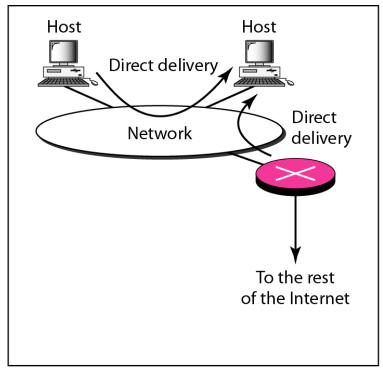
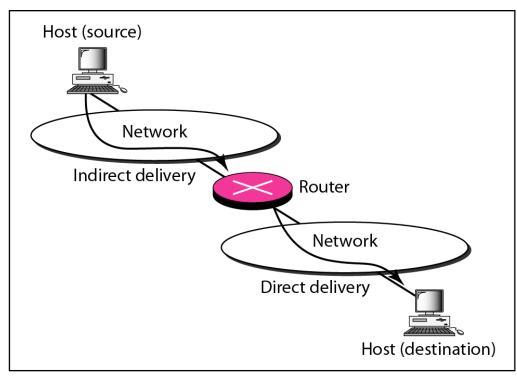
# Network Layer: Delivery, Forwarding, and Routing

#### 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.

#### Figure 22.1 Direct and indirect delivery





a. Direct delivery

b. Indirect and direct delivery

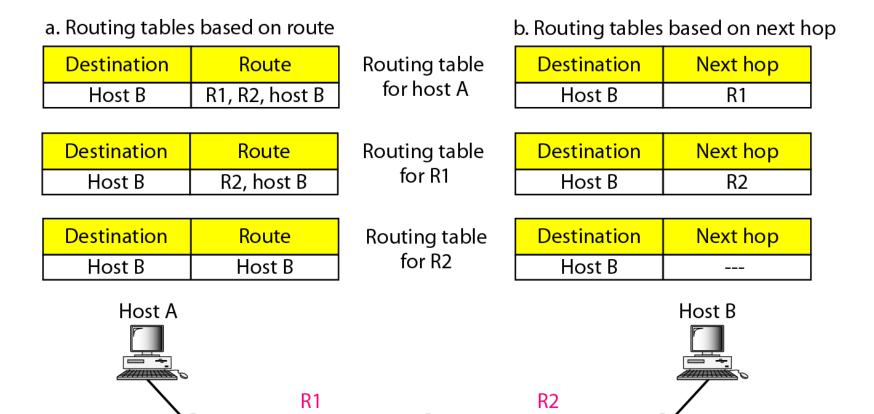
#### 22-2 FORWARDING

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.

