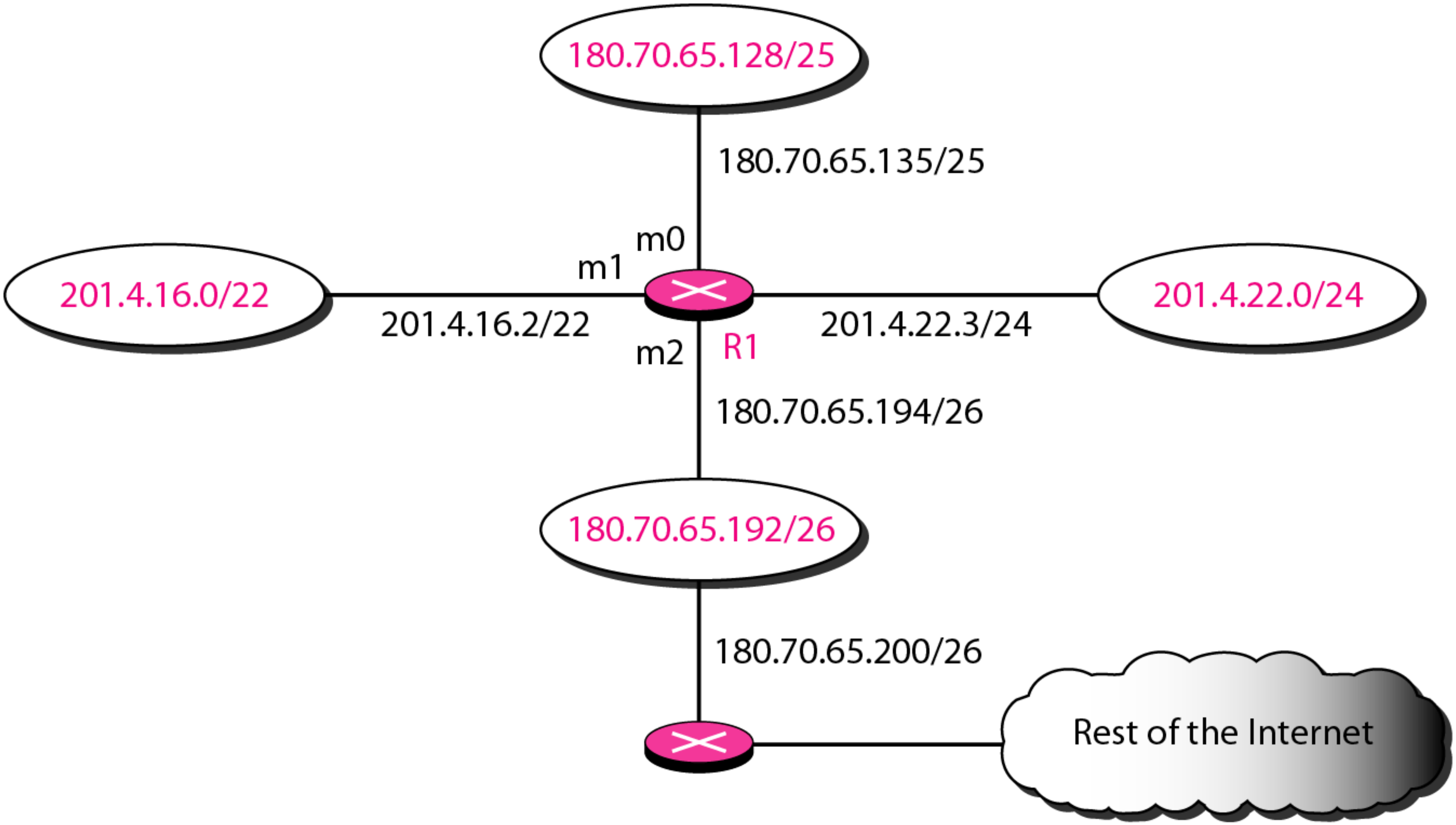


Table 22.1 ***Routing table for router R1 in Figure 22.6***

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
Any	Any	180.70.65.200	m2

Example 22.2

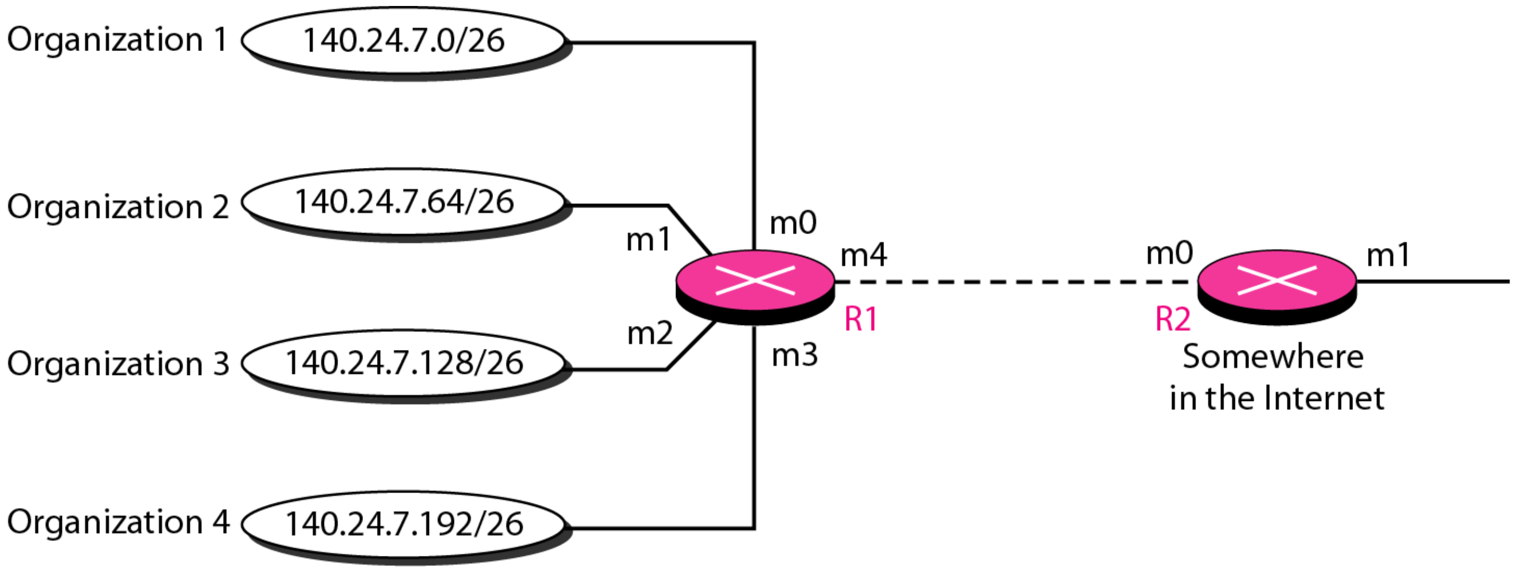
Show the forwarding process if a packet arrives at R1 in Figure 22.6 with the destination address 180.70.65.140.

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.*

Figure 22.7 *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	m4

Routing table for R1

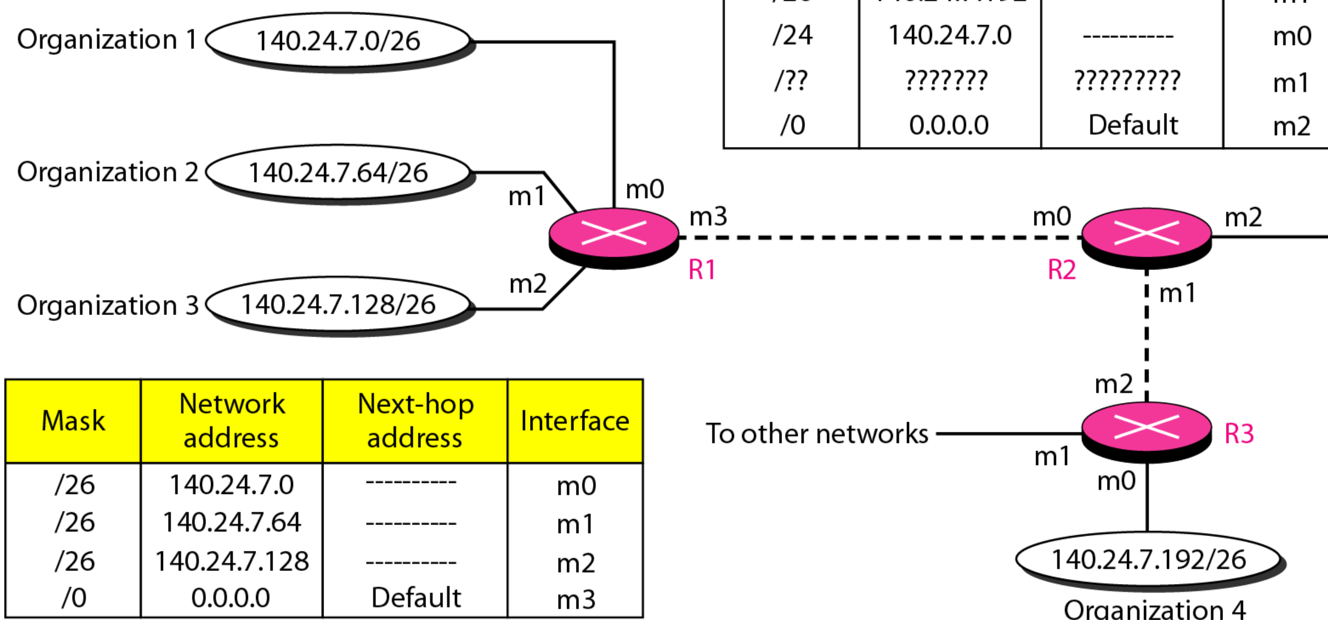
Mask	Network address	Next-hop address	Interface
/24	140.24.7.0	----------	m0
/0	0.0.0.0	Default	m1

Routing table for R2

Figure 22.8 *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

Figure 22.10 *Common fields in a routing table*

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

Example 22.6

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 next slide shows the list of the contents of a 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.

