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.***

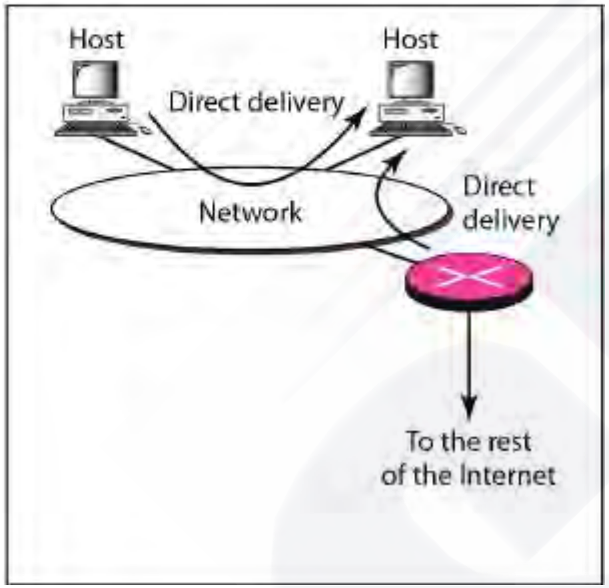
Direct and indirect delivery

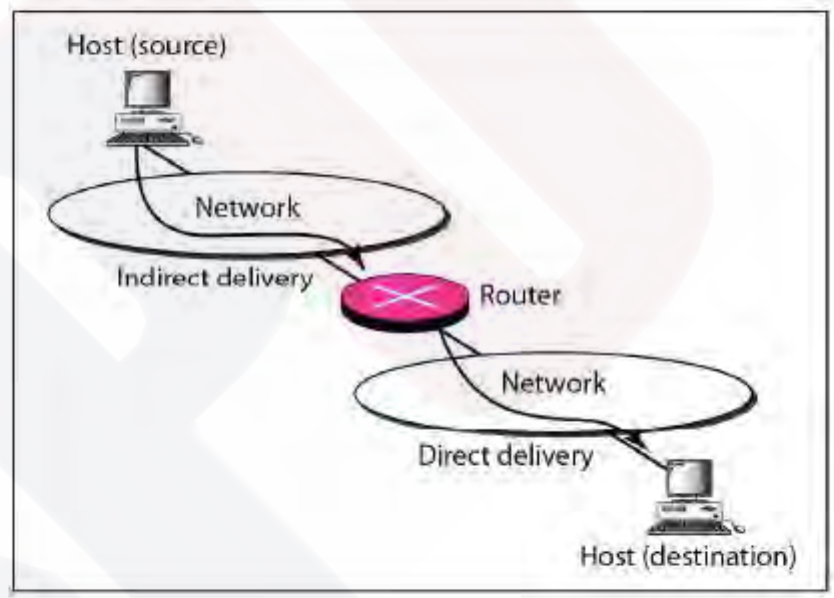
- In a direct delivery, the final destination of the packet is a host connected to the same physical network as the deliverer
- The direct delivery occurs when the source and the destination of the packet are located on the same physical network
- The sender can easily determine if the delivery is direct.

- It can extract the network address of the destination using the mask and compare this address with addresses of the networks to which it is connected
- If a match is found, the delivery is direct

- If the destination host is not on the same network as the deliverer, the packet is delivered indirectly
- In this form, the packet goes from router to router until it reaches the one connected to the same physical network as its final destination

Direct and indirect delivery





FORWARDING TECHNIQUES

- ***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.***

- Default method
- Next-hop method
- Network -Specific method

Default method

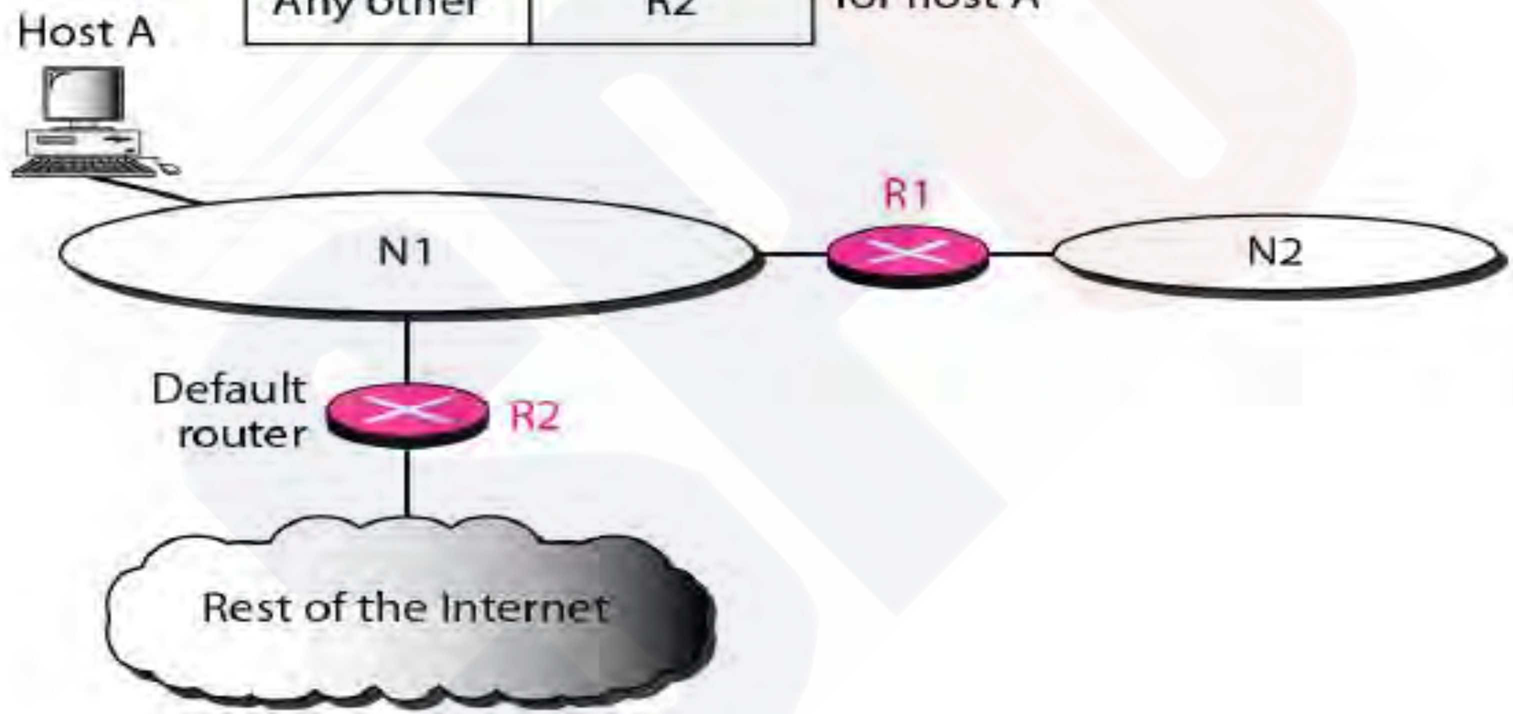
- In the ***default method***

  A host sends all packets that are going out of the network to a specific router called the default

Default method

Destination	Next hop
N2	R1
Any other	R2

Routing table for host A



- Host A is connected to a network with two routers R1 and R2
- Router R1 routes the packet to hosts connected to network N2
- For the rest of the Internet, router R2 is used.
- Consequently, instead of listing all networks in the entire Internet, host A can just have one entry called the default (normally defined as network address 0.0.0.0

next-hop method

- In the ***next-hop method***, the routing table holds only the address of the next hop for each destination

Routing tables based on next hop

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	---

Route method versus next-hop method

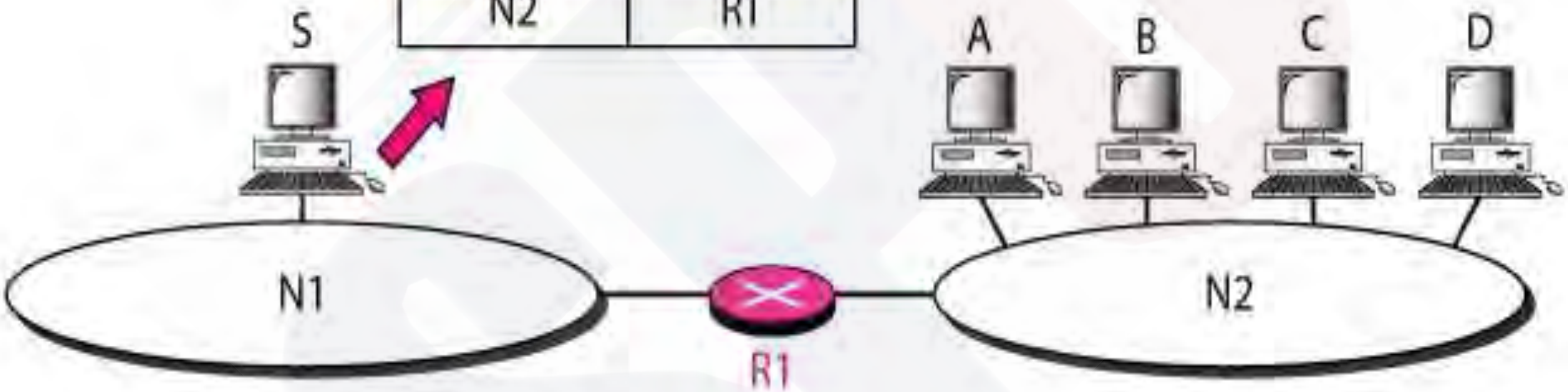
Routing table	Routing tables based on route: Destination	Routing tables based on route: Route	Routing tables based on next hop: Destination	Routing tables based on next hop: Next hop
Routing table for host A	Host B	R1, R2, host B	Host B	R1
Routing table for R1	Host B	R2, host B	Host B	R2
Routing table for R2	Host B	Host B	Host B	---

network-specific method

- In the ***network-specific*** method
- the routing table holds only one entry that defines the address of the destination network instead of all hosts on that network

Routing table for host S based on network-specific method

Destination	Next hop
N2	R1



Host-specific versus network-specific method

Routing table for host S based on host-specific method

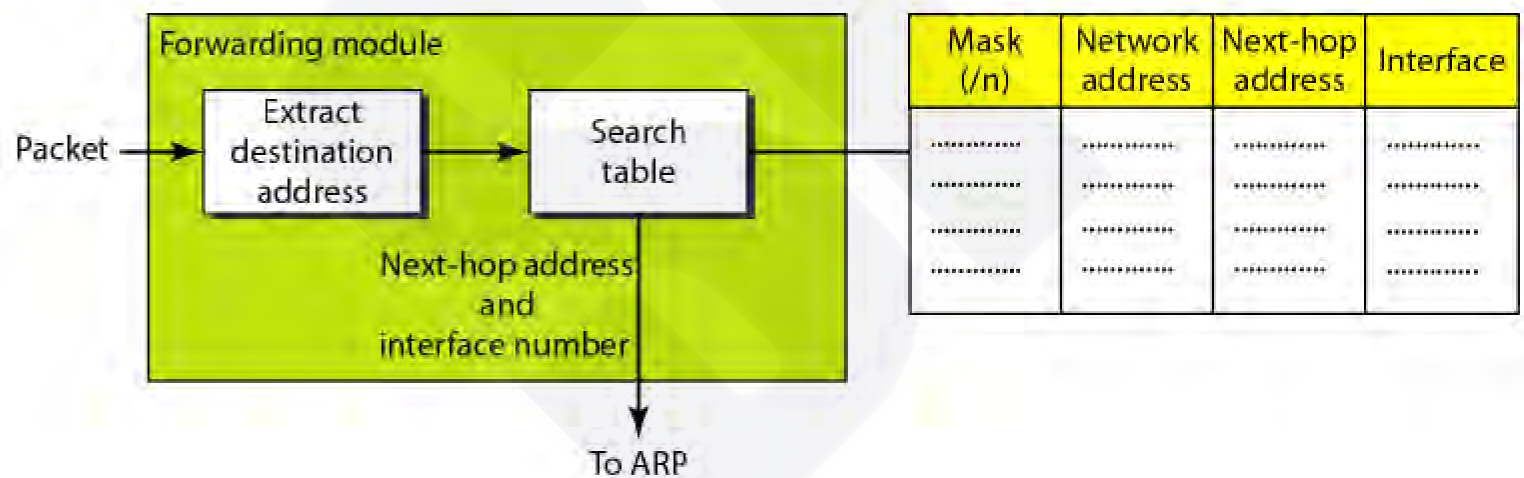
Destination	Next hop
A	R1
B	R1
C	R1
D	R1

