Tue 7 Apr

Chapter 08

Network Layer: Routing of Packets

- Data Communications and Networking, With TCP/IP protocol suite Sixth Edition
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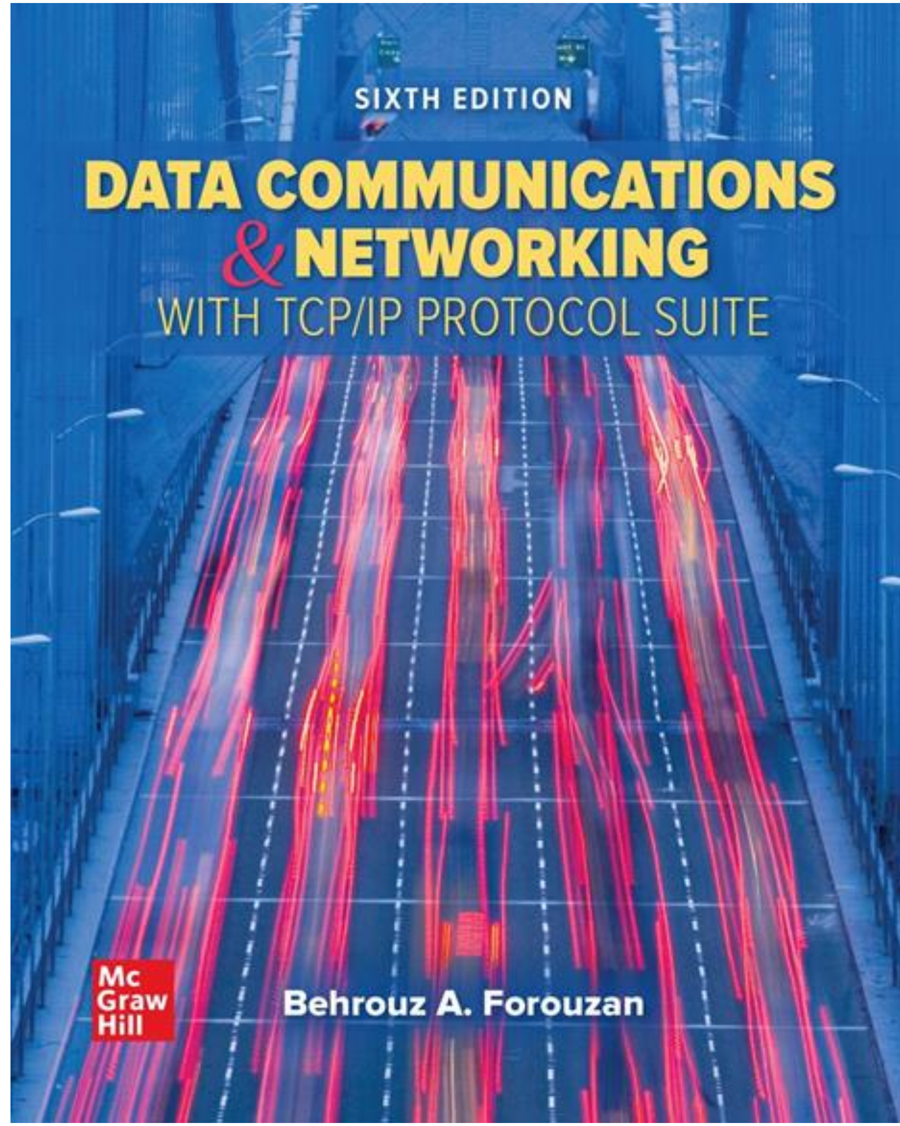
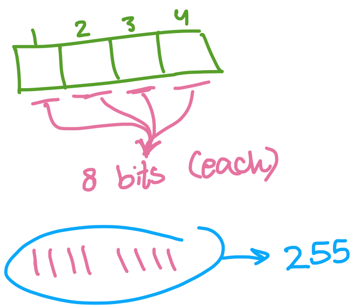


Chapter 8: Outline

- **8.1 Introduction**
- **8.2 Routing Algorithms**



subnet mask
AND IP address

Network address

Wed 8 Apr

Routing (IP routing)

- Routing Protocol: determines the **best path** (route) that the packets should follow to arrive to the desired destination
- Routing Protocols: A **software** in the network layer that implements **routing algorithms** and responsible for:
  - Filling and updating routing tables (by finding the shortest paths **(best path)** from each source to each destination) This part is called **Routing**
  - Deciding which output interface an incoming packet should be transmitted on (by referring to the routing table). This part is called **Forwarding**

8-1 INTRODUCTION

- Unicast routing in the Internet, with a large number of routers and a huge number of hosts, can be done only by using hierarchical routing: routing in several steps using different routing algorithms.