Example 22.6 (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

The destination column here defines the network address. The term gateway used by UNIX is synonymous with router. This column actually defines the address of the next hop. The value 0.0.0.0 shows that the delivery is direct. The last entry has a flag of G, which means that the destination can be reached through a router (default router). The Iface defines the interface.

Example 22.6 (continued)

More information about the IP address and physical address of the server can be found by 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
. . .
```

22-3 UNICAST ROUTING PROTOCOLS

A routing table can be either static or dynamic. A static table is one with manual entries. A dynamic table is one that is updated automatically when there is a change somewhere in the Internet. A routing protocol is a combination of rules and procedures that lets routers in the Internet inform each other of changes.

Topics discussed in this section:

Optimization
Intra- and Interdomain Routing
Distance Vector Routing and RIP
Link State Routing and OSPF
Path Vector Routing and BGP

Figure 22.12 *Autonomous systems: Intra domain, Interdomain*

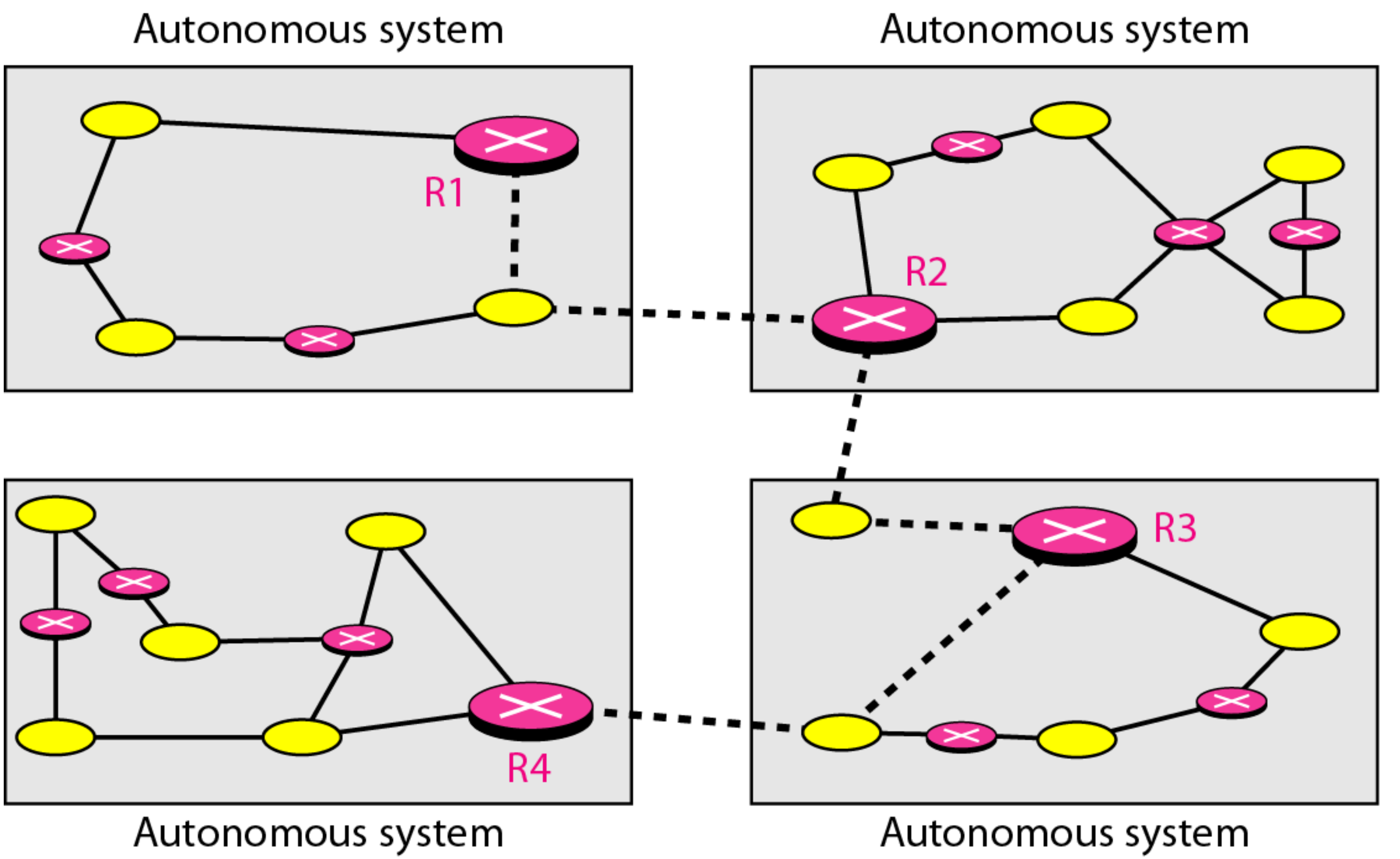
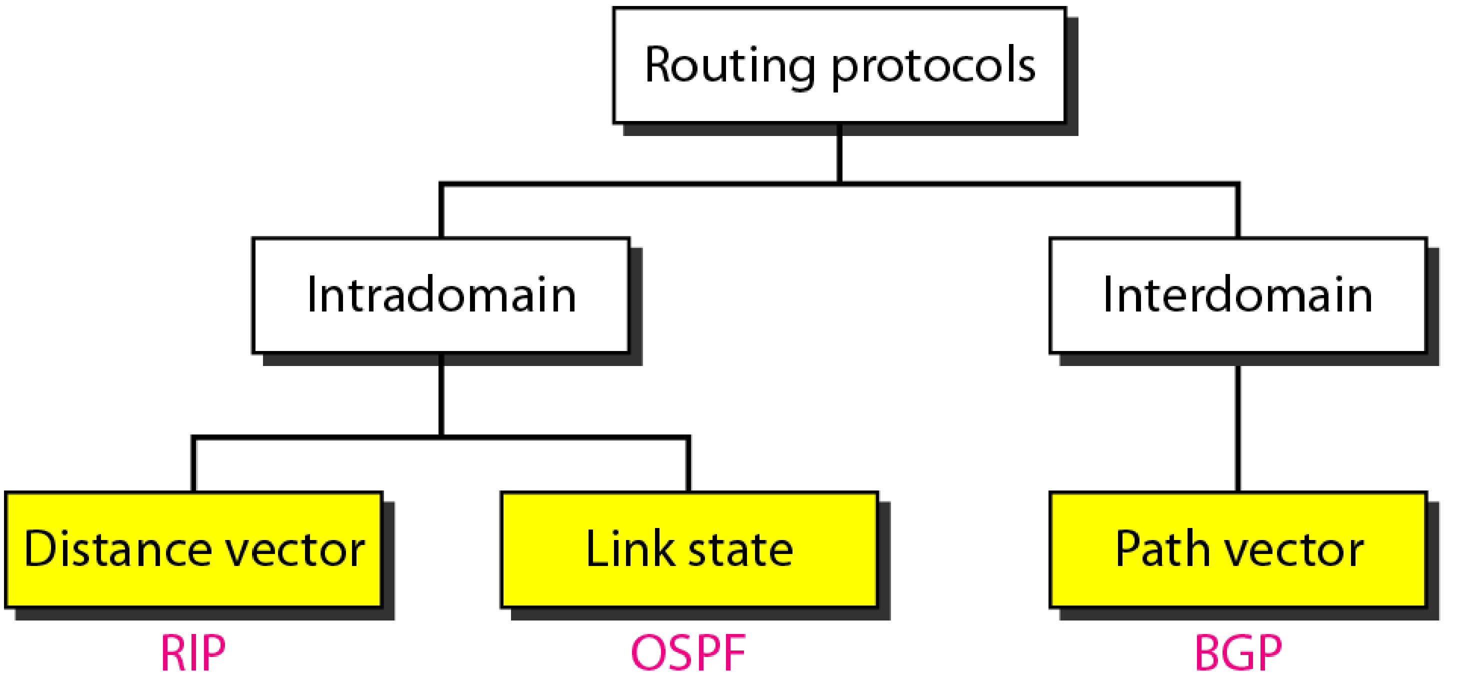


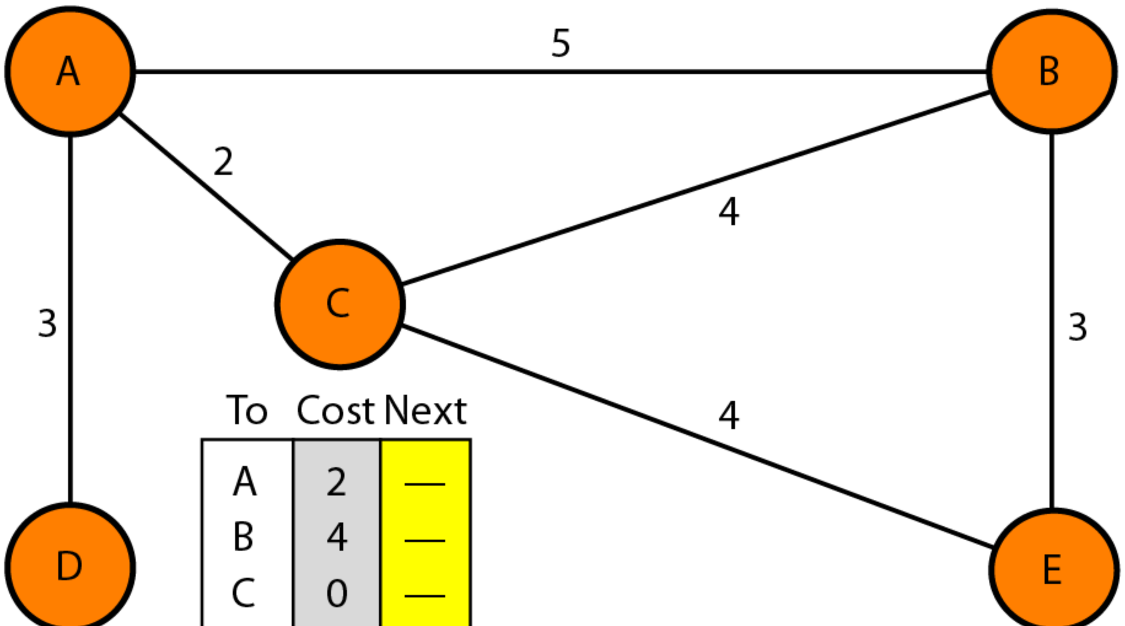
Figure 22.13 *Popular routing protocols*



Distance vector routing

- The least cost route between any two nodes is the route with minimum distance.
- Each node maintains a vector (table) of minimum distances to every node.
- It also shows next hop in the route.

Figure 22.14 *Distance vector routing tables*



A's table

To	Cost	Next
A	0	—
B	5	—
C	2	—
D	3	—
E	6	C

B's table

To	Cost	Next
A	5	—
B	0	—
C	4	—
D	8	A
E	3	—

C's table

To	Cost	Next
A	2	—
B	4	—
C	0	—
D	5	A
E	4	—

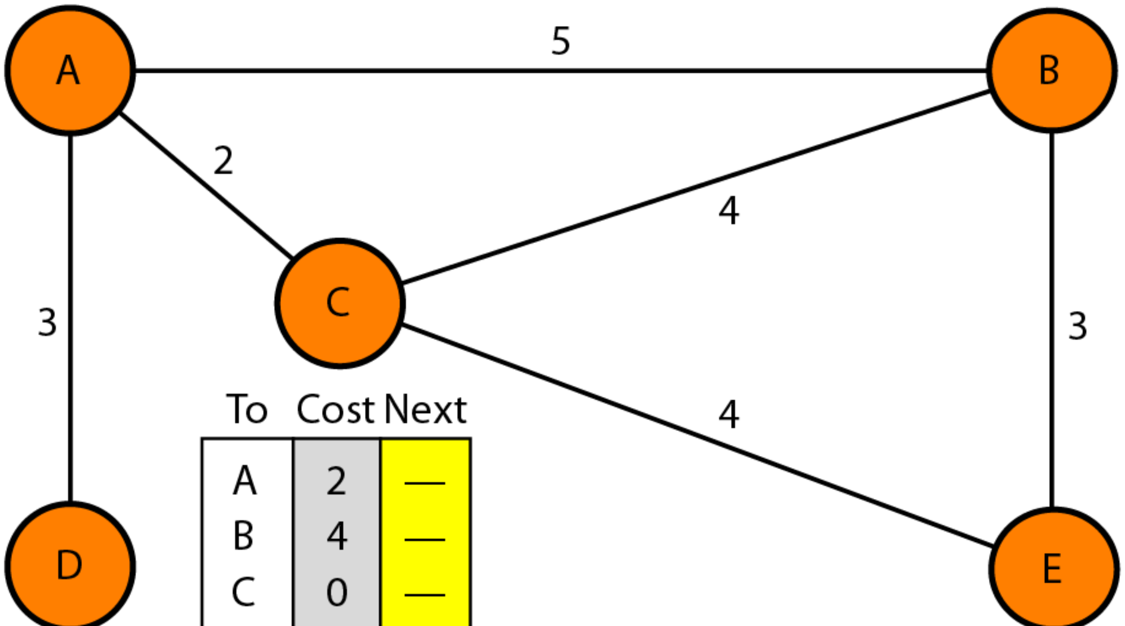
D's table

To	Cost	Next
A	3	—
B	8	A
C	5	A
D	0	—
E	9	A

E's table

To	Cost	Next
A	6	C
B	3	—
C	4	—
D	9	C
E	0	—

Figure 22.15 *Initialization of tables in distance vector routing*



To	Cost	Next
A	0	—
B	5	—
C	2	—
D	3	—
E	∞	

A's table

To	Cost	Next
A	5	—
B	0	—
C	4	—
D	∞	
E	3	—

B's table

To	Cost	Next
A	2	—
B	4	—
C	0	—
D	∞	
E	4	—

C's table

To	Cost	Next
A	3	—
B	∞	
C	∞	
D	0	—
E	∞	

D's table

To	Cost	Next
A	∞	
B	3	B
C	4	C
D	∞	
E	0	D