Routing table for host S based on network-specific method

Destination	Next hop
N2	R1

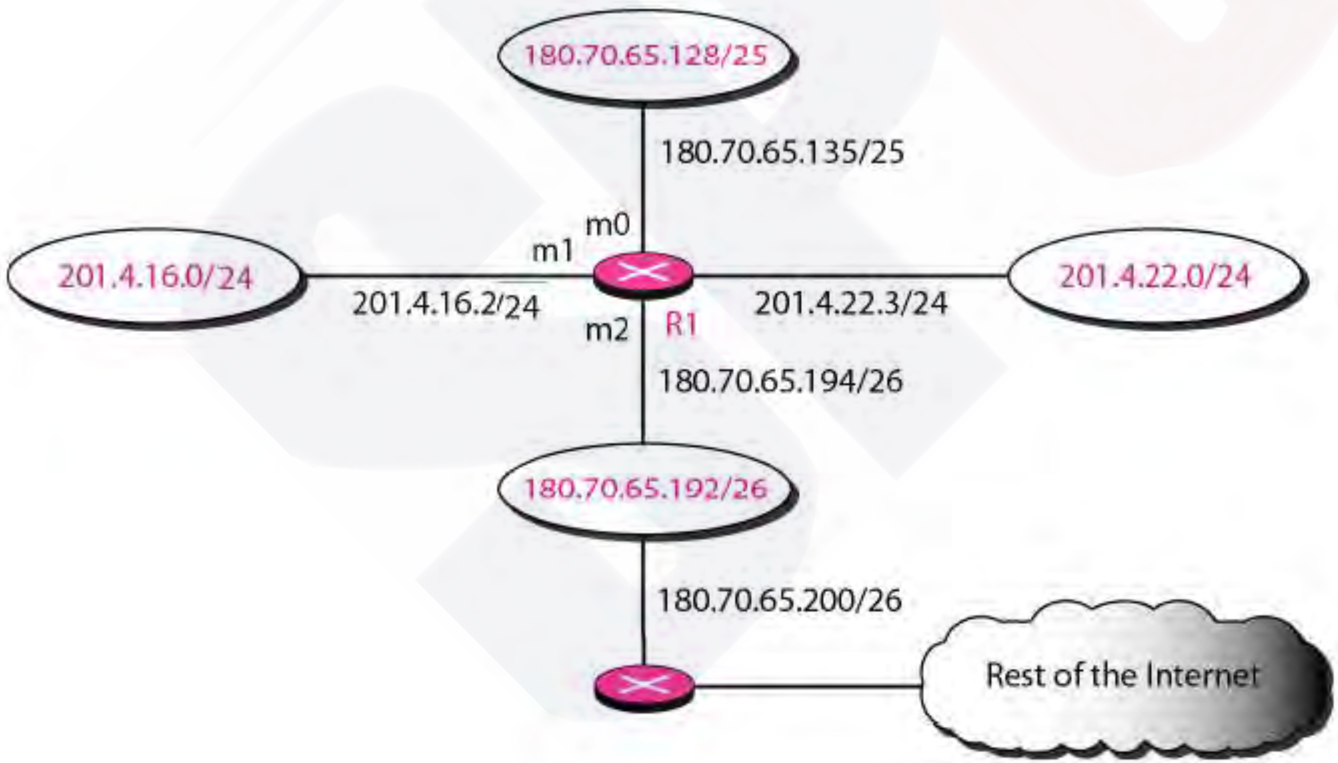
Simplified forwarding module in classless address

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

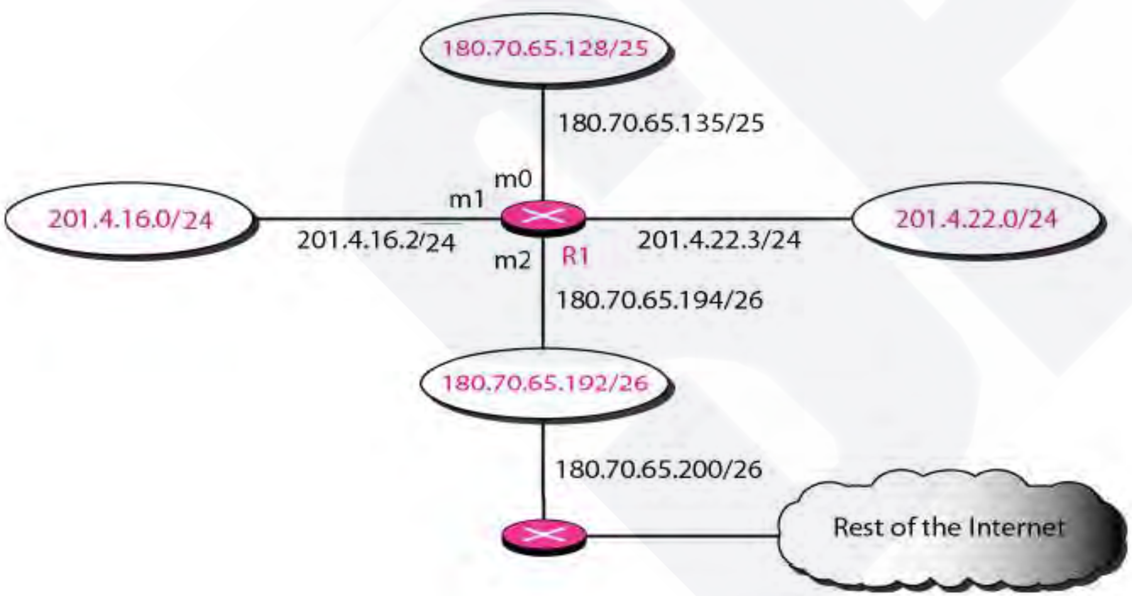


example

- ***Make a routing table for router R1, using the***
- ***configuration in the Figure***



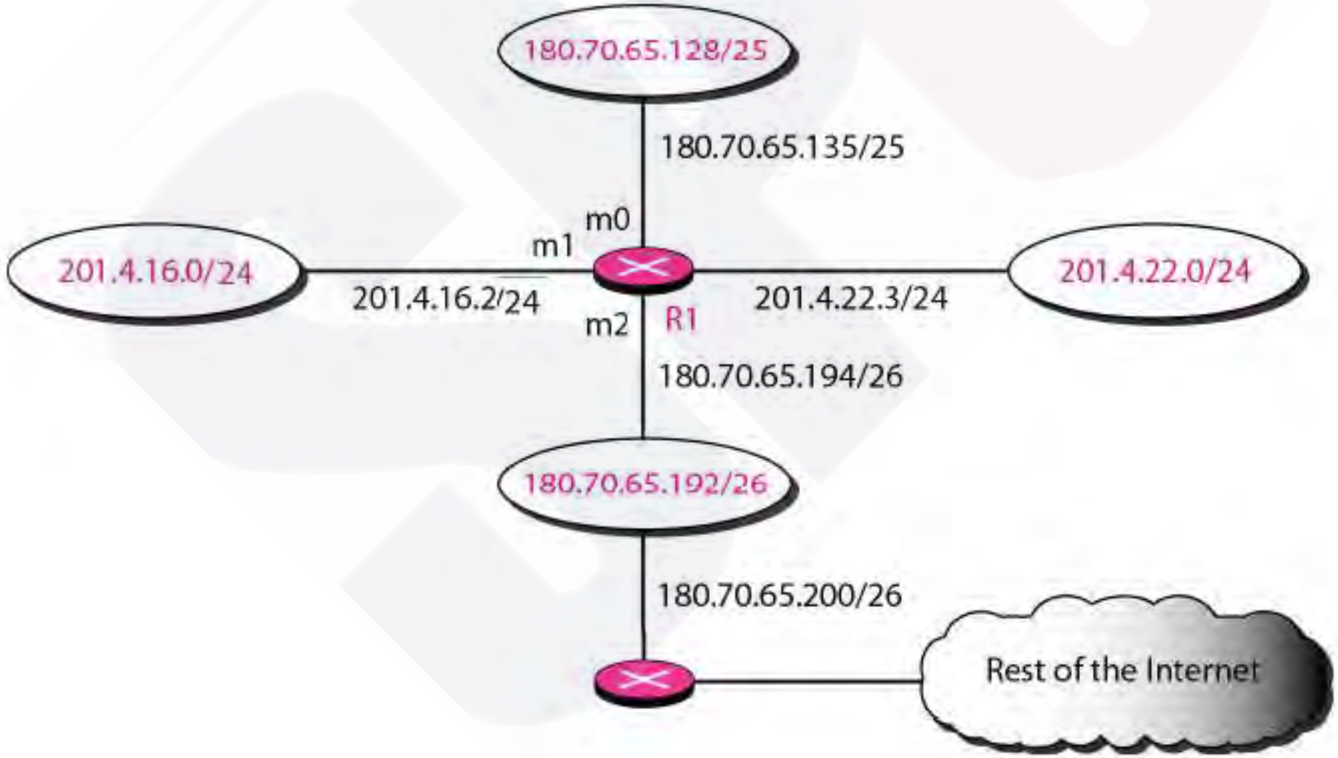
Mask	Network Address	Next Hop	Interface
/26	180.70.65.192	—	m2
/25	180.70.65.128	—	m0
/24	201.4.22.0	—	m3
/24	201.4.16.0	....	m1
Any	Any	180.70.65.200	m2



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

EXAMPLE

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

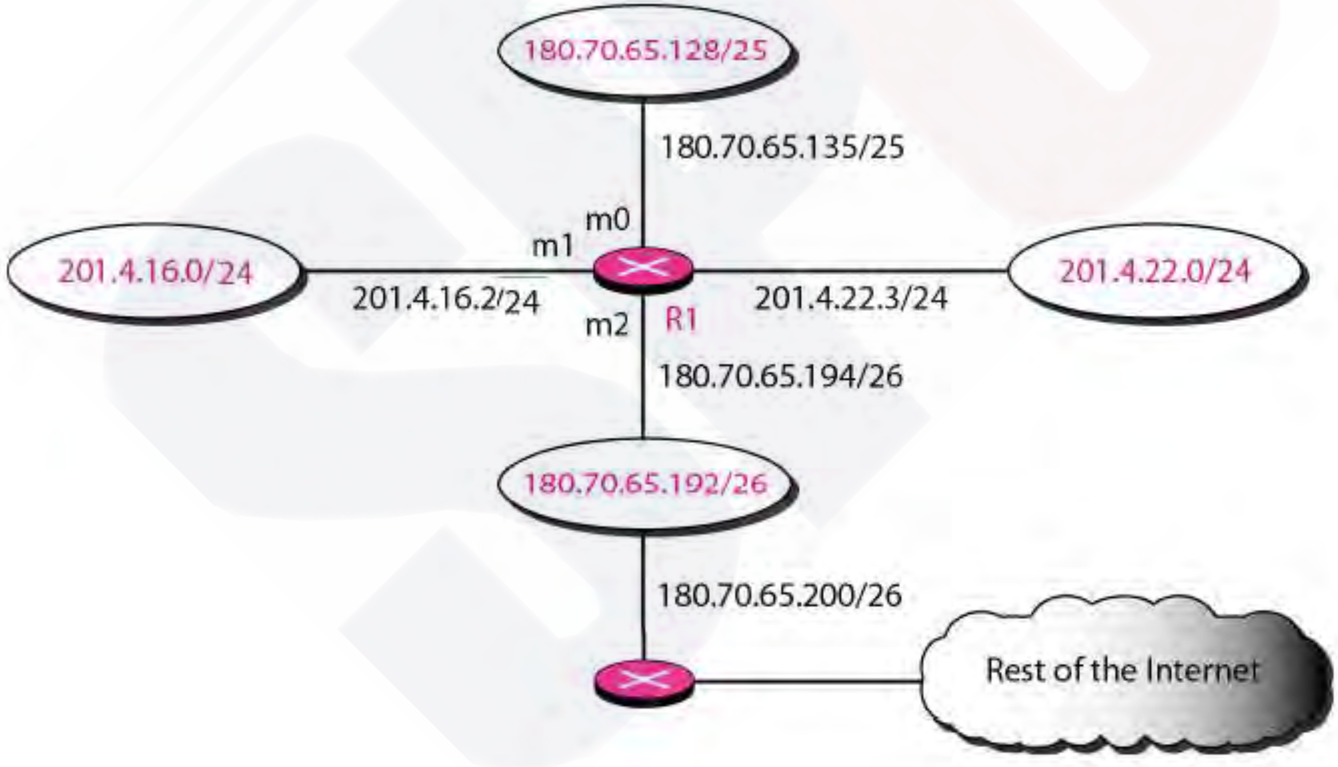


Solution

- ***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.***
- ***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

- ***Show the forwarding process if a packet arrives at R1 in the previous Figure with the destination address 201.4.22.35***