Forwarding Techniques
Forwarding Process
Routing Table

#### Figure 22.2 Route method versus next-hop method

Network

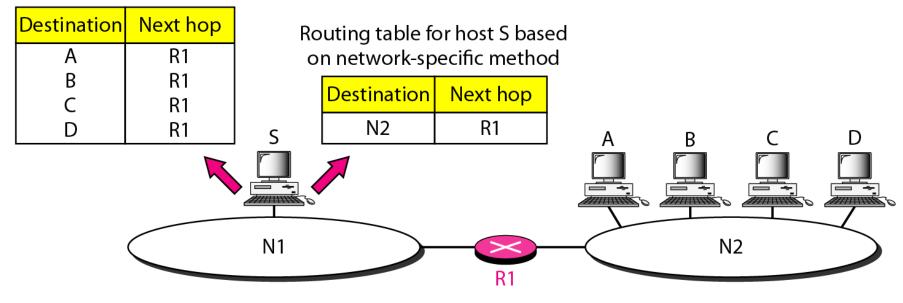


Network

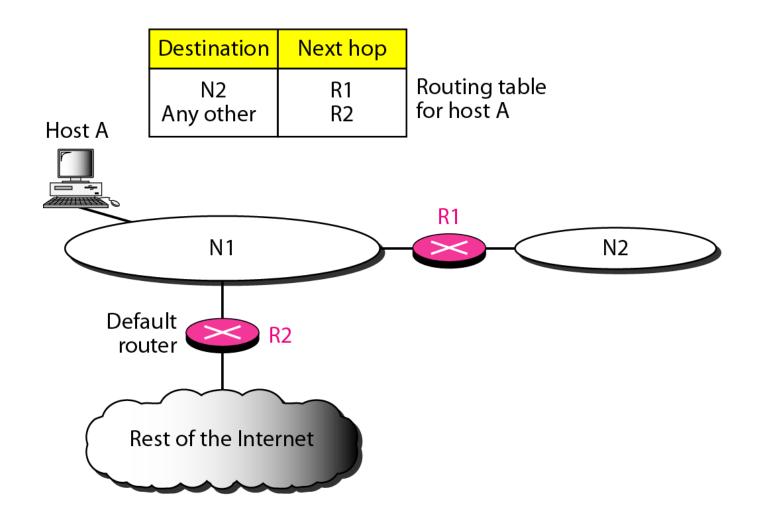
Network

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

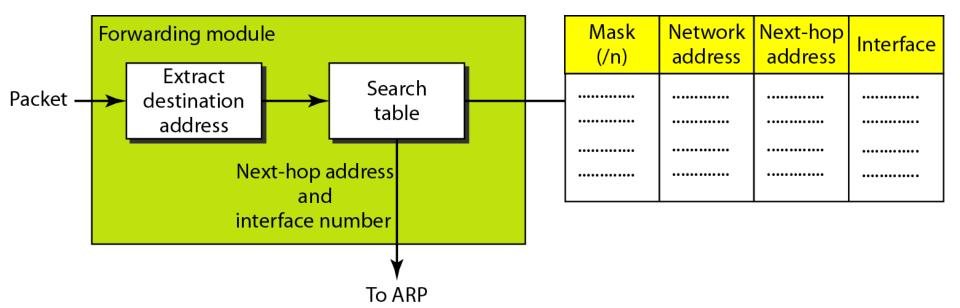
Routing table for host S based on host-specific method



#### Figure 22.4 Default method



#### **Figure 22.5** Simplified forwarding module in classless address



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

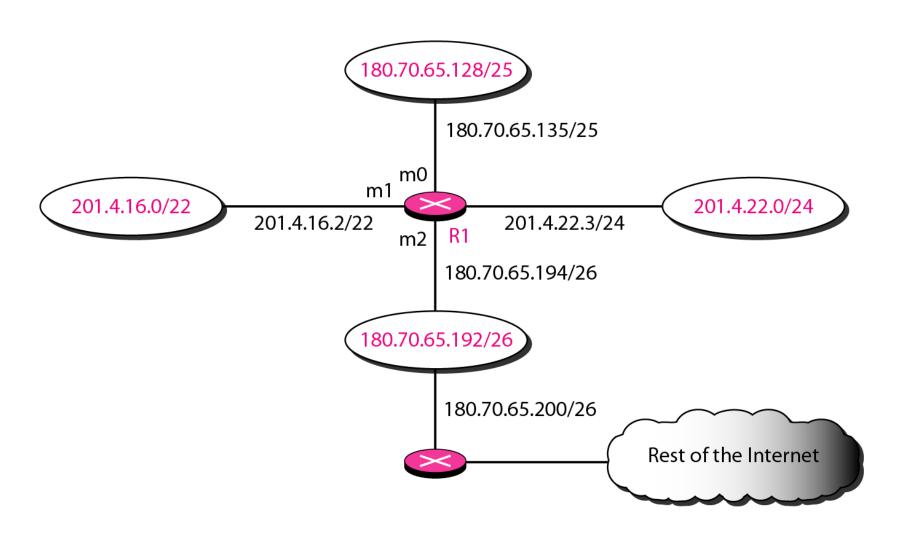
## Example 22.1

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.

Show the forwarding process if a packet arrives at R1 in Figure 22.6 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).

### Example 22.3 (continued)

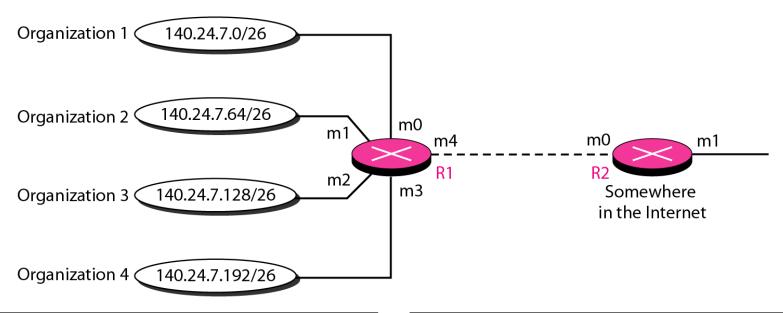
3. The third mask (/24) is applied to the destination address. The result is 201.4.22.0, which matches the corresponding network address. The destination address of the packet and the interface number m3 are passed to ARP.

Show the forwarding process if a packet arrives at R1 in Figure 22.6 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.