E's table

Note

In distance vector routing, each node shares its routing table with its immediate neighbors periodically and when there is a change.

Figure 22.16 *Updating in distance vector routing*

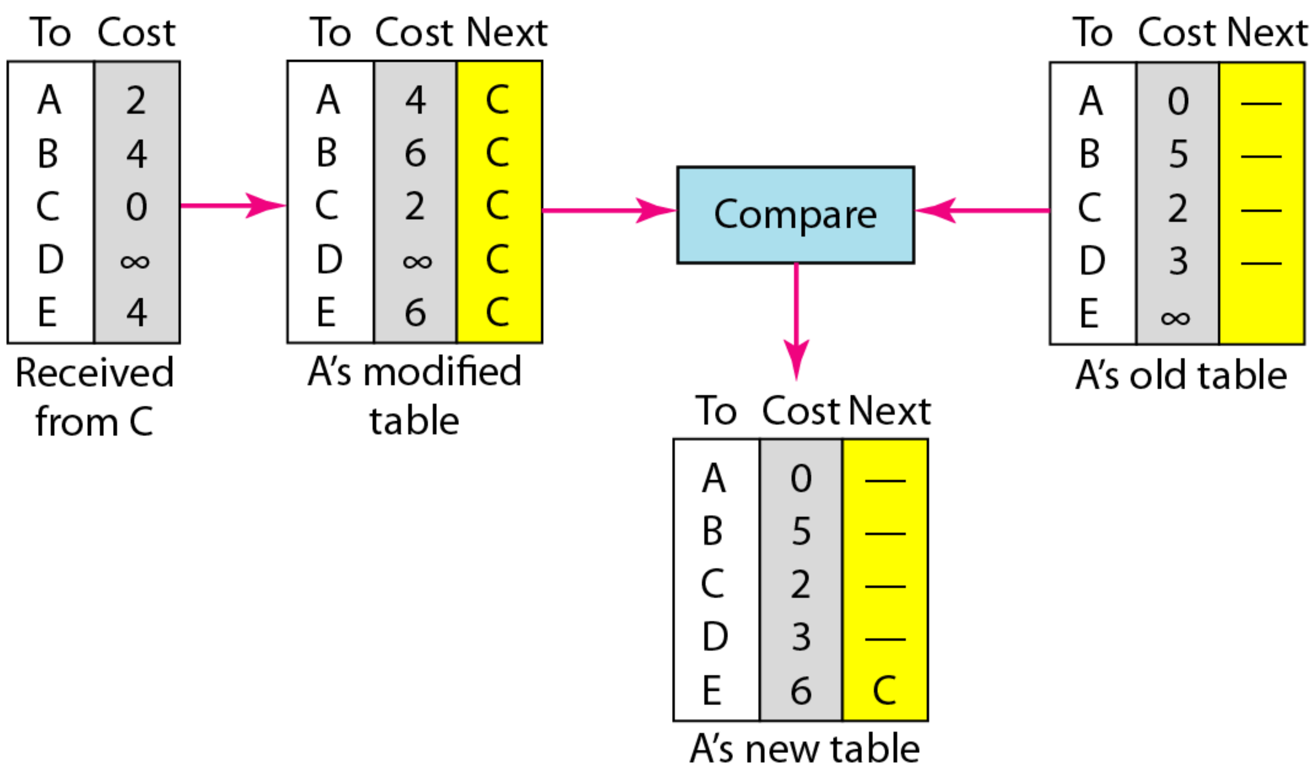


Figure 22.17 *Two-node instability*

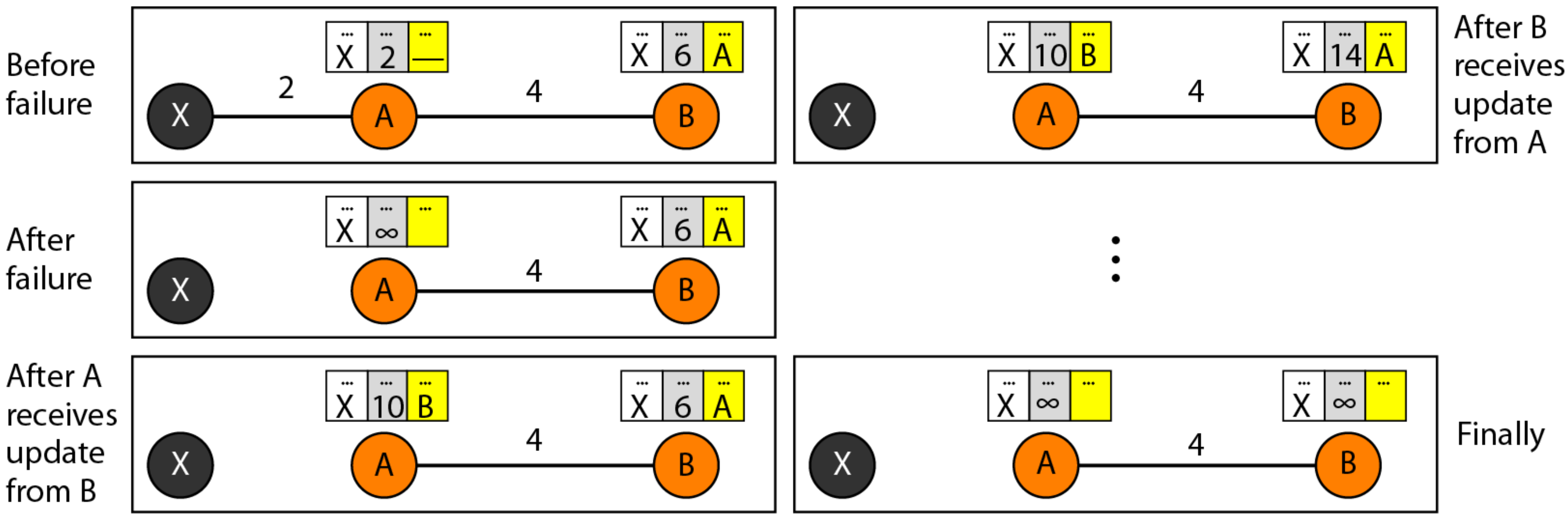
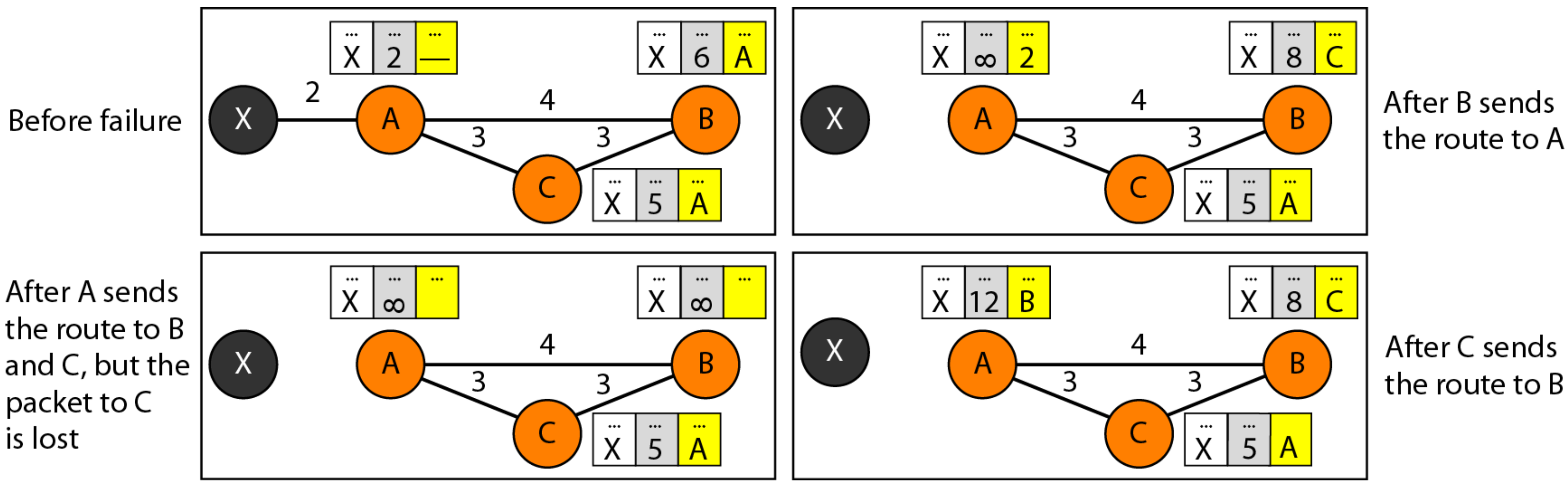


Figure 22.18 *Three-node instability*



Count to infinity problem

- **Define infinity:** **Infinity is defined as 16.**

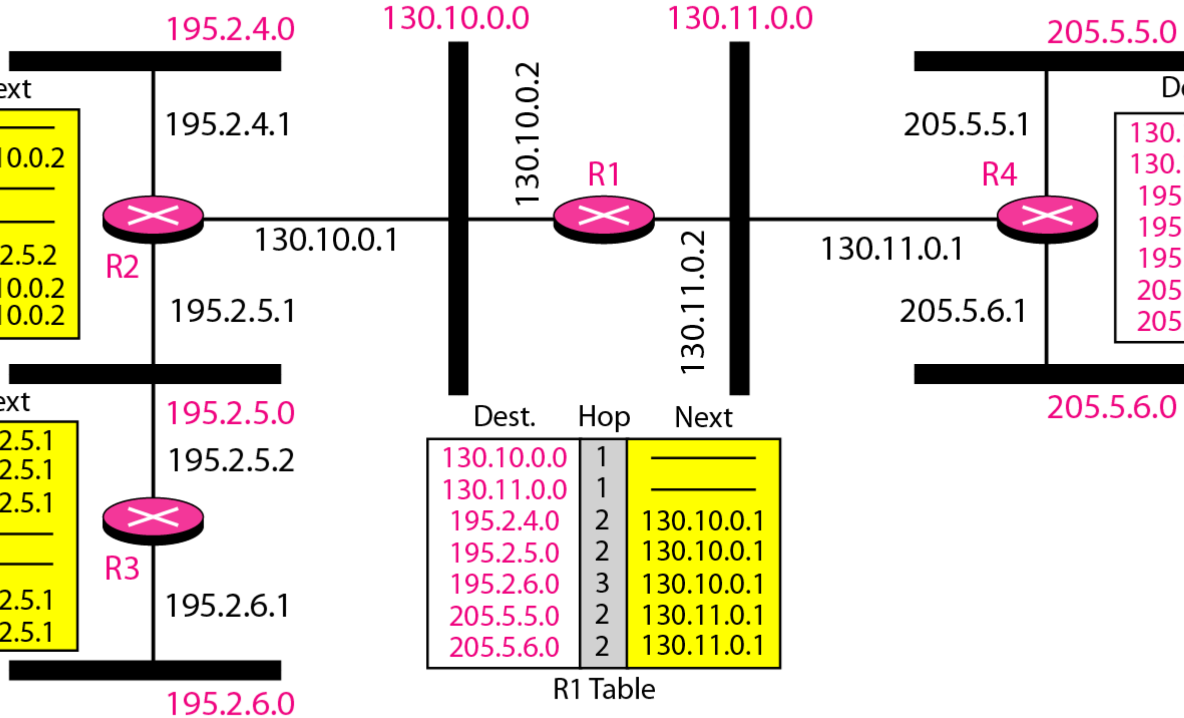
- **Split horizon:** **Advertise information only to those which are not the source or via route. Example: B does not sends detail about X to A.**

- **Split horizon and poison reverse:** **If split horizon is used and if the details of the node is not present , the receiver deletes the entry. To avoid**

RIP: Routing Information Protocol

- **Routing protocol based on distance vector.**
- **Its intra domain routing protocol.**
- **The routing table contains network address and number of hops as link weight.**
- **The infinity is defined as 16.**
- **The next hop is address of router to forward the packet.**