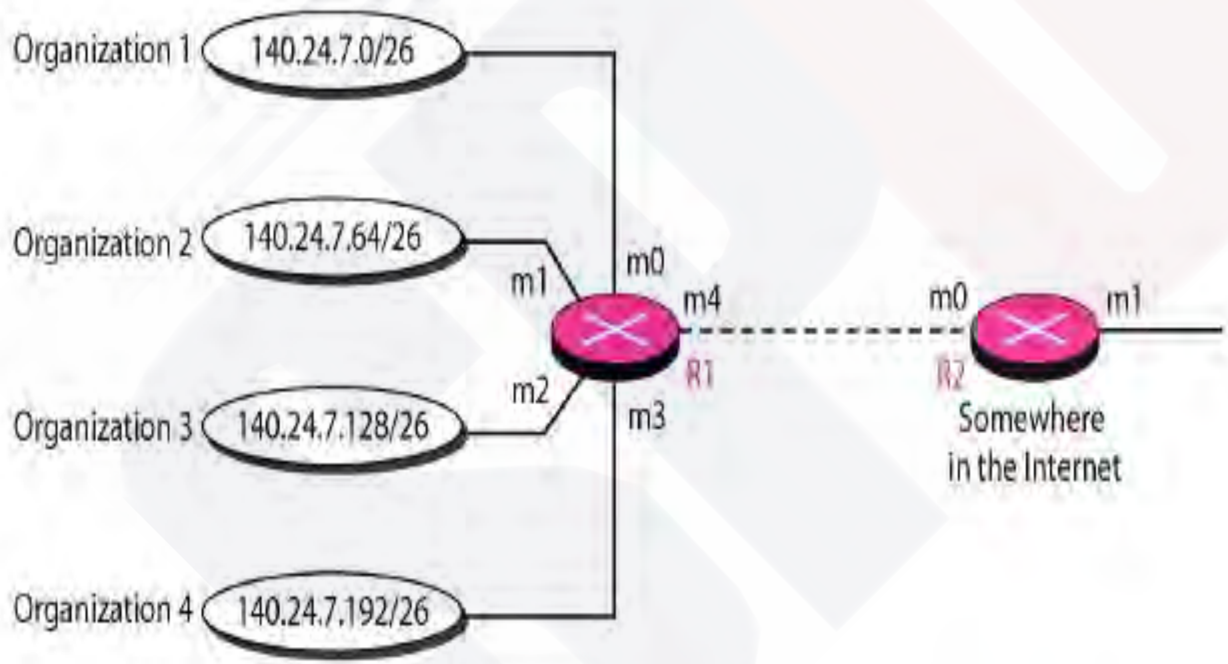


Solution

- ***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***

- ***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.***

Address Aggregation



- Router R1 is connected to network of 4 organization that each use 64 addresses
- Router R2 is somewhere far from R1
- R1 has a longer routing table Because each packet must be correctly routed to the appropriate organization
- Router R2, can have a very small routing table

- For R2:
- Any packet with destination 140.24.7.0 to 140.24.7.255 is sent out from interface m0 regardless of the organization number
- This is called address aggregation because the blocks of addresses for 4 organizations are aggregated into one larger block

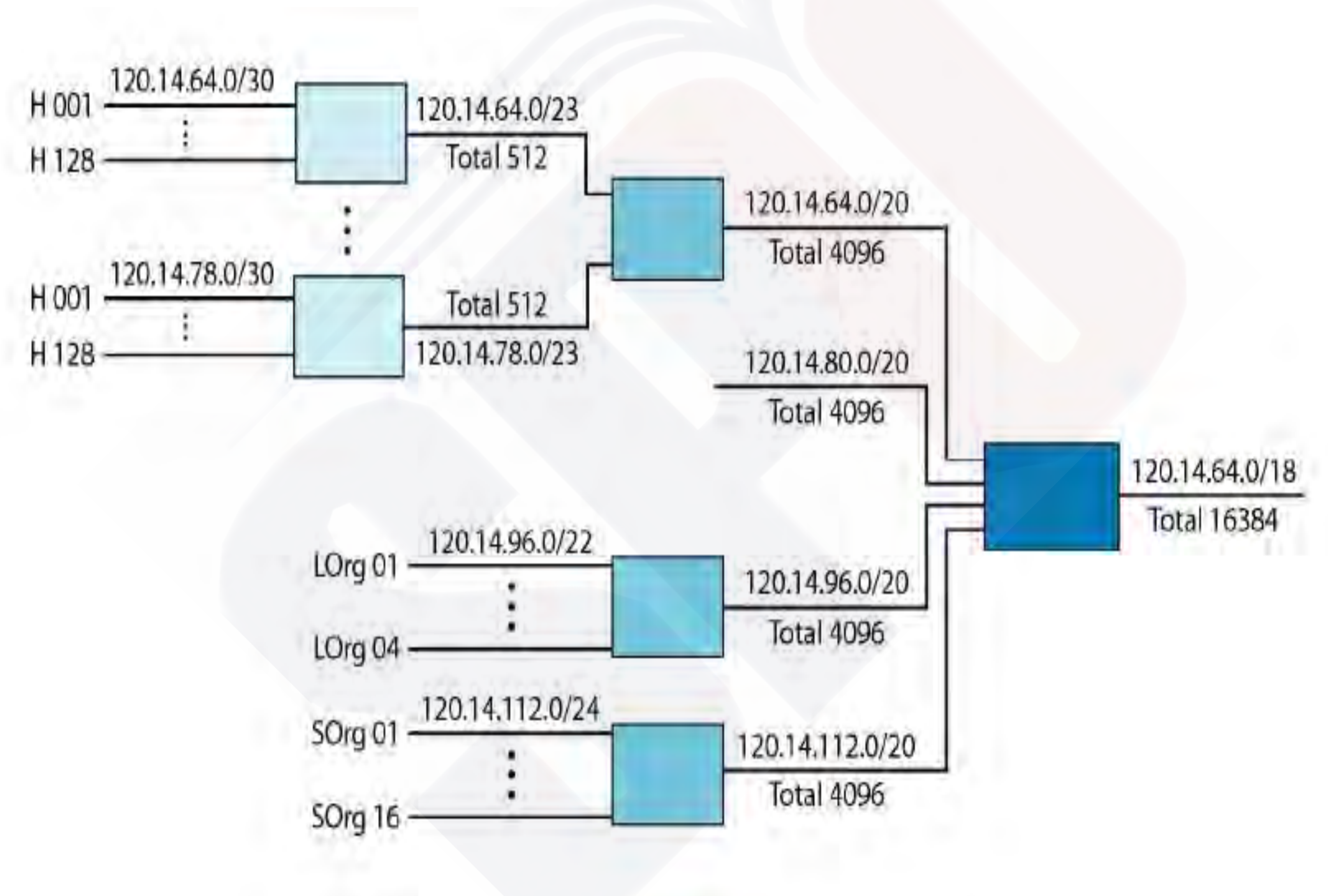
Hierarchical Routing

- As we know, the internet today has a sense of hierarchy.
- The internet is divided into interntional and national ISP
- National ISP’s are divided regional ISPs
- Regional ISPs are divided into local ISPs

- For example Let us take the case of local ISP:
- A local ISP can be assigned a single, but large block of addresses with certain prefix length.
- The local ISP can divide this block into smaller blocks of different size and can assign these to individual users and organization, both large and small.
- If the block assigned to the local ISP starts with a.b.c.d/n, the ISP can create blocks starting with e.f.g.h/ m
- m>n

- All customers of the local ISP are defined as a.b.c.d/n   to the rest of the internet
- Every packet destined for one of the addresses in this large block is routed to the local ISP.
- Inside the local ISP the router must recognize the subblocks and route the packet to destined customer.

example



H 001
H 128
120.14.64.0/30
120.14.64.0/23
Total 512
H 001
H 128
120.14.78.0/30
Total 512
120.14.78.0/23
120.14.64.0/20
Total 4096
120.14.80.0/20
Total 4096
120.14.64.0/18
Total 16384
LOrg 01
LOrg 04
120.14.96.0/22
120.14.96.0/20
Total 4096
SOrg 01
SOrg 16
120.14.112.0/24
120.14.112.0/20
Total 4096

- A regional ISP is granted 16384 addresses starting from 120.14.64.0
- The regional has decided to divide this block into 4 subblocks each with 4096 addresses
- 3 of these subblocks are assigned to three local ISPs, the last is reserved for future use.
- The mask for each block is /20 because the original block is /18
- The first local ISP has divided its subblock to 8 smaller blocks.

Routing table for regional ISP

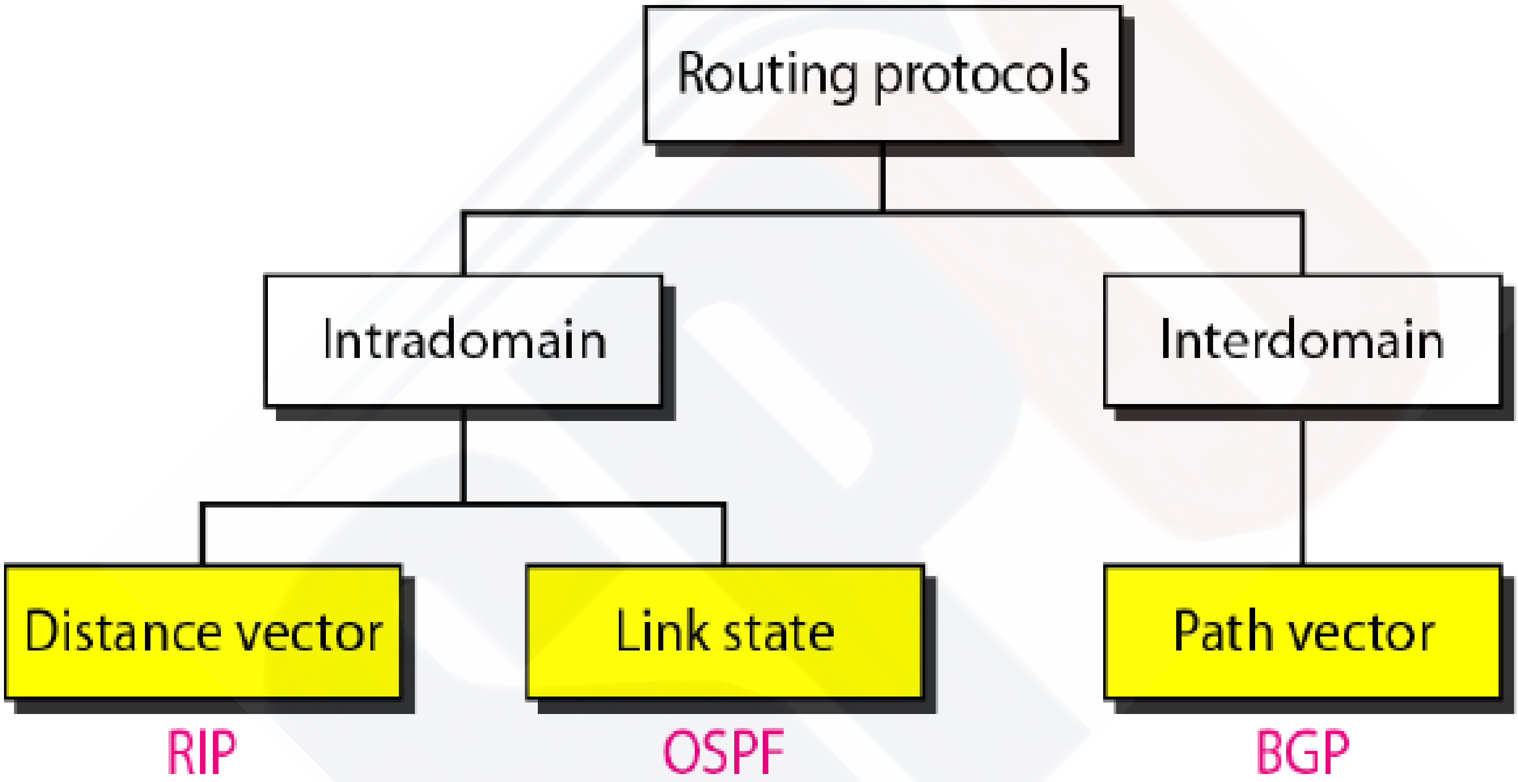
Mask	Network address	Next-hop address	Interface
/20	120.14.64.0	---	m0
/20	120.14.96.0	---	m2
/20	120.14.112.0	---	m3
/0	0.0.0.0	default router	m4

Routing table for local ISP 1

Mask	Network address	Next-hop address	Interface
/23	120.14.64.0	---	m0
/23	120.14.66.0	---	m1
/23	120.14.68.0	---	m2
/23	120.14.70.0	---	m3
/23	120.14.72.0	---	m4
/23	120.14.74.0	---	m5
/23	120.14.76.0	---	m6
/23	120.14.78.0	---	m7
/0	0.0.0.0	default router	m8

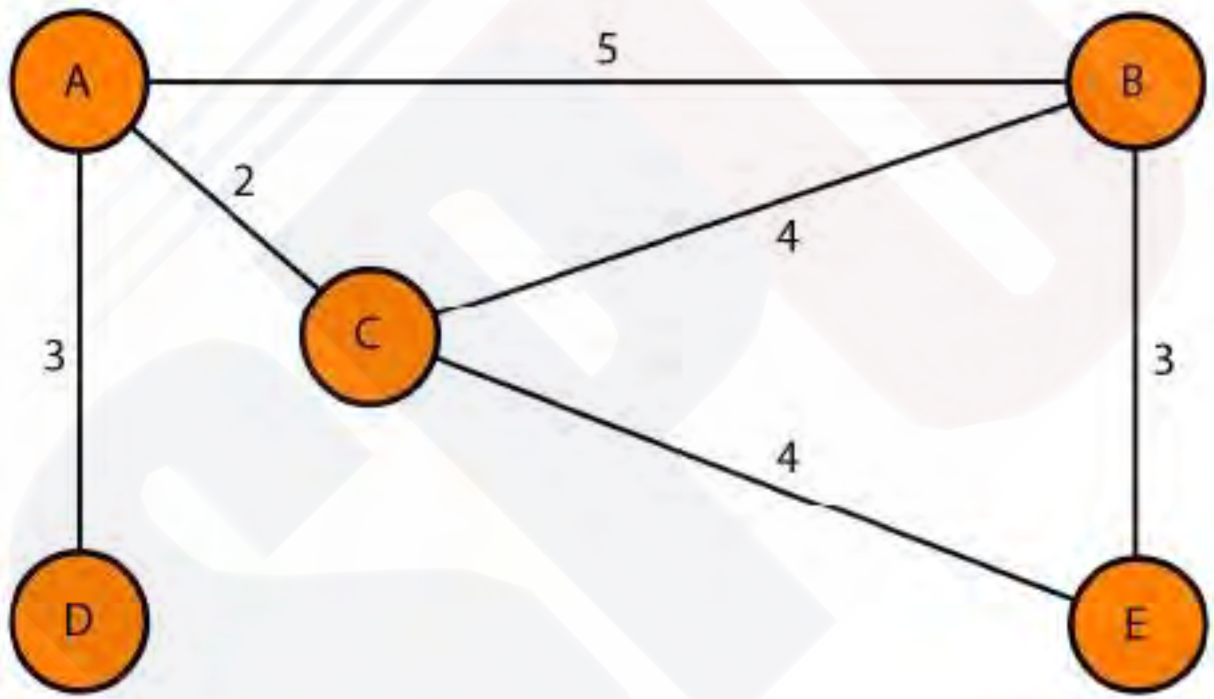
UNICAST ROUTING PROTOCOLS

- *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.*


Routing protocols
Intradomain
Interdomain
Distance vector
Link state
Path vector
RIP
OSPF
BGP