#### Figure 22.7 Address aggregation



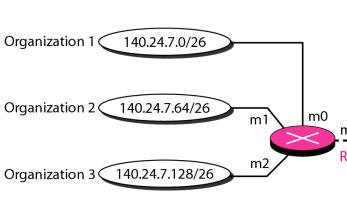
Mask	Network address	Next-hop address	Interface
/26	140.24.7.0		m0
/26	140.24.7.64		m1
/26	140.24.7.128		m2
/26	140.24.7.192		m3
/0	0.0.0.0	Default	m4

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

Routing table for R2

Routing table for R1

### Figure 22.8 Longest mask matching

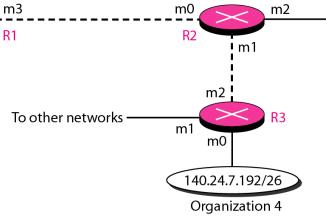


Mask	Network address	Next-hop address	Interface
/26	140.24.7.0		m0
/26	140.24.7.64		m1
/26	140.24.7.128		m2
/0	0.0.0.0	Default	m3

Routing table for R1

#### 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	140.24.7.192		m0
/??	???????	????????	m1
/0	0.0.0.0	Default	m2

Routing table for R3

## Example 22.5

As an example of hierarchical routing, let us consider Figure 22.9. 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.

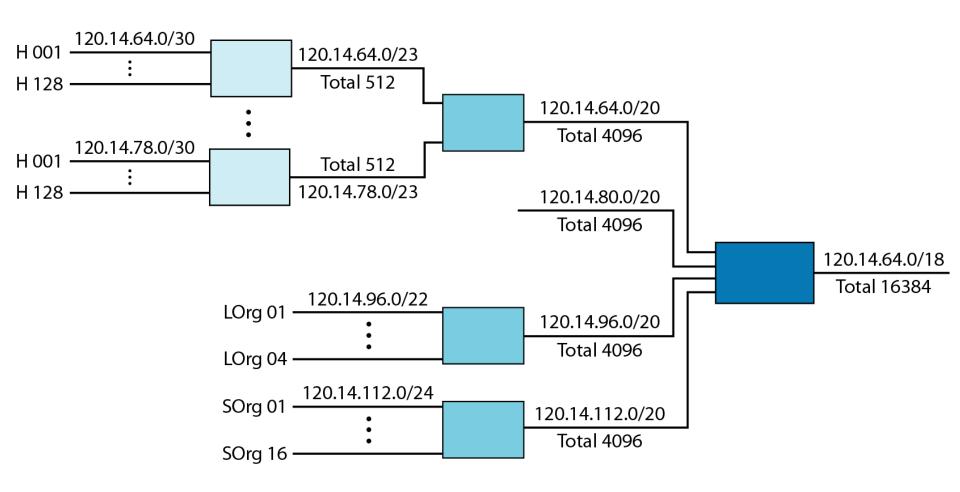
## Example 22.5 (continued)

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.

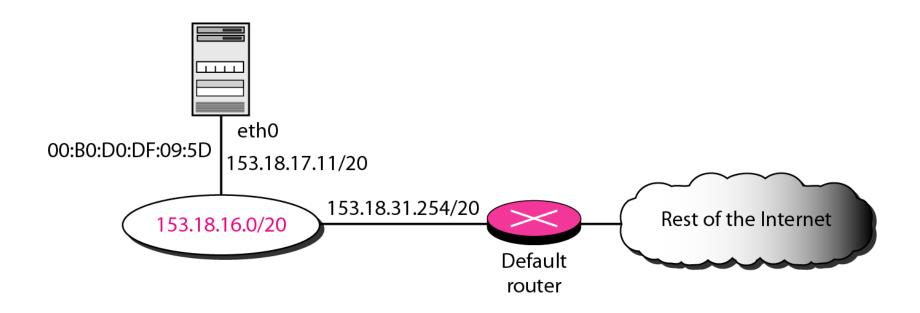
#### Figure 22.9 Hierarchical routing with ISPs