Figure 22.19 *Example of a domain using RIP*



Dest.	Hop	Next
130.10.0.0	1	———
130.11.0.0	2	130.10.0.2
195.2.4.0	1	———
195.2.5.0	1	———
195.2.6.0	2	195.2.5.2
205.5.5.0	3	130.10.0.2
205.5.6.0	3	130.10.0.2

R2 Table

Dest.	Hop	Next
130.10.0.0	2	195.2.5.1
130.11.0.0	3	195.2.5.1
195.2.4.0	2	195.2.5.1
195.2.5.0	1	———
195.2.6.0	1	———
205.5.5.0	4	195.2.5.1
205.5.6.0	4	195.2.5.1

R3 Table

Dest.	Hop	Next
130.10.0.0	1	———
130.11.0.0	1	———
195.2.4.0	2	130.10.0.1
195.2.5.0	2	130.10.0.1
195.2.6.0	3	130.10.0.1
205.5.5.0	2	130.11.0.1
205.5.6.0	2	130.11.0.1

R1 Table

Dest.	Hop	Next
130.10.0.0	2	130.11.0.2
130.11.0.0	1	———
195.2.4.0	3	130.11.0.2
195.2.5.0	3	130.11.0.2
195.2.6.0	4	130.11.0.2
205.5.5.0	1	———
205.5.6.0	1	———

R4 Table

Link state routing

- Each node in domain has entire topology.
- Each node routing can use its own strategy to find the routing.
- It can use Dijkstra’s algorithm for computing routing.
- Actions in Link state Routing
  - Creation of Link State Packet
  - Dissemination of LSPs to other routers through flooding
  - Formation of shortest path
  - Calculation of routing table based on the shortest path tree.