- **Distance Vector Routing and RIP**
- **Link State Routing and OSPF**

Distance vector routing tables



Note

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

A's table

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

B's table

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

C's table

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

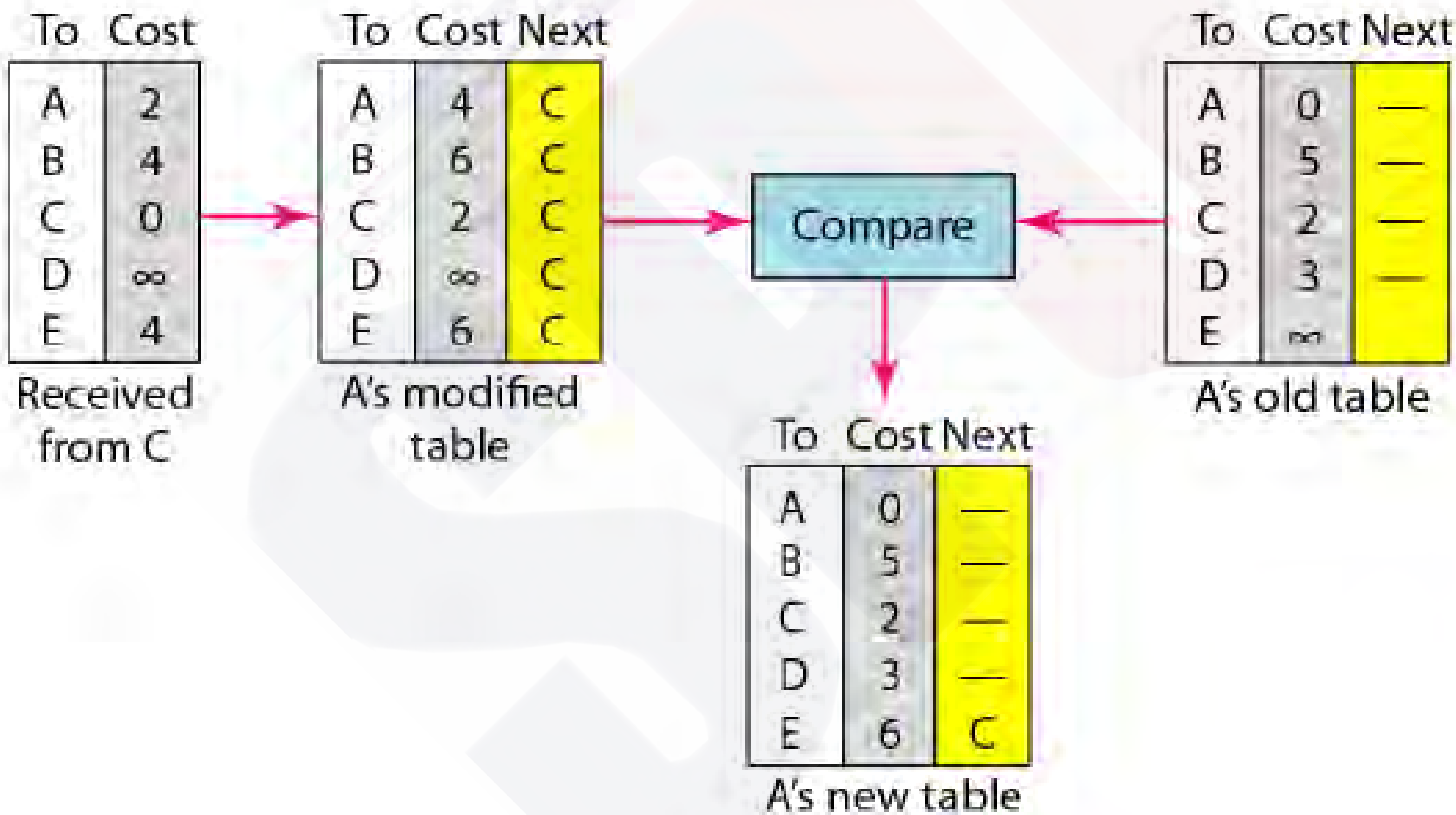
D's table

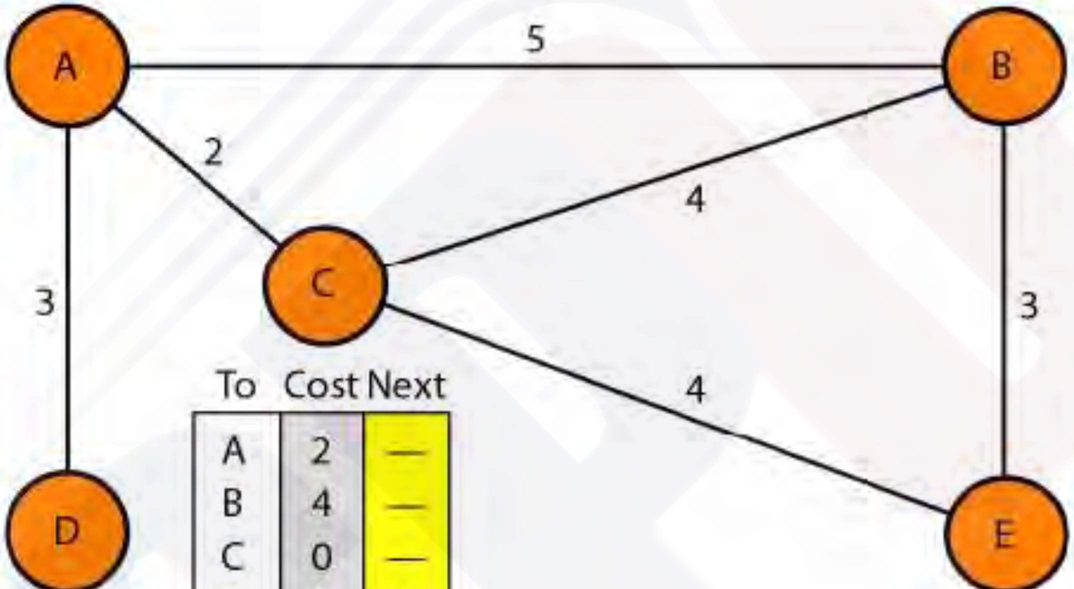
To	Cost	Next
A	3	—
B	∞	
C	∞	
D	0	—
E	∞	

E's table

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

Updating in distance vector routing





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

A's table

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

B's table

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

D's table

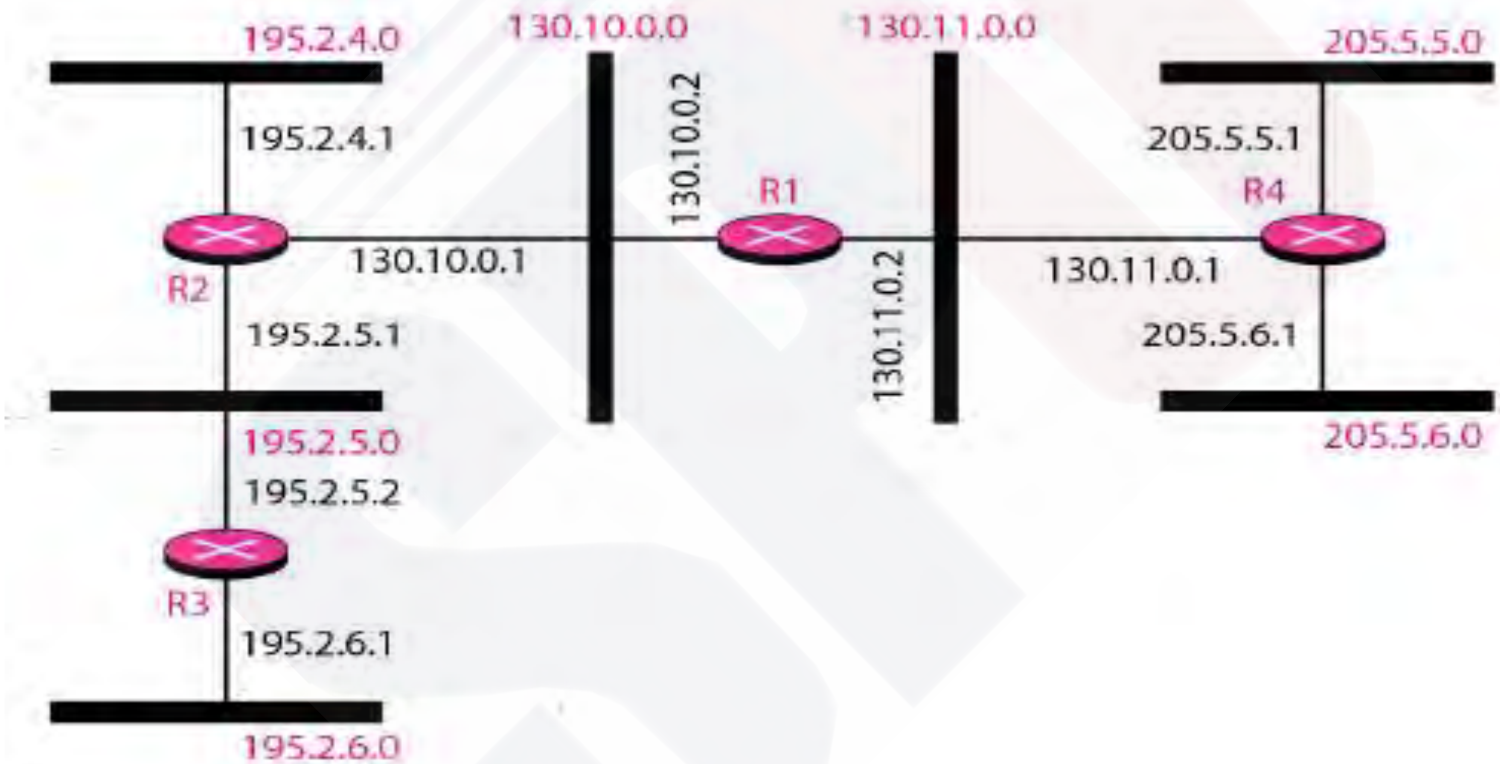
To	Cost	Next
A	2	—
B	4	—
C	0	—
D	5	A
E	4	—