#### Figure 22.10 Common fields in a routing table

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

#### **Figure 22.11** Configuration of the server for Example 22.6

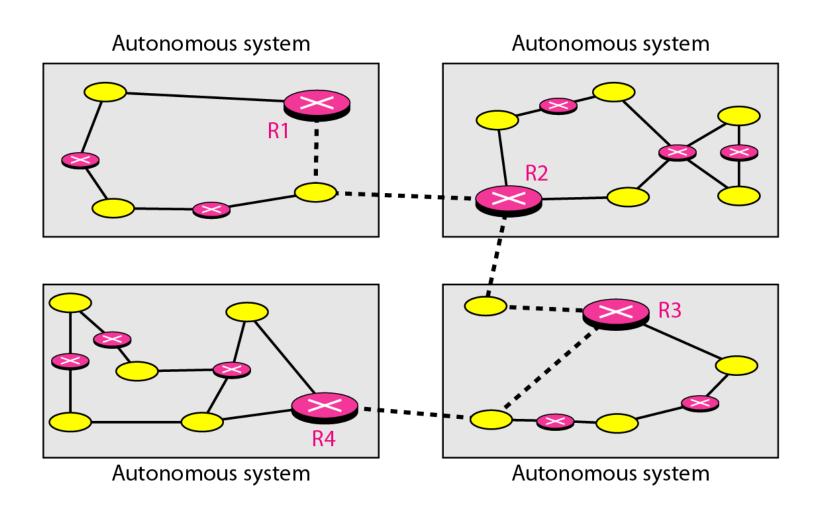


#### 22-3 UNICAST ROUTING PROTOCOLS

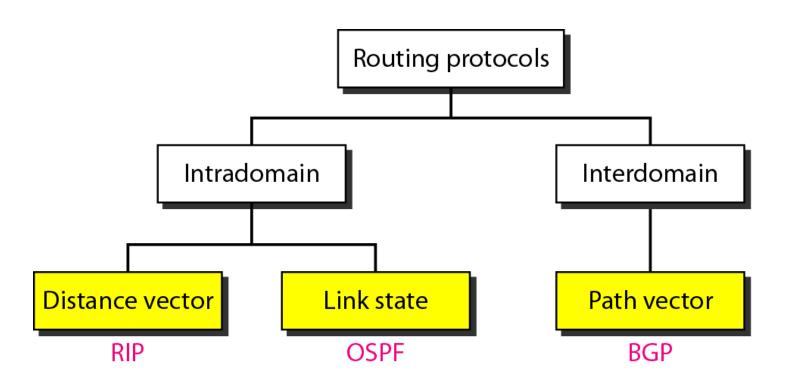
A routing table can be either static or dynamic. A static table is one with manual entries. A dynamic table is one that is updated automatically when there is a change somewhere in the Internet. A routing protocol is a combination of rules and procedures that lets routers in the Internet inform each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