Figure 22.20 *Concept of link state routing*

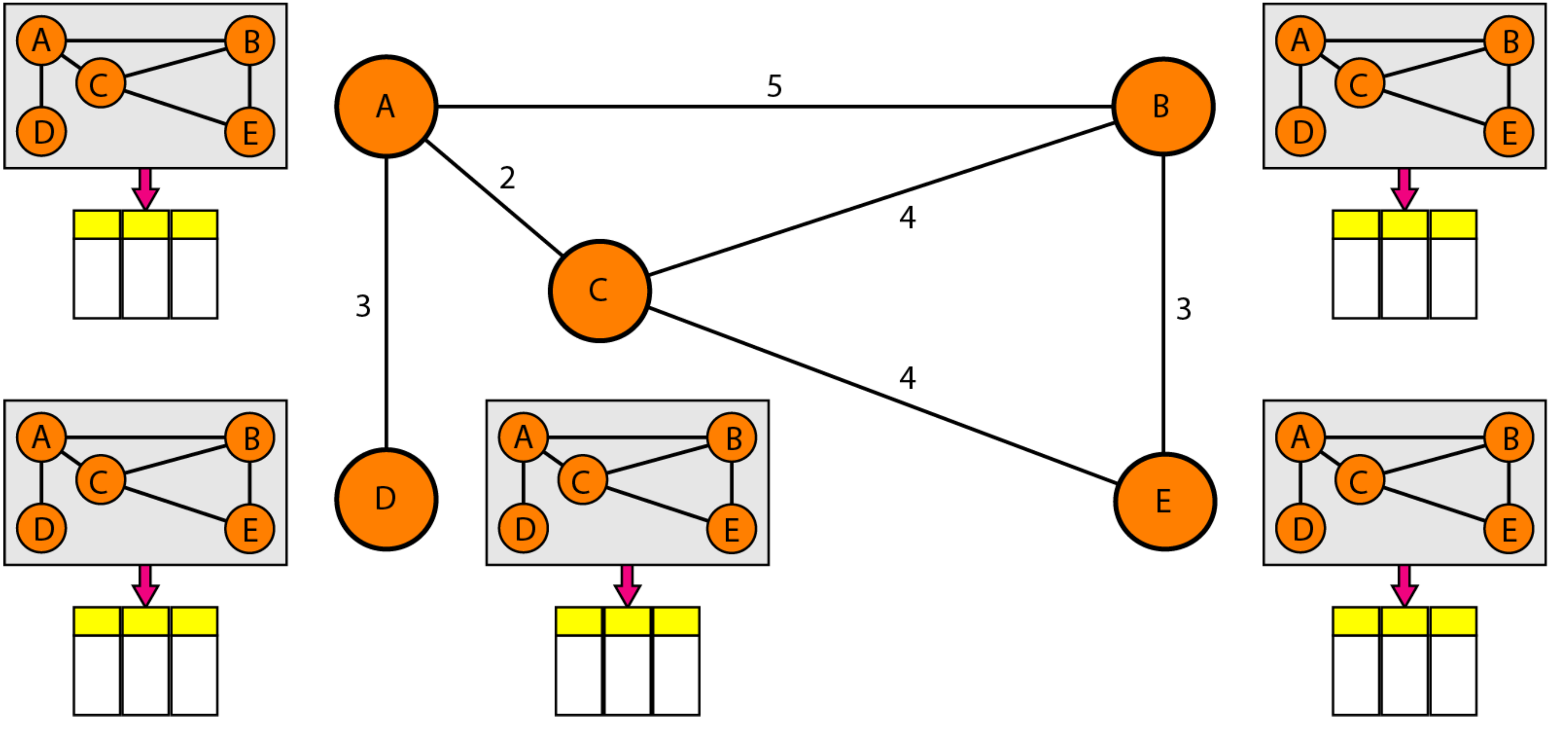


Figure 22.21 *Link state knowledge*

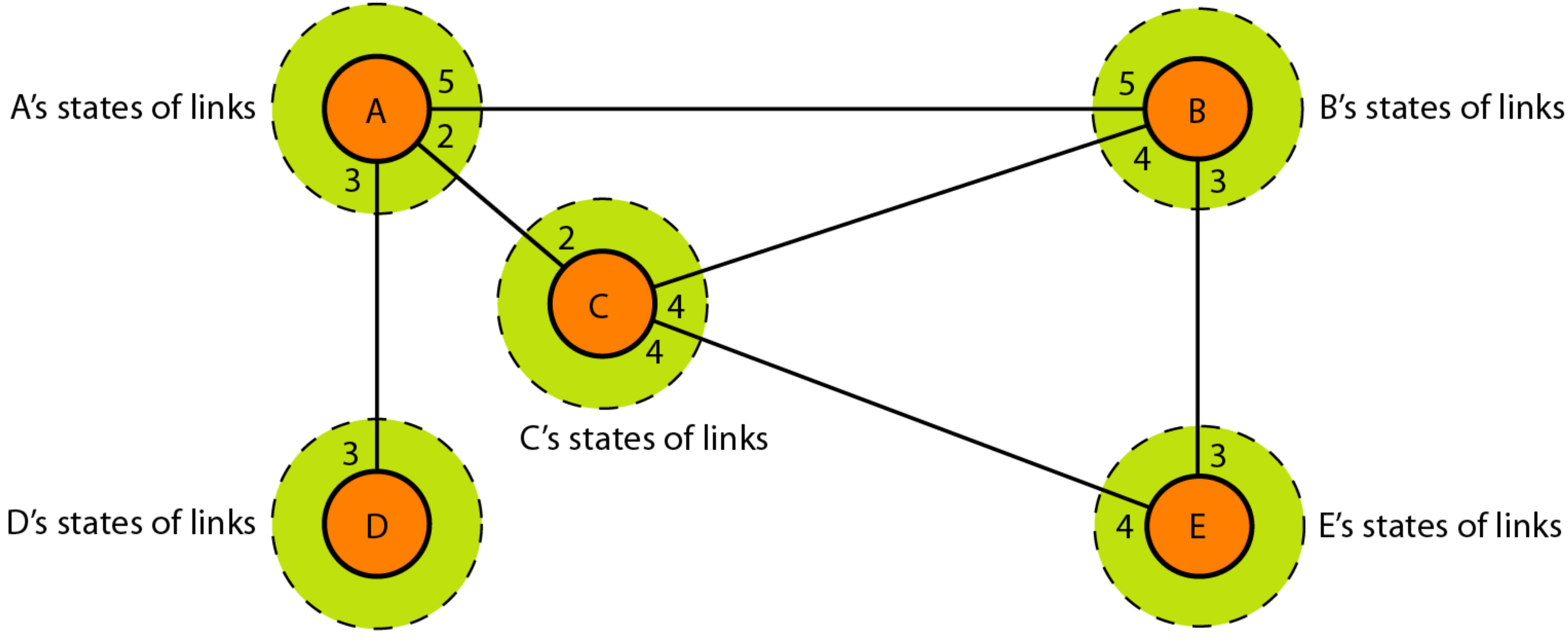


Figure 22.22 *Dijkstra algorithm*

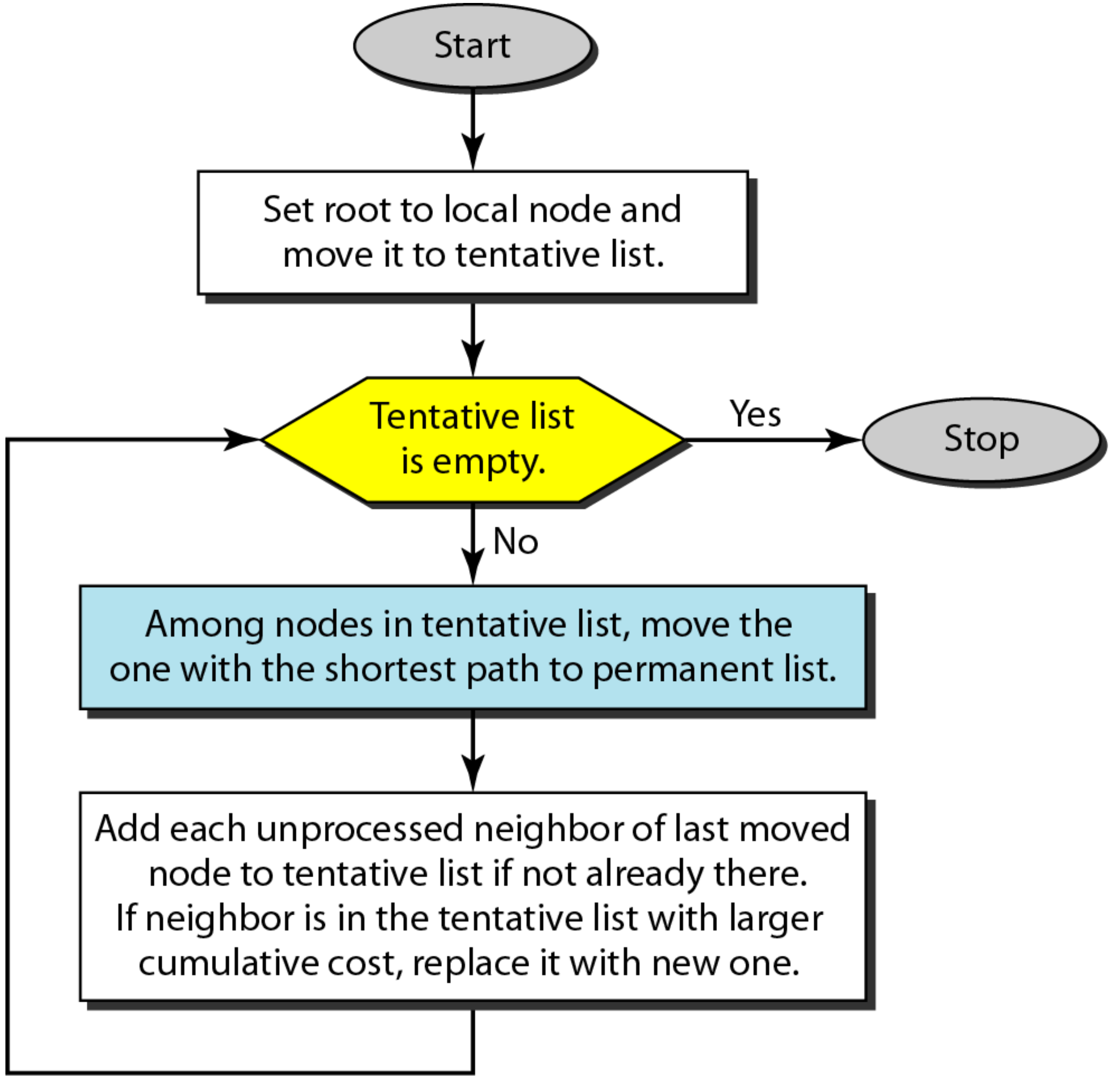
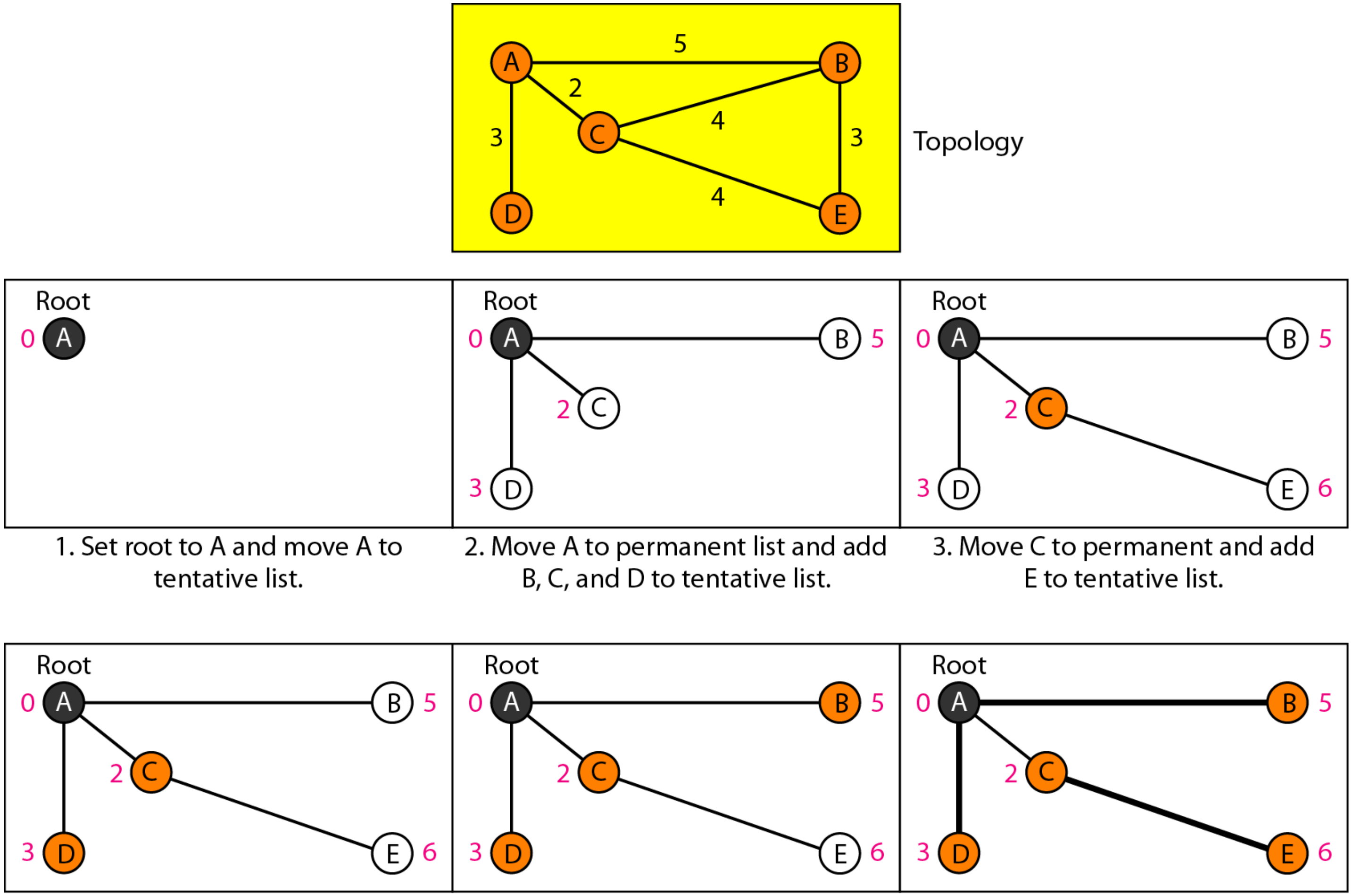


Figure 22.23 *Example of formation of shortest path tree*



1. Set root to A and move A to tentative list.

2. Move A to permanent list and add B, C, and D to tentative list.

3. Move C to permanent and add E to tentative list.

4. Move D to permanent list.

5. Move B to permanent list.

6. Move E to permanent list (tentative list is empty).

Table 22.2 ***Routing table for node A***

Node	*Cost*	*Next Router*
A	0	—
B	5	—
C	2	—
D	3	—
E	6	C

OSPF: Open Shortest Path First

- Intradomain routing protocol based on Link state algorithm
- OSPF divides an autonomous system into areas
- OSPF protocol allos the administrator to assign a cost, called metric to each route. (metric can be min delay, max throughput, ...etc)
- Different types of links are considered.

Figure 22.24 *Areas in an autonomous system*

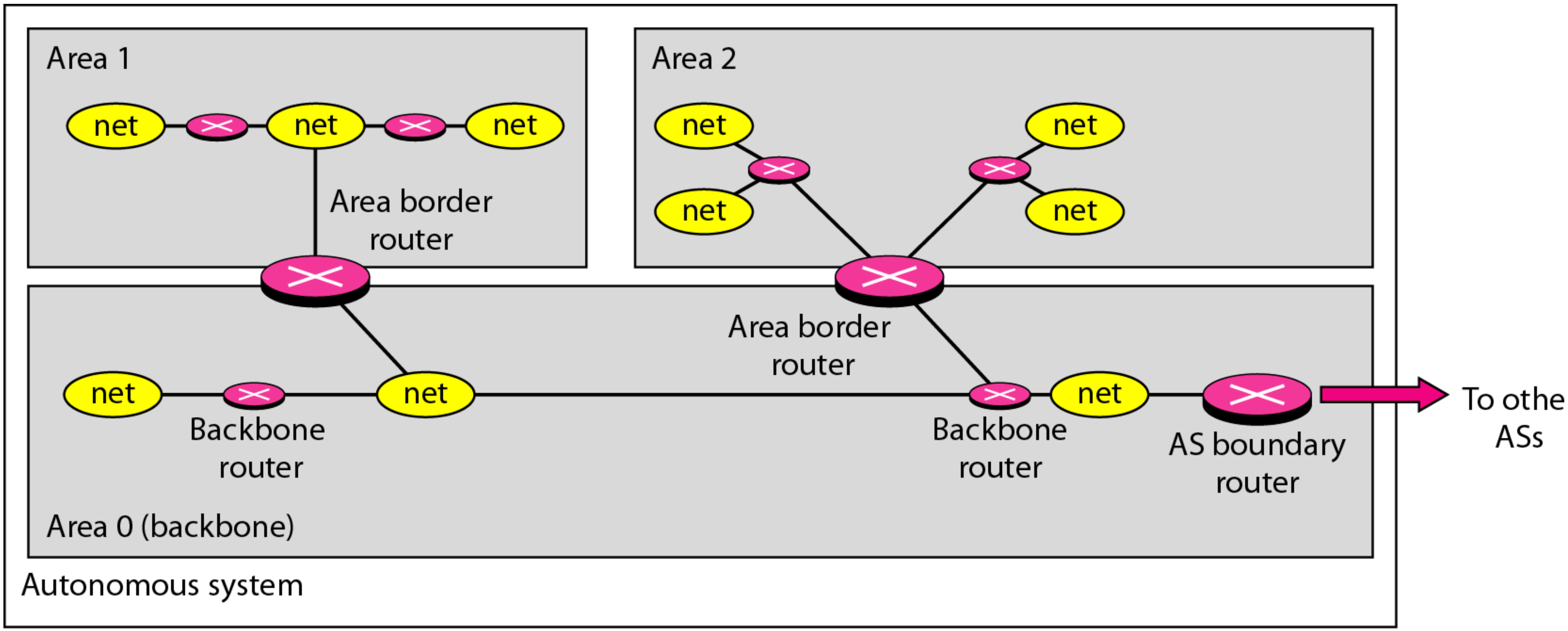