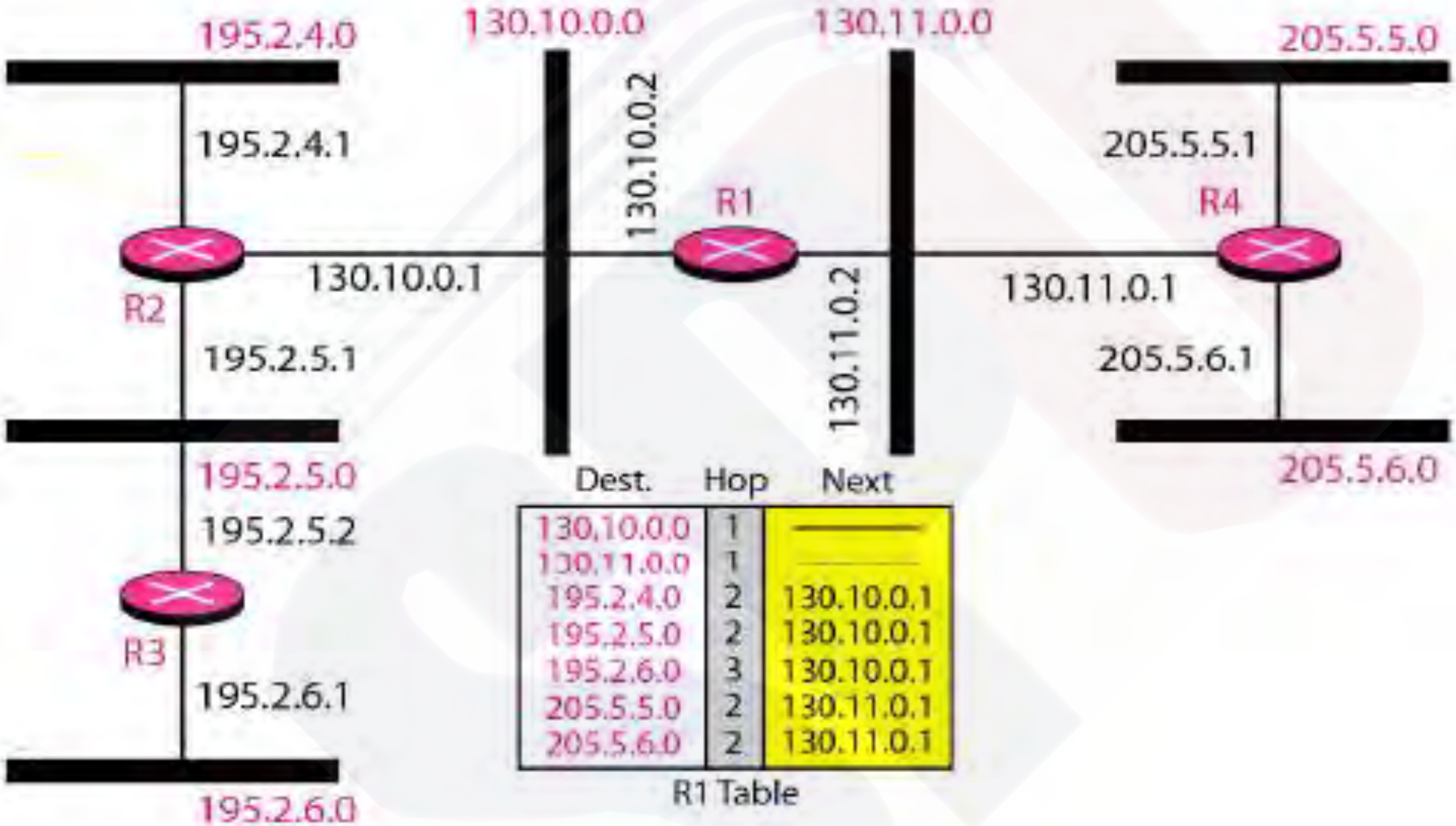
C's table

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

E's table

Example of a domain using RIP



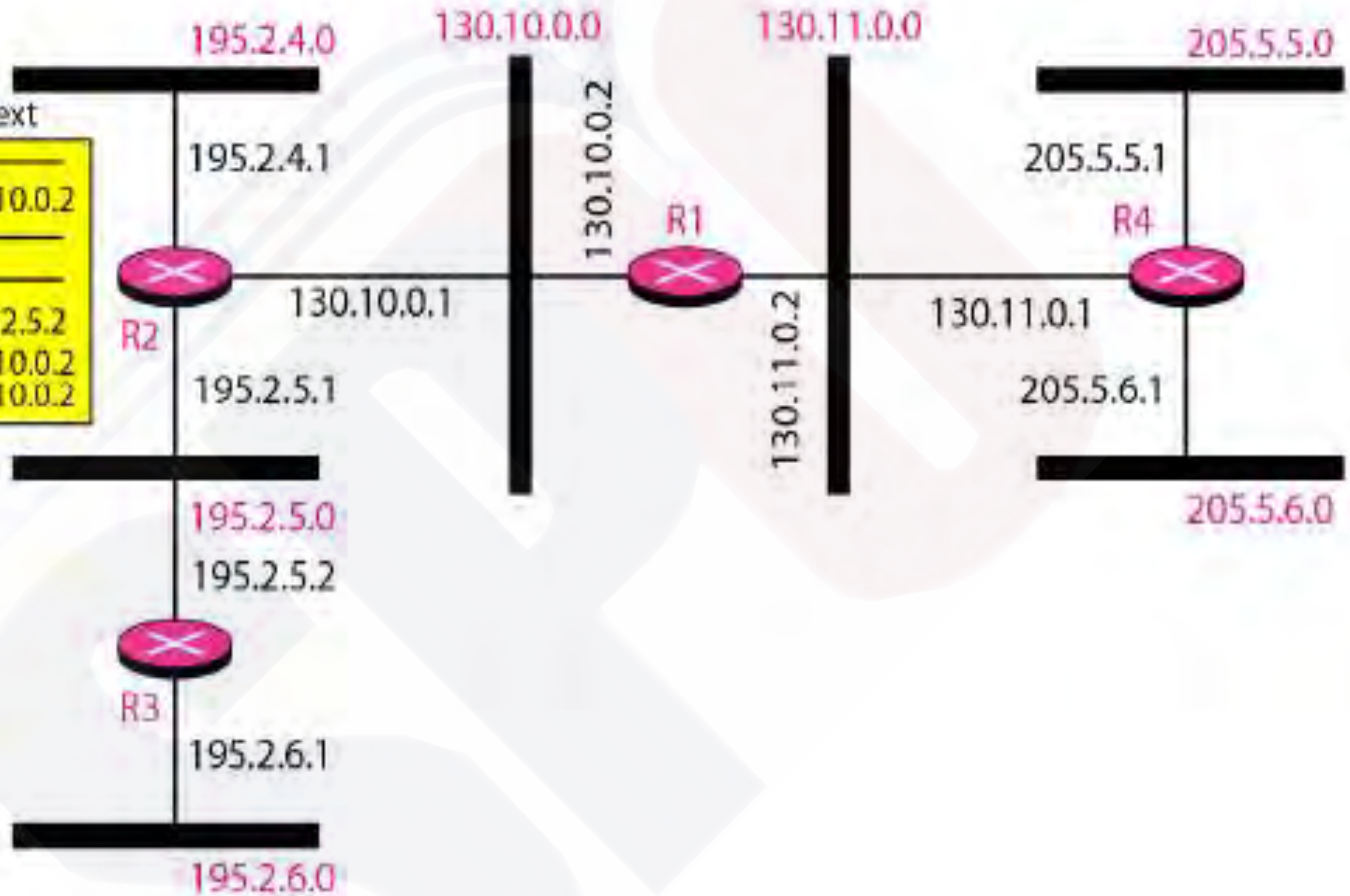


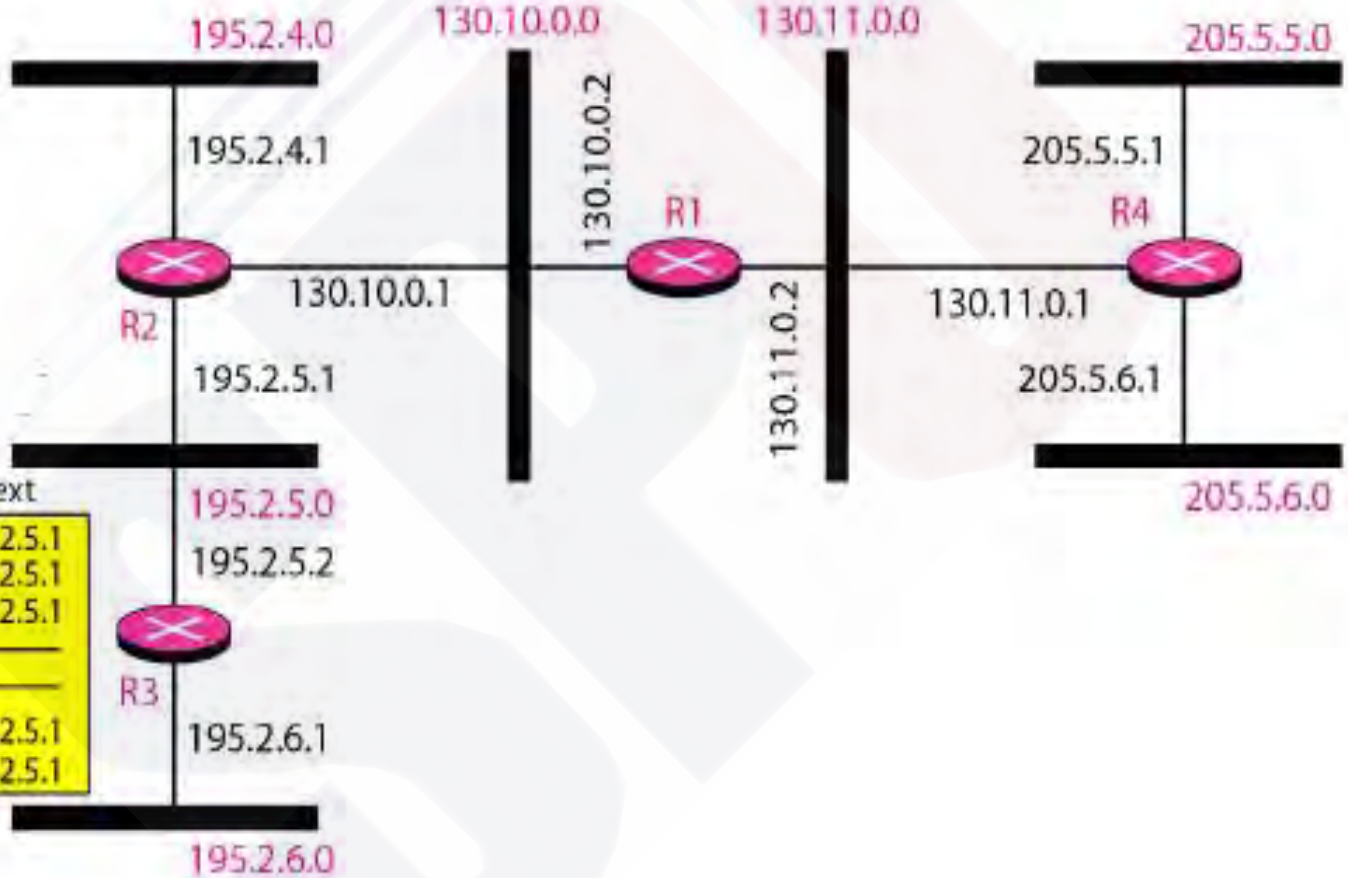
Dest.	Hop	Next
130.10.0.0	1	———
130.11.0.0	1	———
195.2.4.0	2	130.10.0.1
195.2.5.0	2	130.10.0.1
195.2.6.0	3	130.10.0.1
205.5.5.0	2	130.11.0.1
205.5.6.0	2	130.11.0.1