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

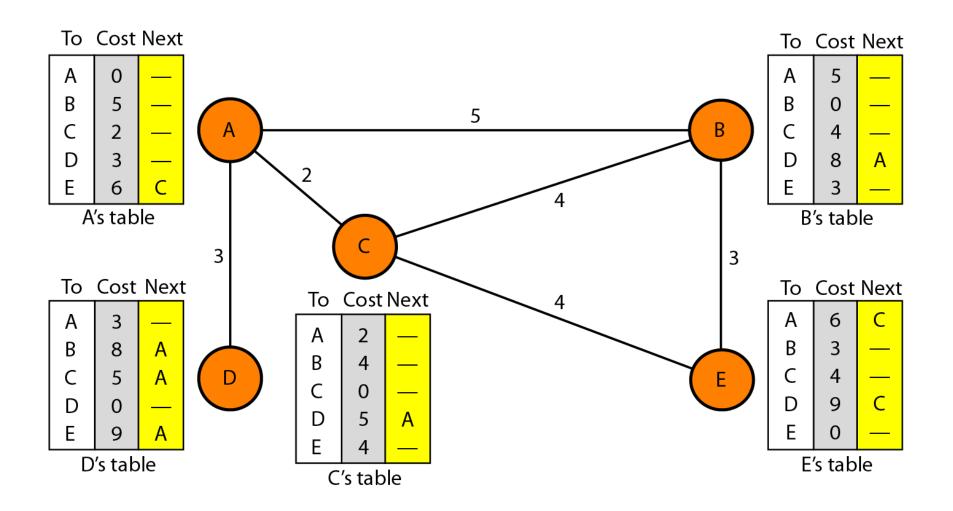
#### Figure 22.12 Autonomous systems



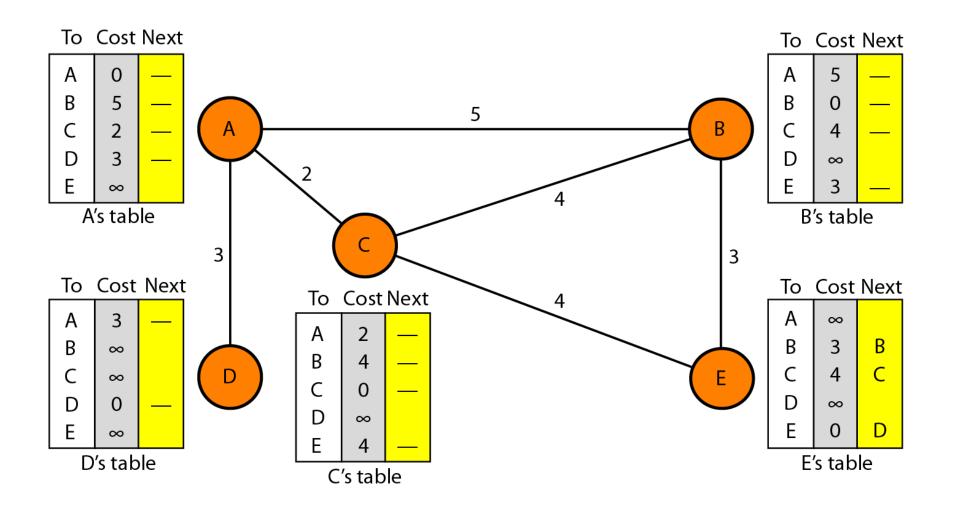
#### Figure 22.13 Popular routing protocols



#### Figure 22.14 Distance vector routing tables



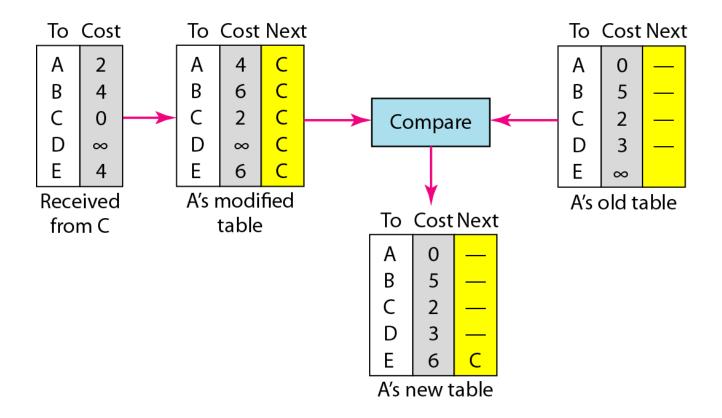
#### Figure 22.15 Initialization of tables in distance vector routing



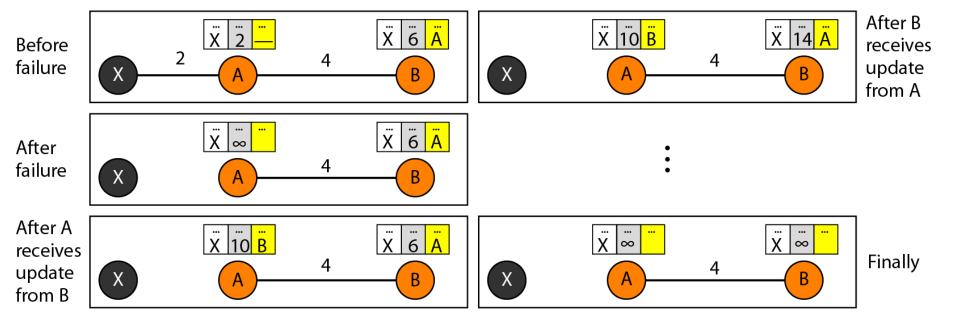
## Note

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

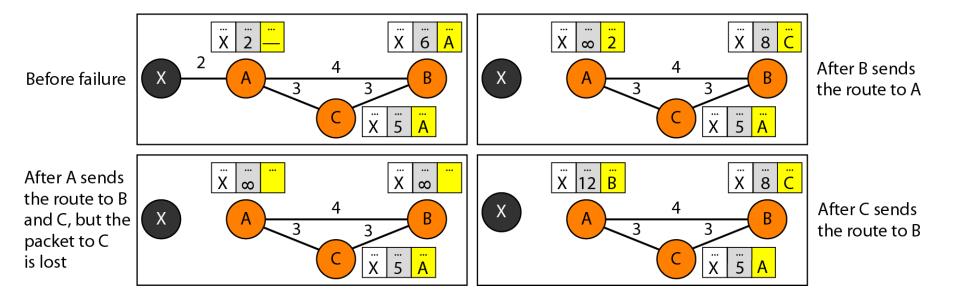
#### Figure 22.16 Updating in distance vector routing