Figure 22.25 ***Types of links***

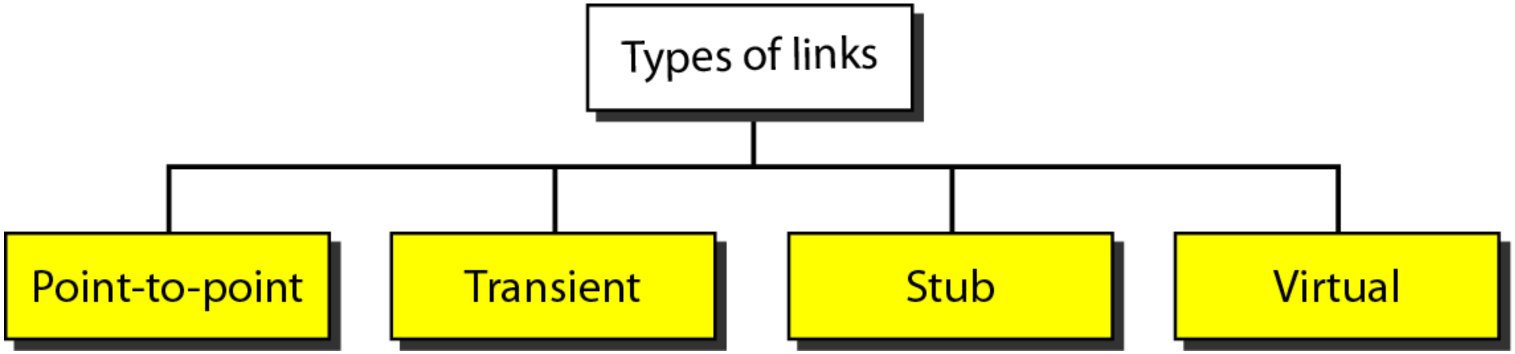


Figure 22.26 *Point-to-point link*

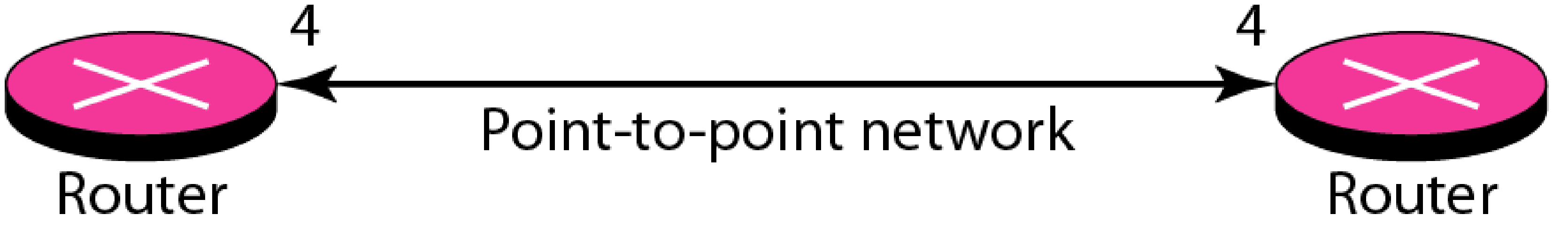


Figure 22.27 *Transient link*

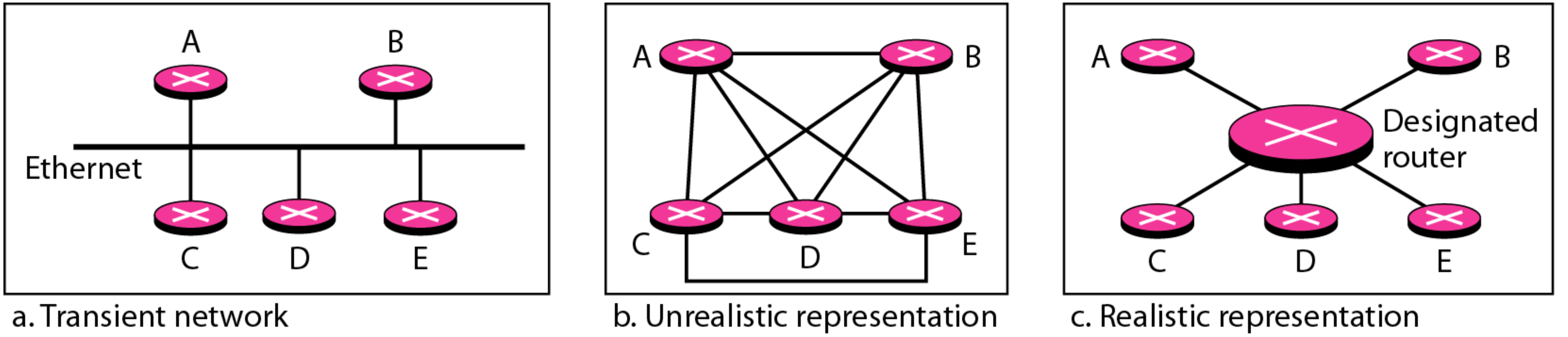


Figure 22.28 ***Stub link***

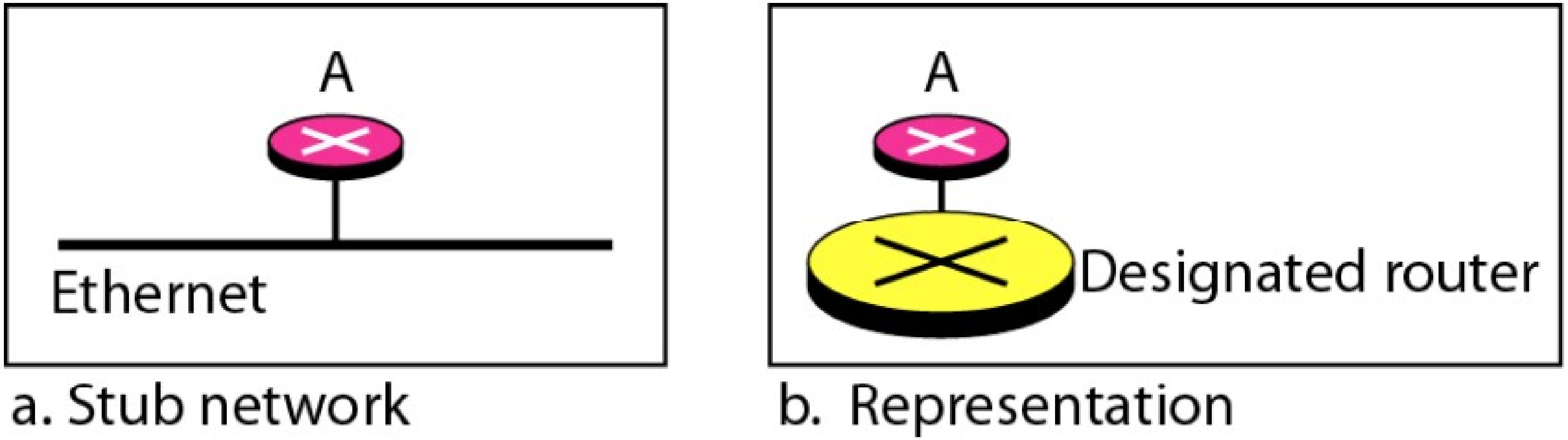
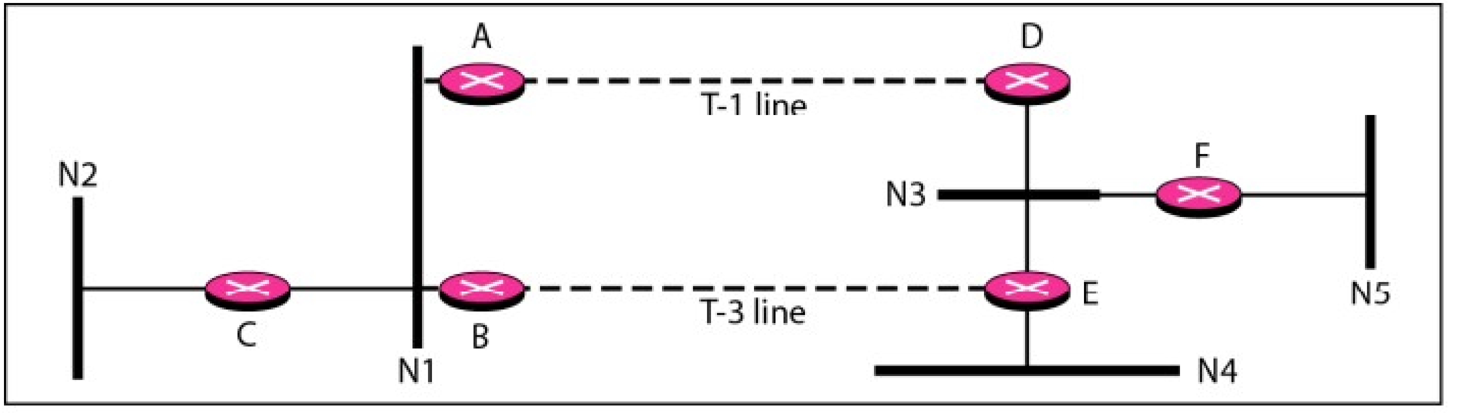
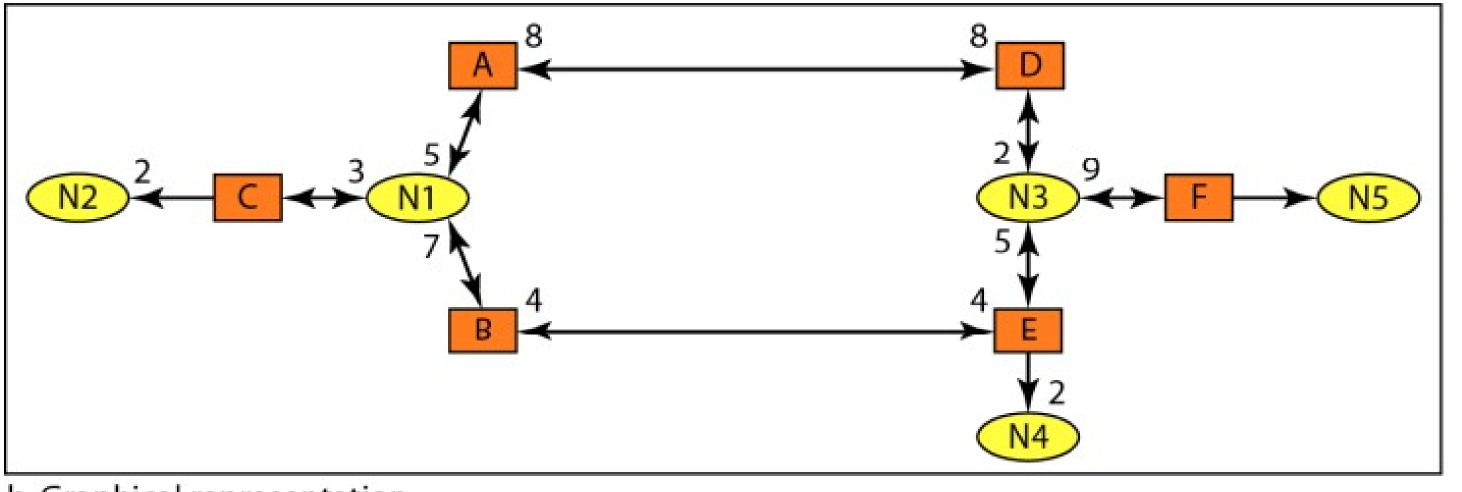


Figure 22.29 *Example of an AS and its graphical representation in OSPF*



a. Autonomous system



b. Graphical representation

Path Vector Routing

- Interdomain routing
- Similar to distance vector routing
- There is one node in each AS and creates routing table and advertises to entire AS. Its called speaker node.

Figure 22.30 *Initial routing tables in path vector routing*

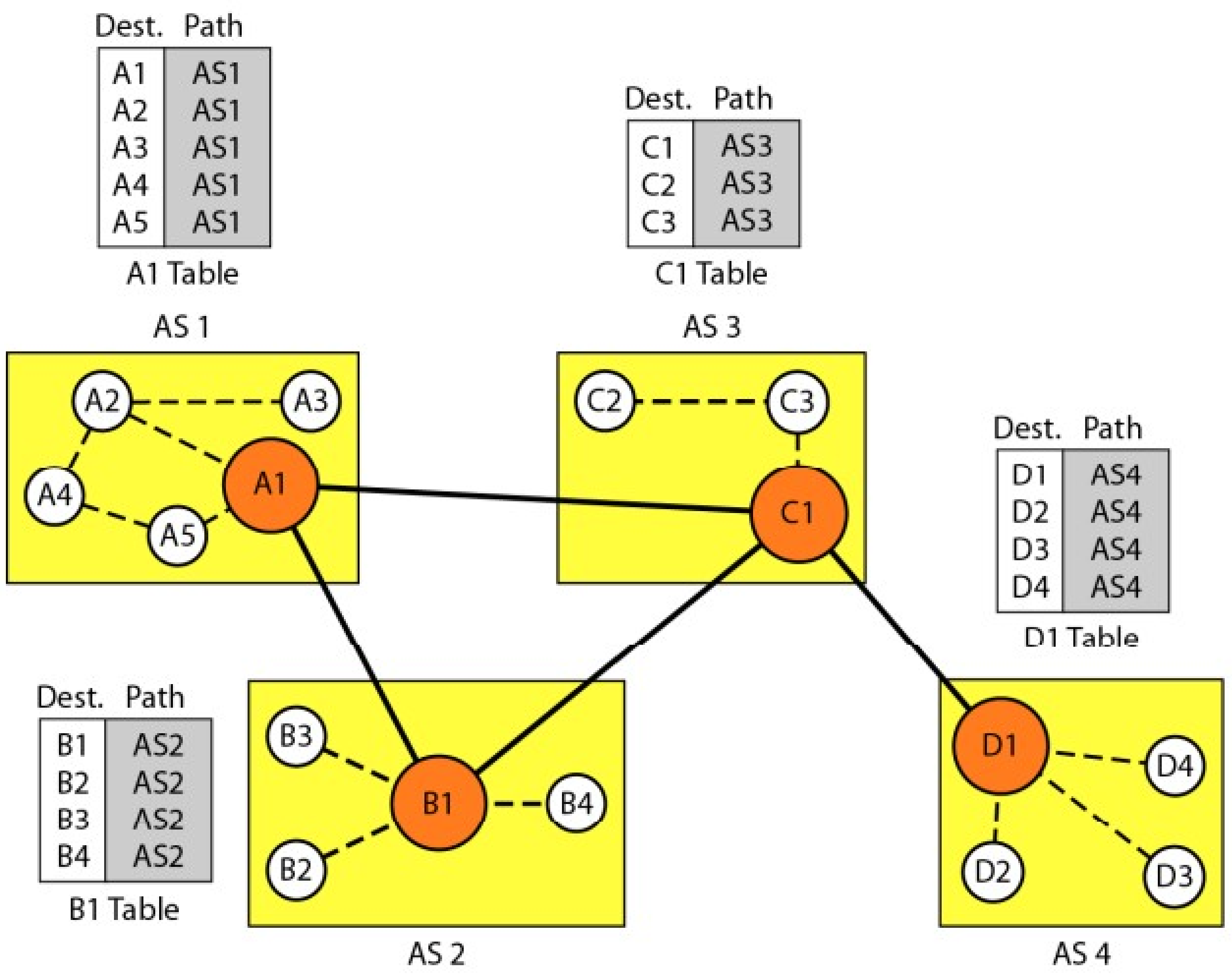


Figure 22.31 *Stabilized tables for three autonomous systems*

Dest.	Path
A1	AS1
…	
A5	AS1
B1	AS1-AS2
…	…
B4	AS1-AS2
C1	AS1-AS3
…	…
C3	AS1-AS3
D1	AS1-AS2-AS4
…	…
D4	AS1-AS2-AS4

A1 Table

Dest.	Path
A1	AS2-AS1
…	
A5	AS2-AS1
B1	AS2
…	…
B4	AS2
C1	AS2-AS3
…	…
C3	AS2-AS3
D1	AS2-AS3-AS4
…	…
D4	AS2-AS3-AS4

B1 Table

Dest.	Path
A1	AS3-AS1