R1 Table

Dest.	Hop	Next
130.10.0.0	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

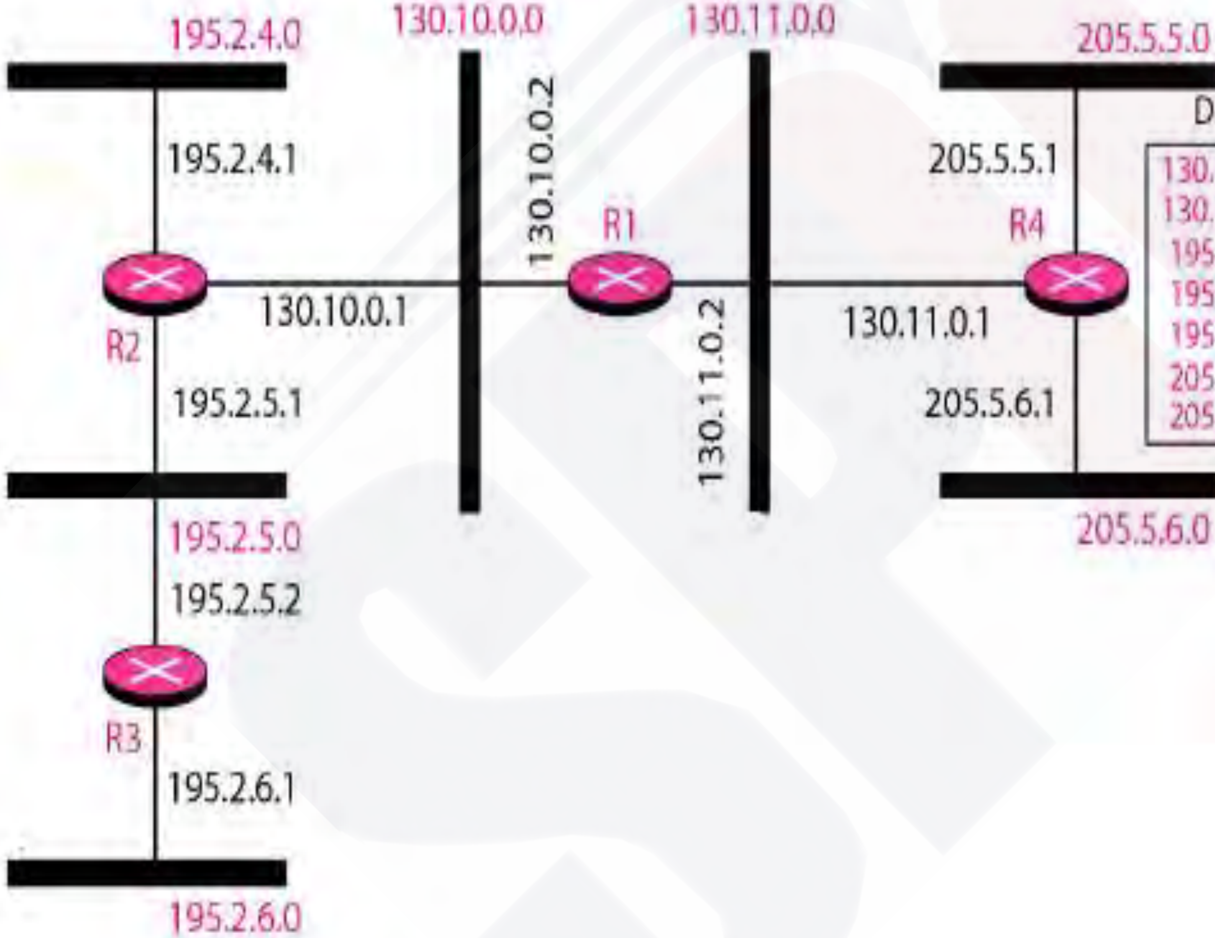
R2 Table





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

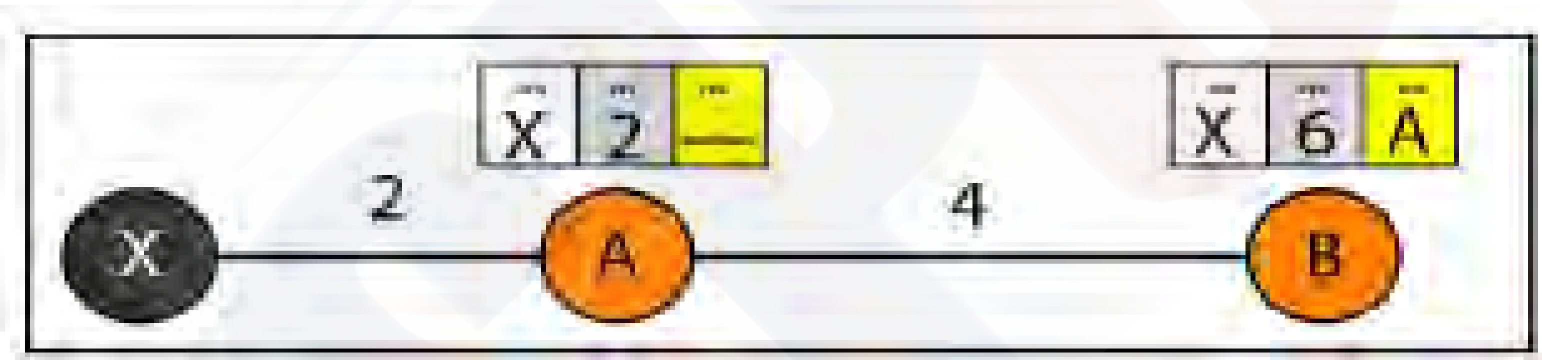


Dest.	Hop	Next
130.10.0.0	2	130.11.0.2
130.11.0.0	1	——
195.2.4.0	3	130.11.0.2
195.2.5.0	3	130.11.0.2
195.2.6.0	4	130.11.0.2
205.5.5.0	1	——
205.5.6.0	1	——