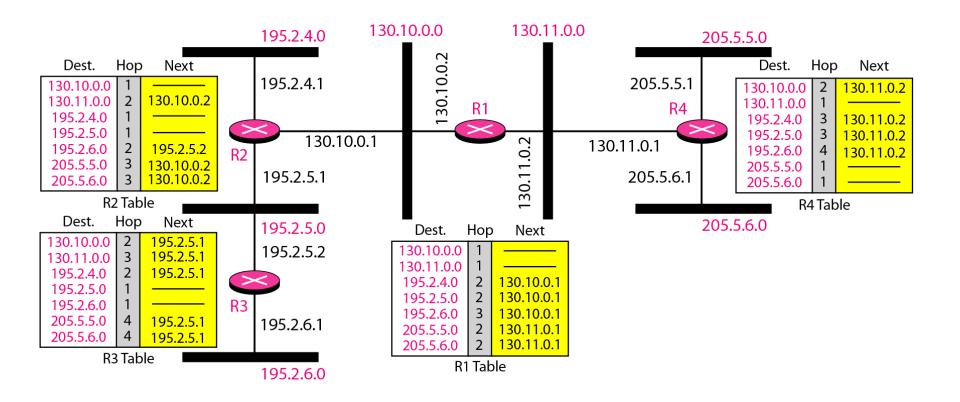
#### Figure 22.17 Two-node instability



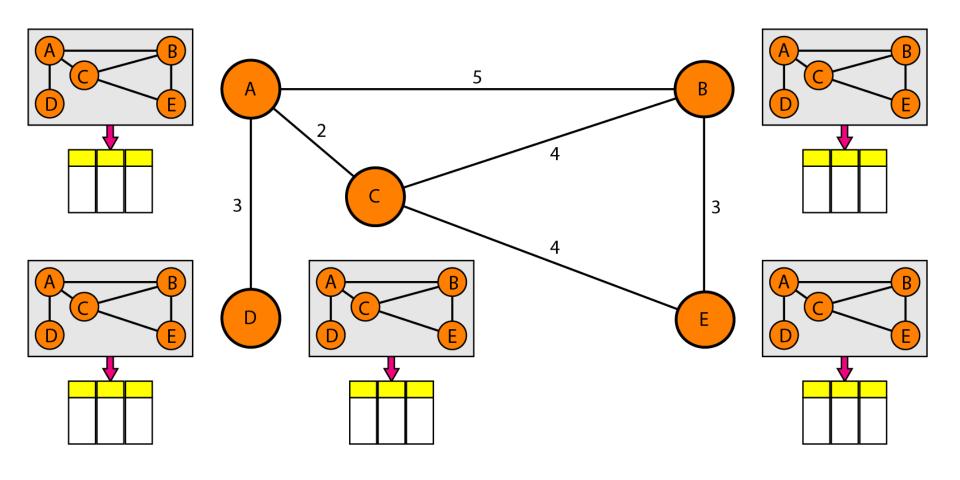
#### Figure 22.18 Three-node instability



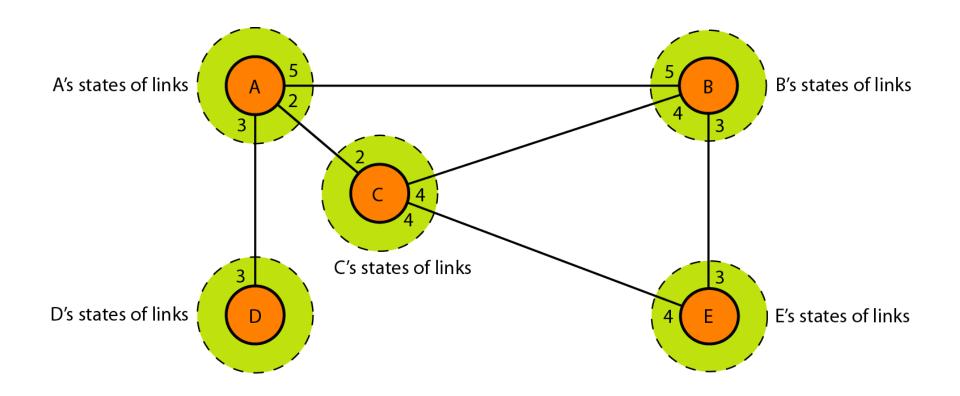
#### Figure 22.19 Example of a domain using RIP



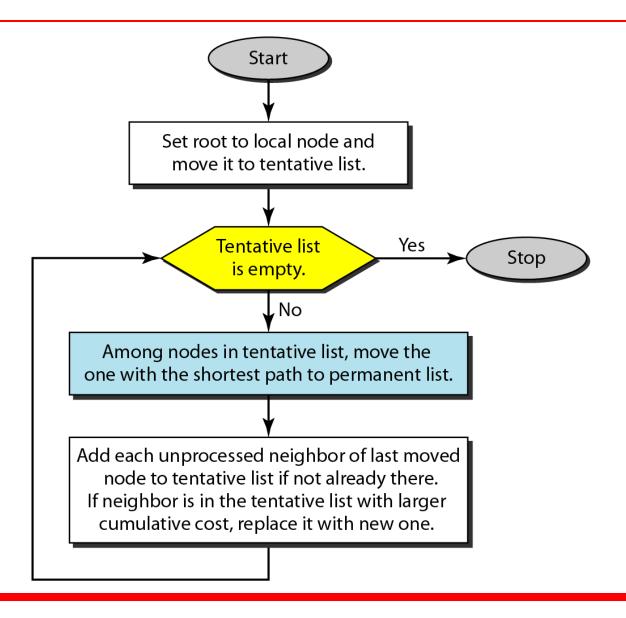
#### Figure 22.20 Concept of link state routing