…	
A5	AS3-AS1
B1	AS3-AS2
…	…
B4	AS3-AS2
C1	AS3
…	…
C3	AS3
D1	AS3-AS4
…	…
D4	AS3-AS4

C1 Table

Dest.	Path
A1	AS4-AS3-AS1
…	
A5	AS4-AS3-AS1
B1	AS4-AS3-AS2
…	…
B4	AS4-AS3-AS2
C1	AS4-AS3
…	…
C3	AS4-AS3
D1	AS4
…	…
D4	AS4

D1 Table

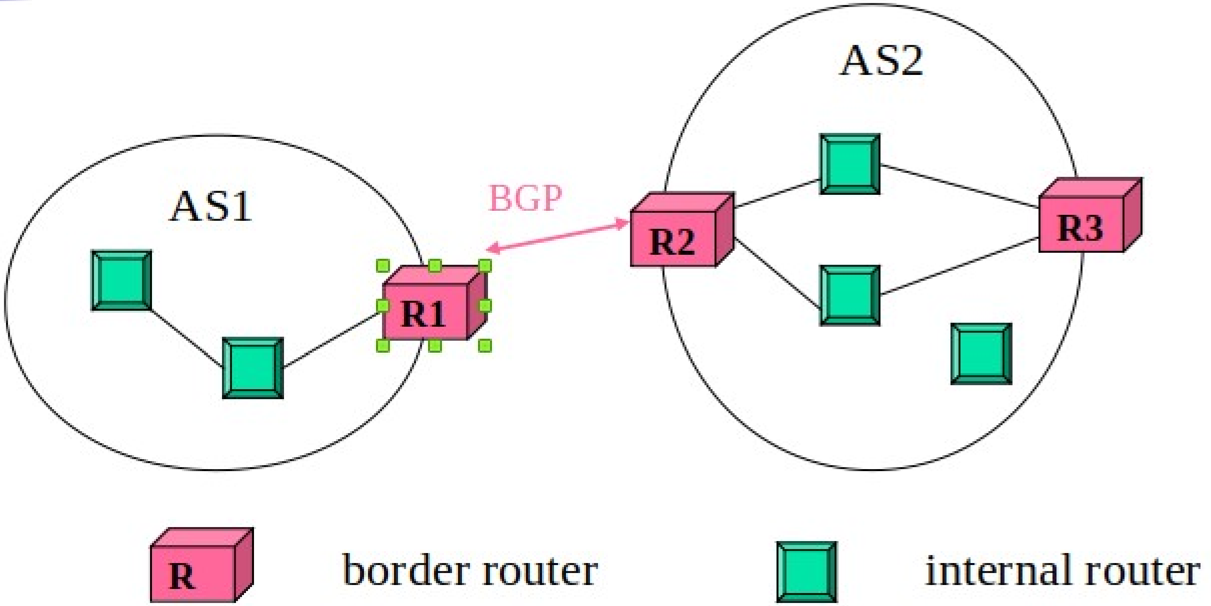
BGP : Border Gateway Protocol

- BGP is an inter domain routing protocol using path vector routing.
- Autonomous Systems are divided into three catgories : Stub, multihomed and transit
- Stub AS: Only one connection to other AS
- Multihome AS: More than one connection to other AS
- Transit AS: It is multihomed AS that allows transient traffic.

BGP : Border Gateway Protocol

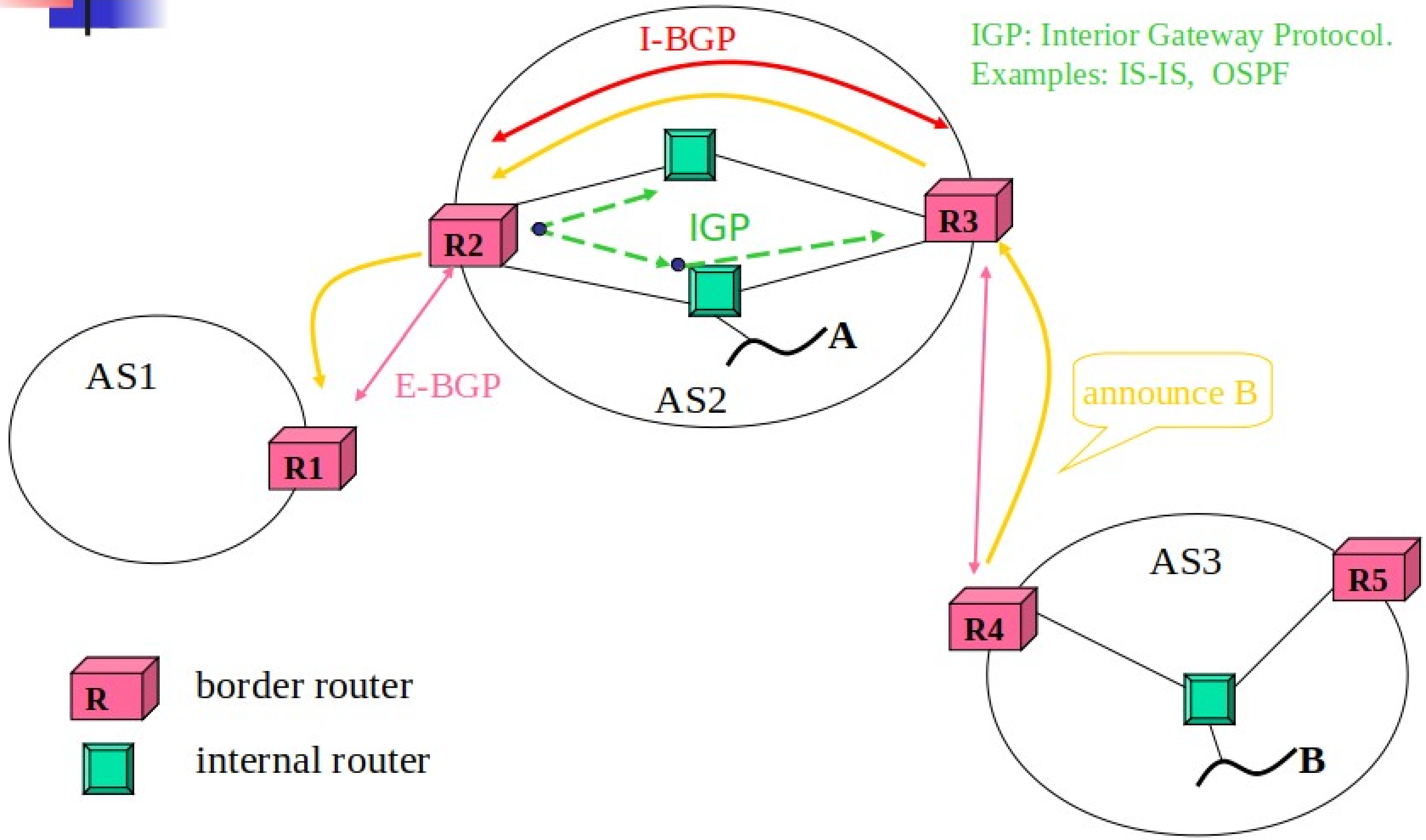
- BGP sessions: The exchange of routing information between two routers using BGP takes place in a session. Uses TCP for reliable communicaiton. TCP connection can last for long time.
- BGP can have two types of sessions: External BGP (E-BGP) and Internal BGP (I-BGP)

Who speaks BGP?



- Two types of routers
  - Border router(Edge), Internal router(Core)
- Two border routers of different ASes will have a BGP session

I-BGP and E-BGP



THANK YOU