R4 Table

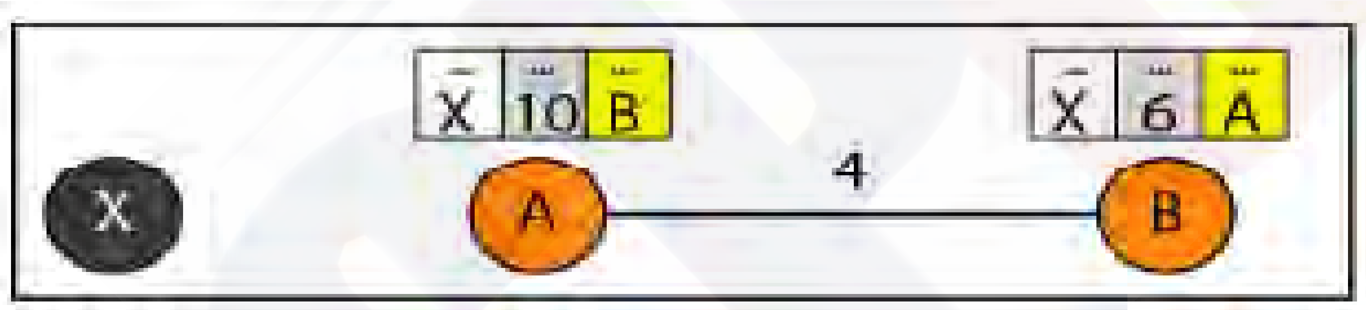
Two-node instability

- Before Failure



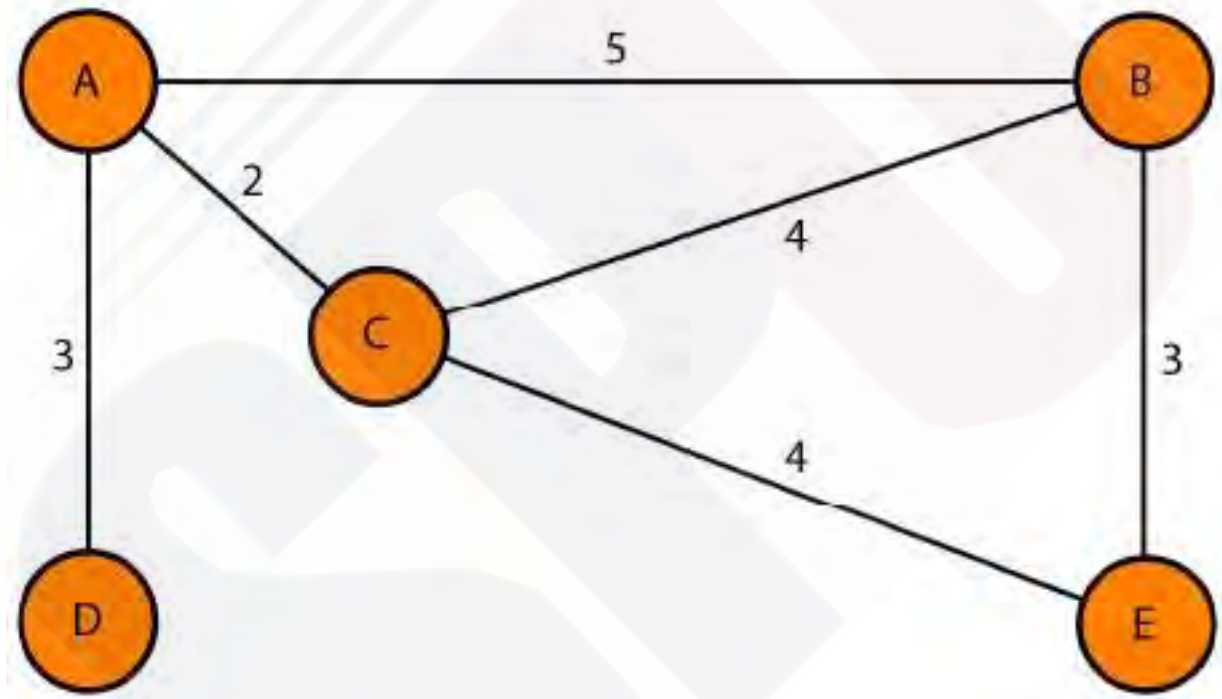
- After failure

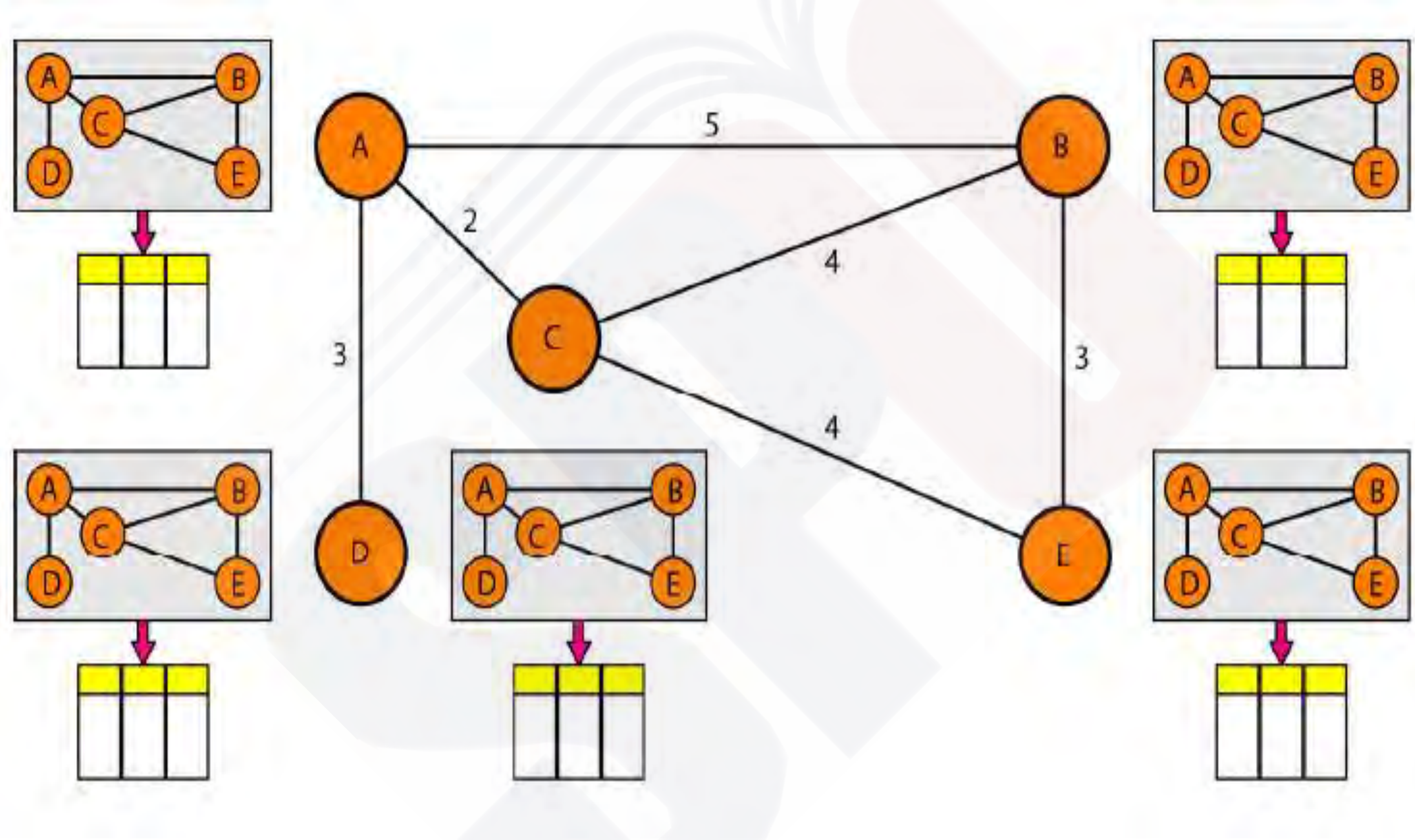
- After A receives updates from B



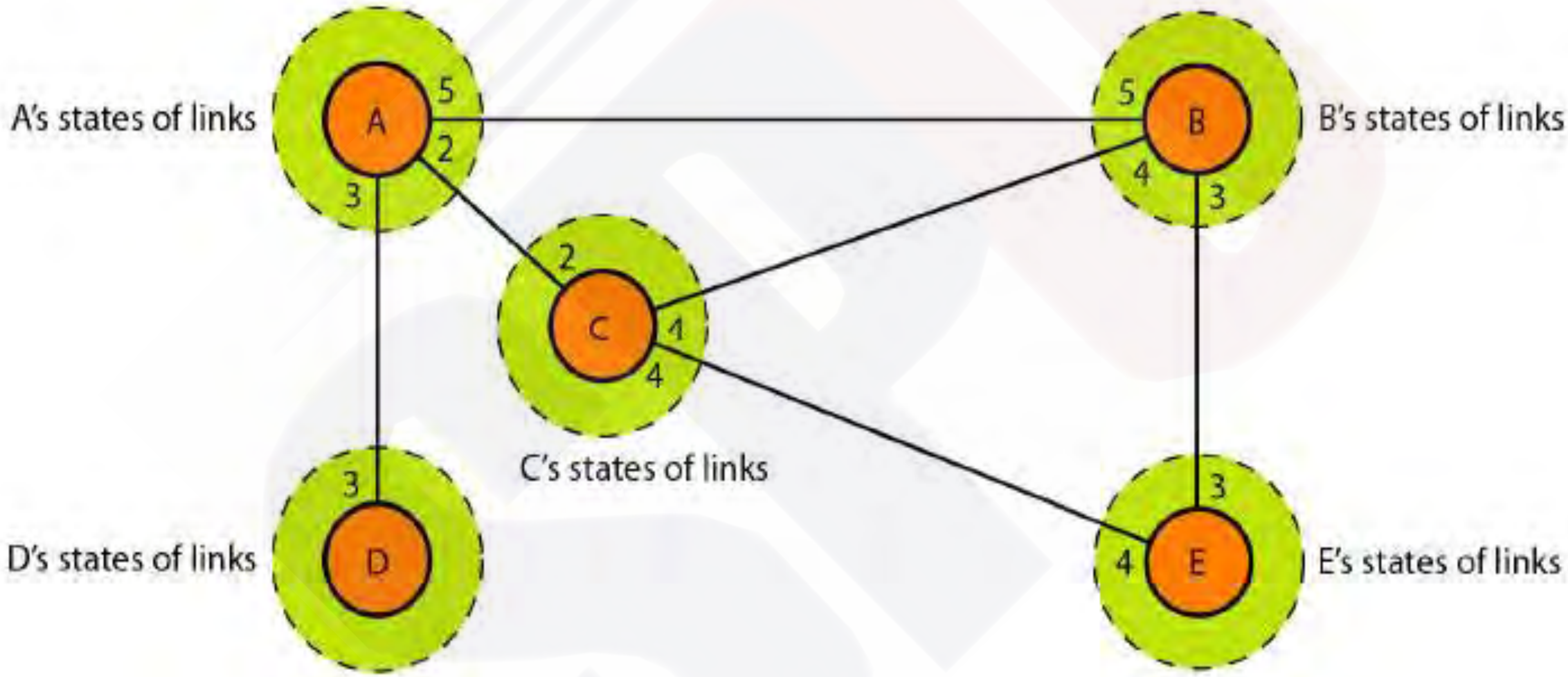
- After B receives updates from A

Concept of link state routing

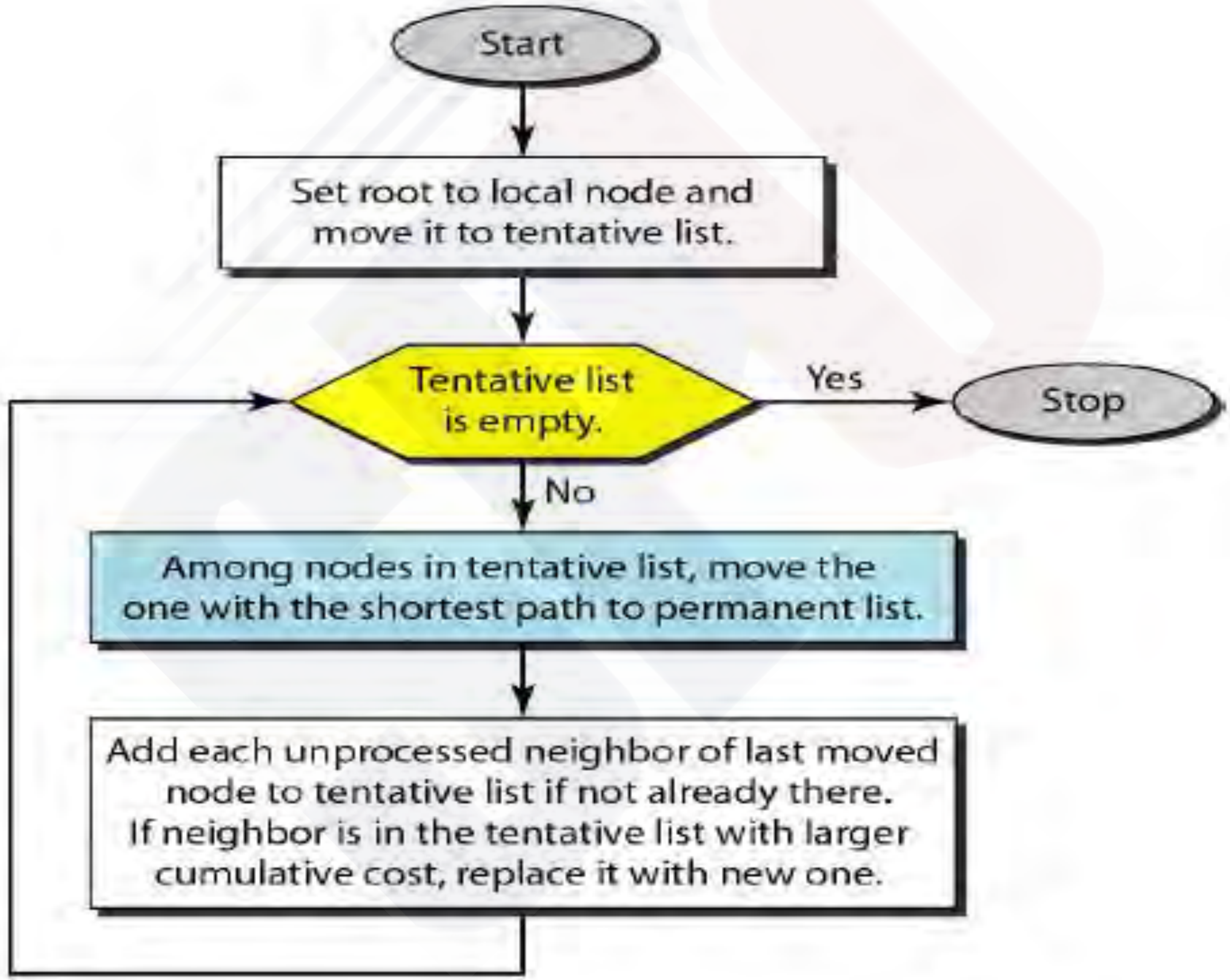



A
B
C
D
E
5
2
4
3
3
4

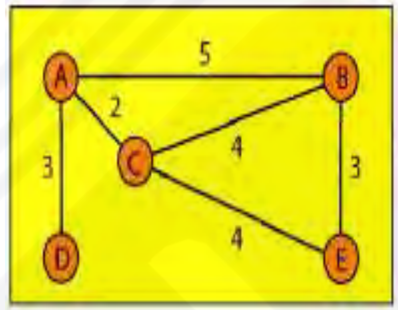
Link state knowledge



Dijkstra algorithm



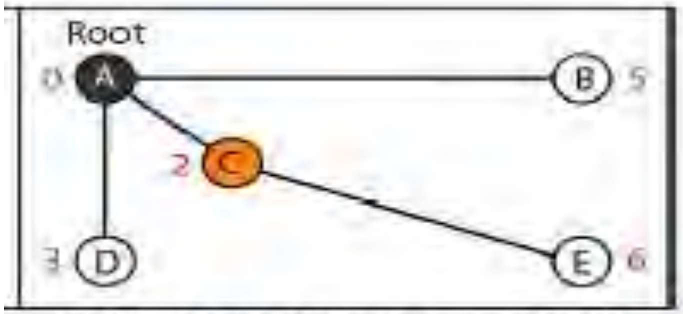
Example of formation of shortest path tree



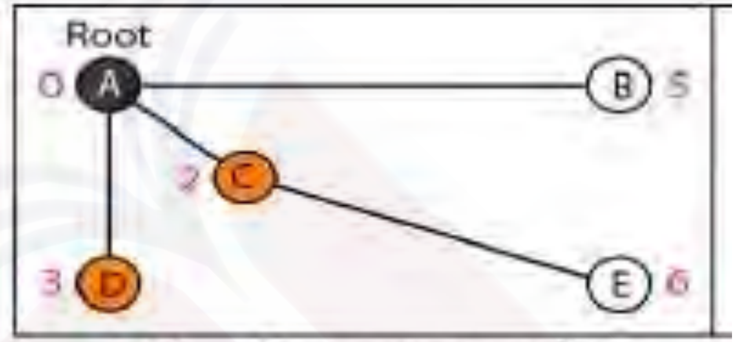
Topology

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

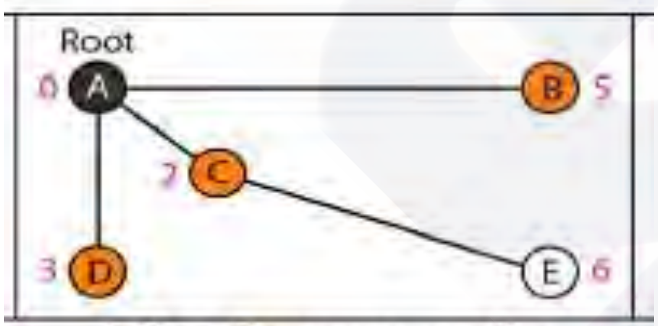
2. Move A to permanent list and add B, C, and D to tentative list.



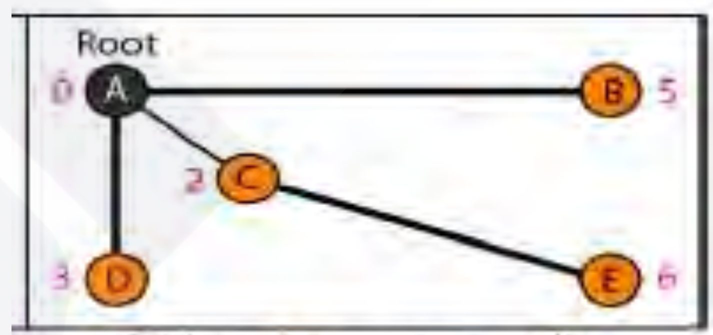
3. Move C to permanent and add E to tentative list.



4. Move D to permanent list.



5. Move B to permanent list.



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

Routing table for node A

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

MULTICAST ROUTING PROTOCOLS

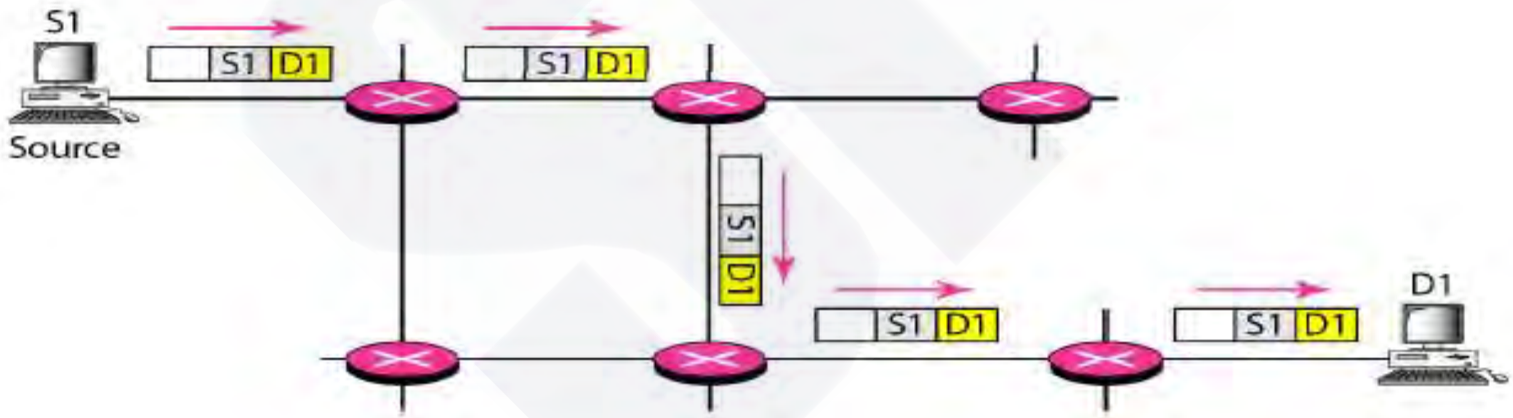
Unicasting

- In unicast communication, there is one source and one destination.
- In the following figure, a unicast packet starts from the source S1 and passes through routers to reach the destination D1

Unicasting

Note

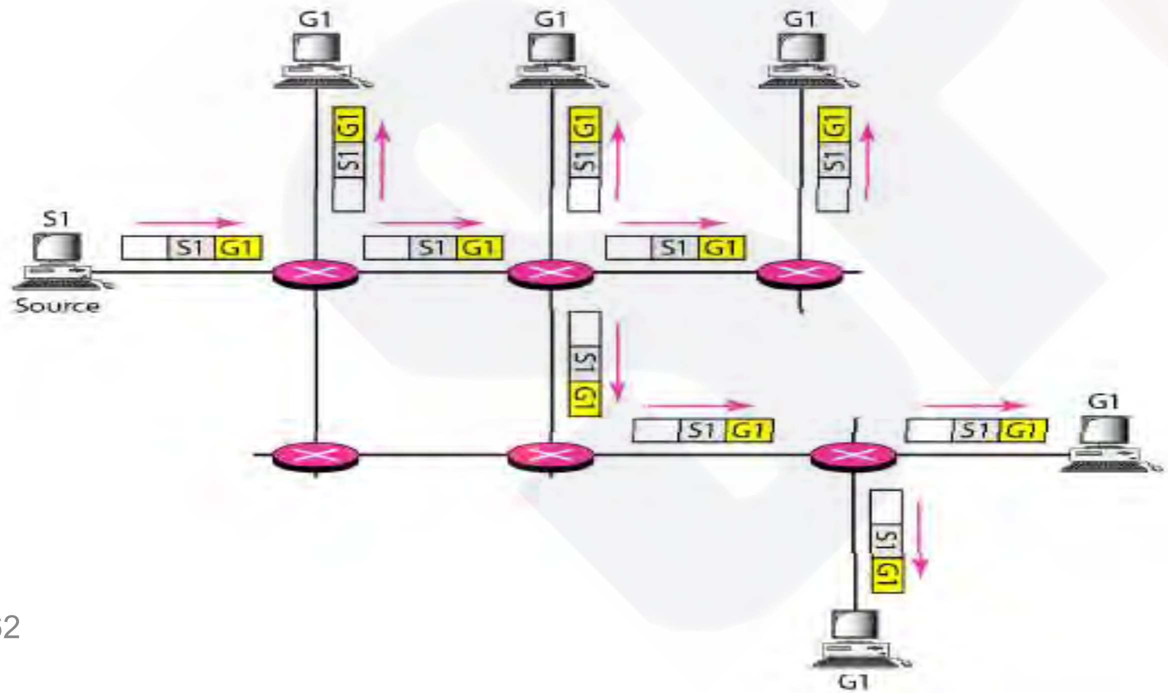
In unicasting, the router forwards the received packet through only one of its interfaces.



Multicasting

Note

In multicasting, the router may forward the received packet through several of its interfaces.