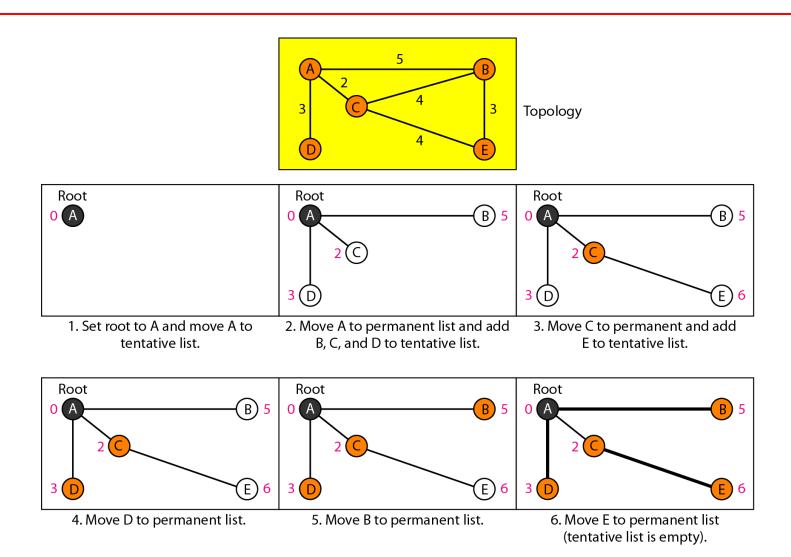
#### Figure 22.21 Link state knowledge



#### Figure 22.22 Dijkstra algorithm



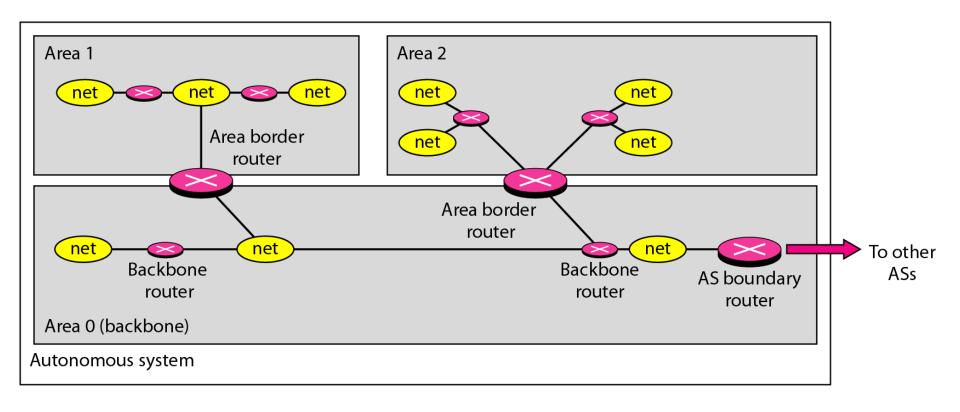
#### Figure 22.23 Example of formation of shortest path tree



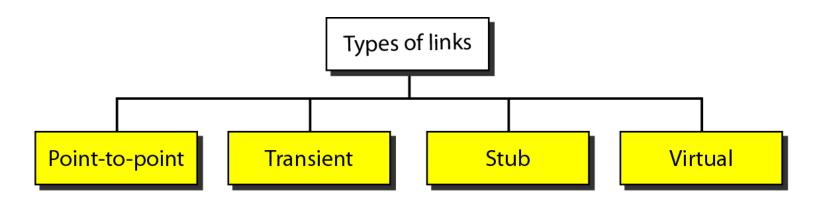
#### **Table 22.2** Routing table for node A

Node	Cost	Next Router
A	0	
В	5	
С	2	_
D	3	_
Е	6	С

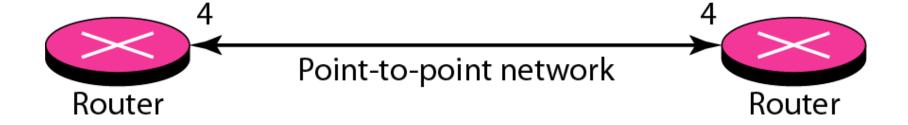
#### Figure 22.24 Areas in an autonomous system