Multicast Routing

- Optimal Routing: **Shortest Path Trees**
- The root of the tree is the source
- The leaves are the potential destinations
- The path from the root to each destination is the shortest path

Unicast Routing

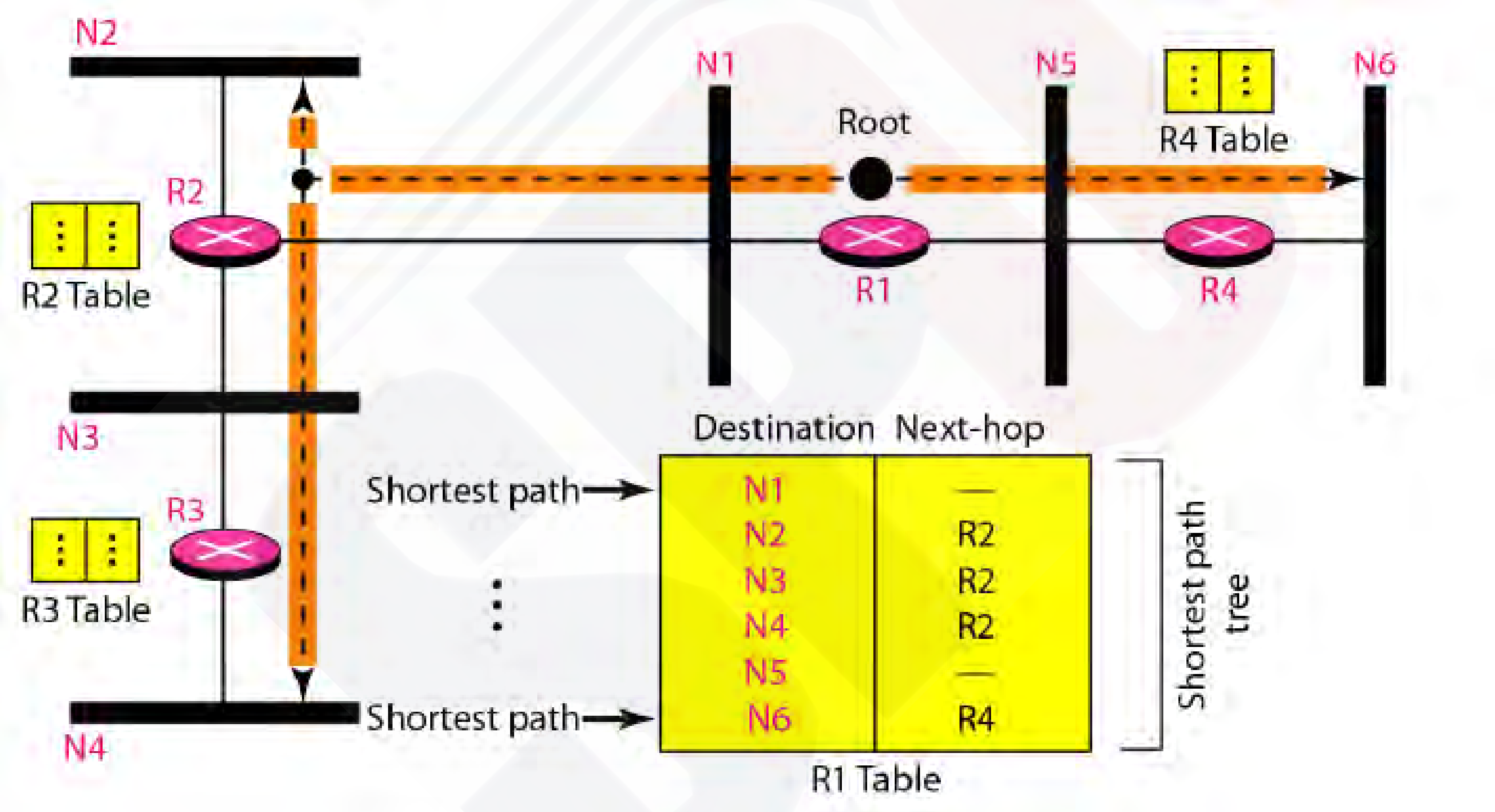
- When a router receives a packet to forward, it needs to find the shortest path to the destination.
- The next hope entry corresponding to the destination is the start of the shortest path
- The router knows the shortest path for each destination, which means that the router has a shortest tree to optimally reaaches all destinations.

- Each line (row) of the routing table is a shortest path
- The whole routing table is a shortest path tree

Unicast Routing

In unicast routing, each router in the domain has a table that defines a shortest path tree to possible destinations.

Shortest path tree in unicast routing



Multicast Routing

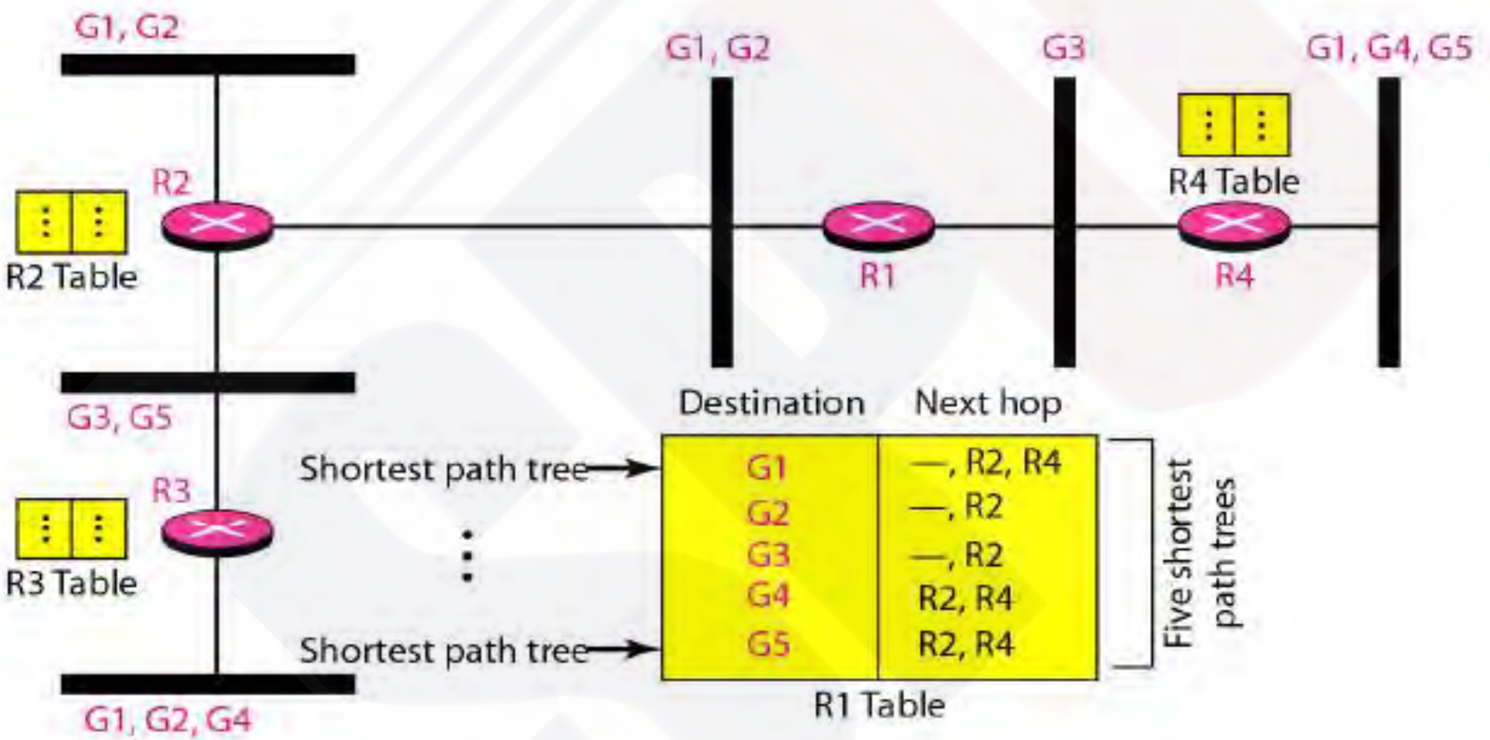
- When a router receives a multicast packet. The situation is different from when it receives a unicast packet
- A multicast packet may have destination in more than one network.
- Forwarding of a single packet to members of group requires a shortest path tree.

- If we have n groups, we may need n shortest path trees
- This gives rise to complexity of multicast routing
- Two approaches are used to solve the problem:
- Source- based trees
- Group-shared tress

Source-based tree approach

- In the source based approach, each router needs to have one shortest path tree for each group.
- The shortest path tree for a group defines the next hop for each network that has loyal member for that group

- For five groups in the domain as illustrated
- G1, G2, G3, G4, G5



- We show that:
- G1 has loyal member in 4 networks
- G3 in 3 networks
- G3 in 2 networks
- G4 in 2 networks
- G5 in 2 networks

Note

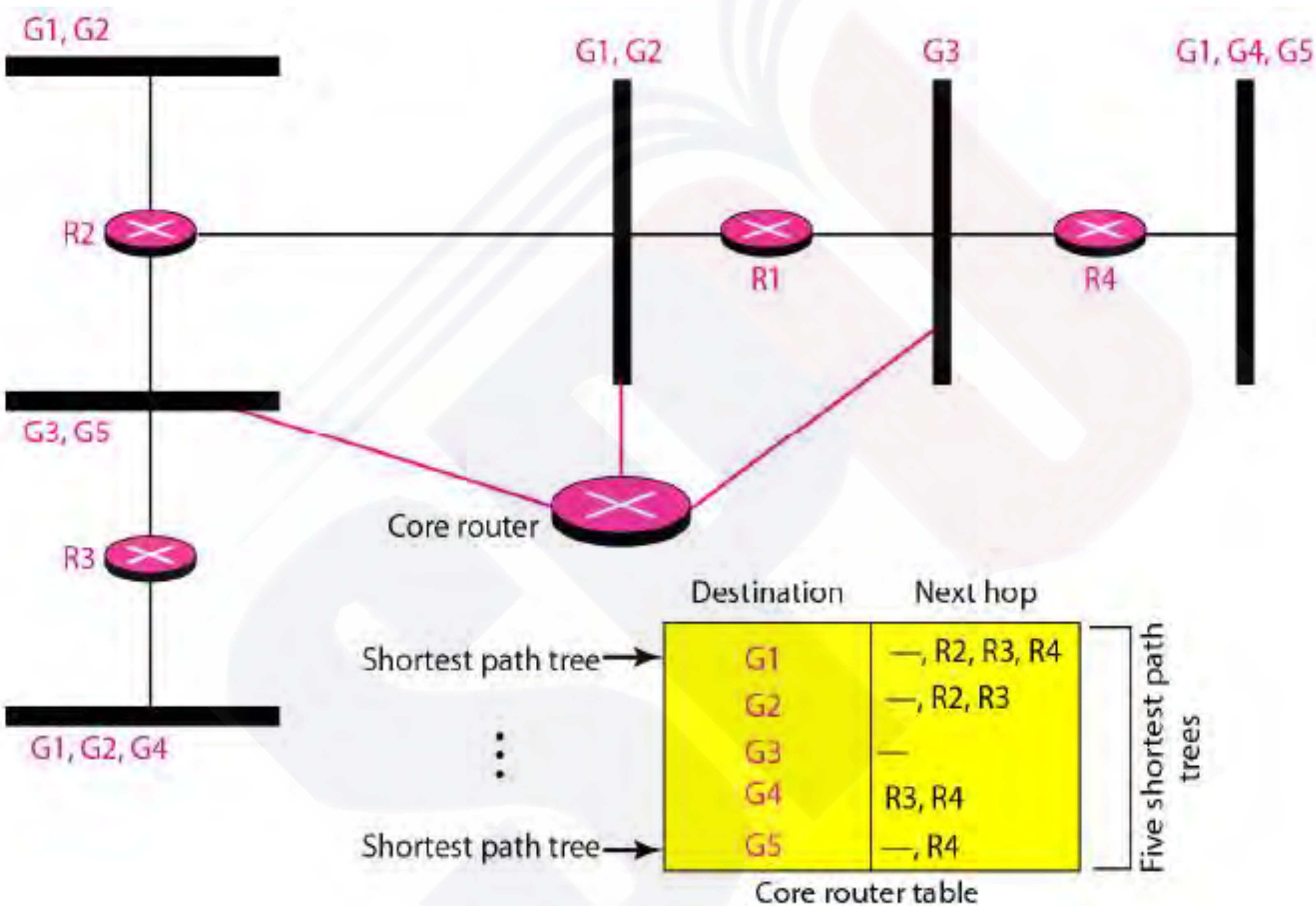
In the source-based tree approach, each router needs to have one shortest path tree for each group.

- For router R1
- There is one shortest path tree for each group
- If router R1 receives a packet with destination address G1, it needs to send a copy of the packet to attached network
- Copy to router R2
- Copy to router R4
- All members of G1 can receive a copy.
- ***<u>Disadvantage :</u>***
- Many groups (say 100 groups or 1000) complex routing table

Group-shared tree approach

- Instead of each router having m shortest path trees, only one designated router, called the center core, takes the responsibility multicast traffic.
- The core has m shortest path trees in its routing table
- The rest of the routers in the domain have none

- If a router receives a multicast packet, it encapsulate the packet in a unicast packet and sent it to the core router
- The core router removes the multicast packet from its capsult and consults its routing table to route the packet


G1, G2
G1, G2
G3
G1, G4, G5
R2
R1
R4
G3, G5
Core router
R3
G1, G2, G4
Destination
Next hop
Shortest path tree
Shortest path tree
G1 —, R2, R3, R4
G2 —, R2, R3
G3 —
G4 R3, R4
G5 —, R4
Five shortest path trees
Core router table

Note

In the group-shared tree approach, only the core router, which has a shortest path tree for each group, is involved in multicasting.