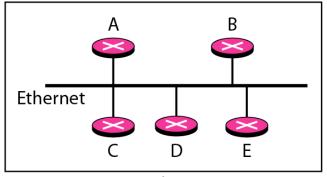
### Figure 22.25 Types of links



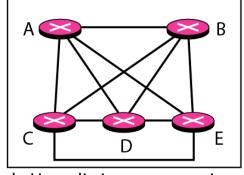
#### Figure 22.26 Point-to-point link



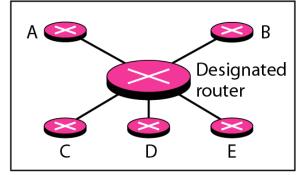
#### Figure 22.27 Transient link



a. Transient network

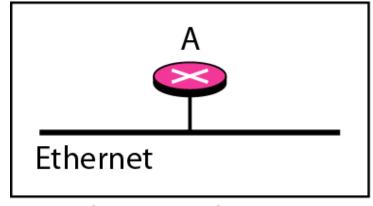


b. Unrealistic representation

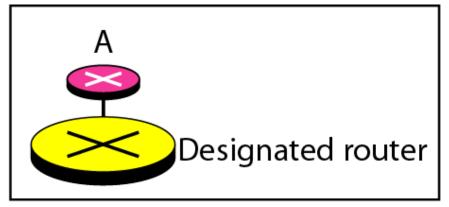


c. Realistic representation

#### Figure 22.28 Stub link

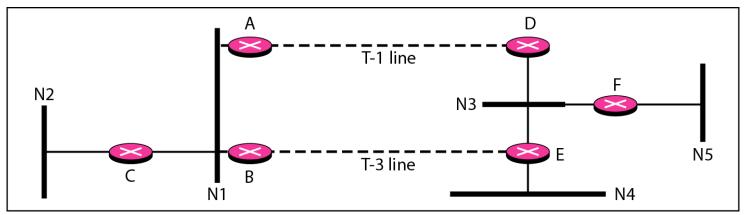


a. Stub network

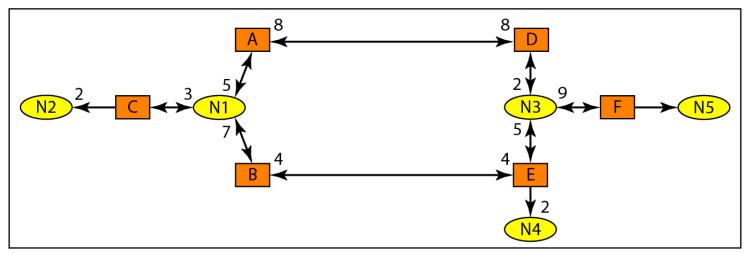


b. Representation

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

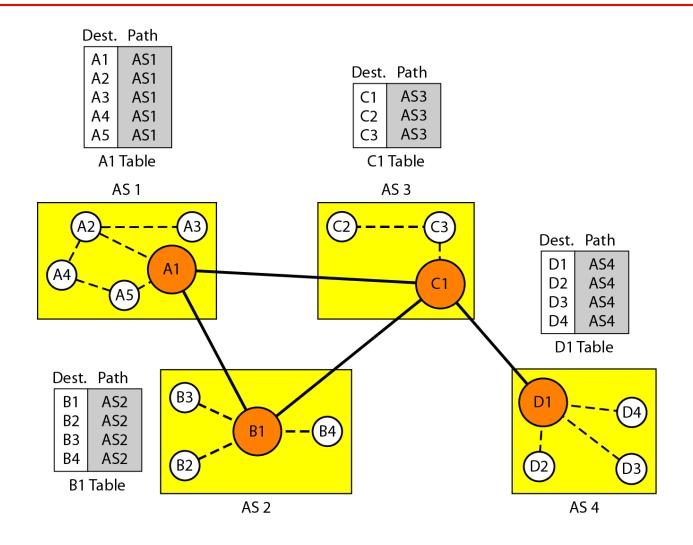


a. Autonomous system



b. Graphical representation

#### 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  B4	AS2  AS2
C1  C3	AS2-AS3  AS2-AS3
D1  D4	AS2-AS3-AS4  AS2-AS3-AS4
	B1 Table

est.	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
С3	AS4-AS3
D1	AS4
D4	AS4
	D1 Table

#### Figure 22.32 Internal and external BGP sessions