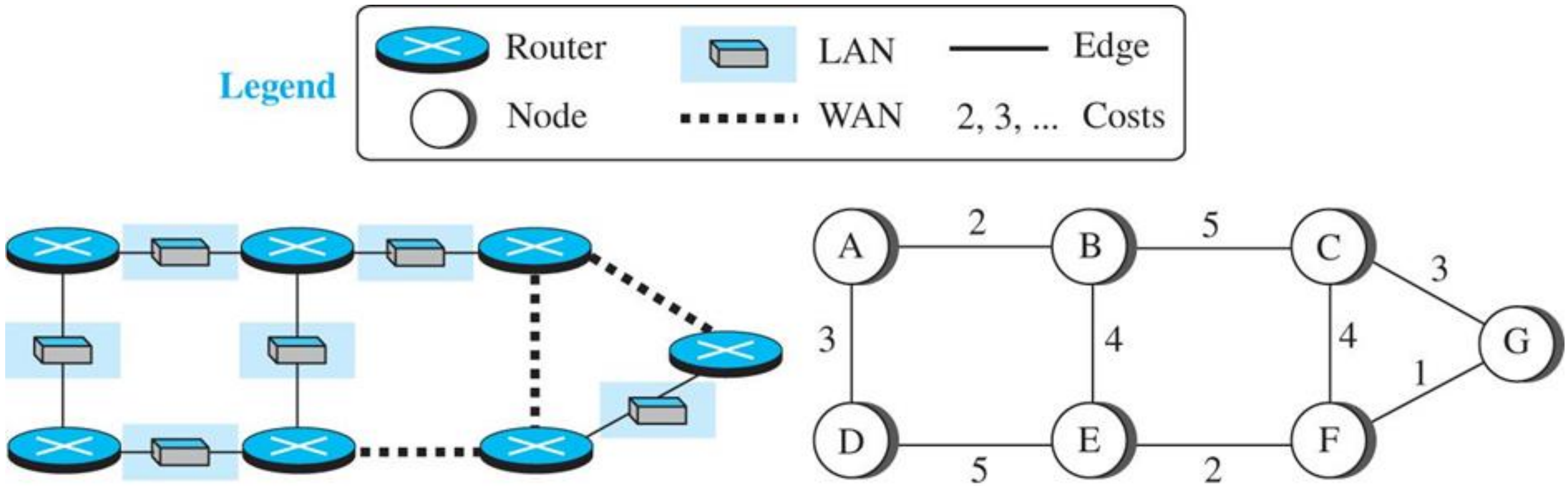
8.1.1 General Idea

- In unicast routing, a packet is routed, hop by hop, from its source to its destination by the help of forwarding tables.
- The source host needs no forwarding table because it delivers its packet to the default router in its local network.
- The destination host needs no forwarding table either because it receives the packet from its default router in its local network.
- This means that only the routers that glue together the networks in the internet need forwarding tables.

An Internet as a Graph

- To find the best route, an internet can be modeled as a graph.
- A graph in computer science is a set of nodes and edges (lines) that connect the nodes.
- To model an internet as a graph, we can think of each router as a node and each network between a pair of routers as an edge.
- An internet is, in fact, modeled as a weighted graph, in which each edge is associated with a cost.

Figure 8.1 An internet and its graphical representation

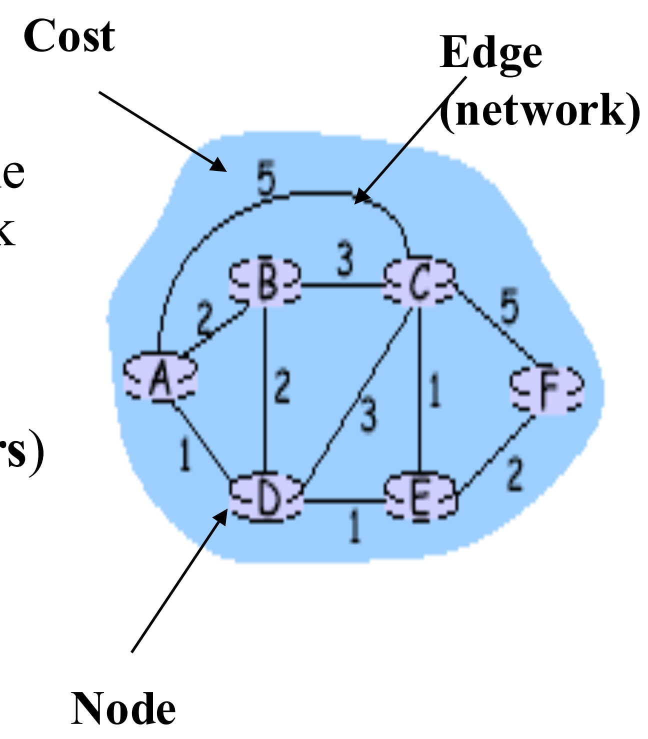


a. An internet

b. The weighted graph

Graph representation of a network

- Graph **nodes** are **routers**
- Graph **edges** are **physical links**
  - Each link has a value which represents the "cost" of sending a packet across the link
  - The **cost** is assigned based on a **metric**
  - Cost metric can be:
    - Number of networks (**hops or routers**)
    - Geographic distance
    - Link delay
    - Capacity (speed)
    - Reliability
    - Combination of the above



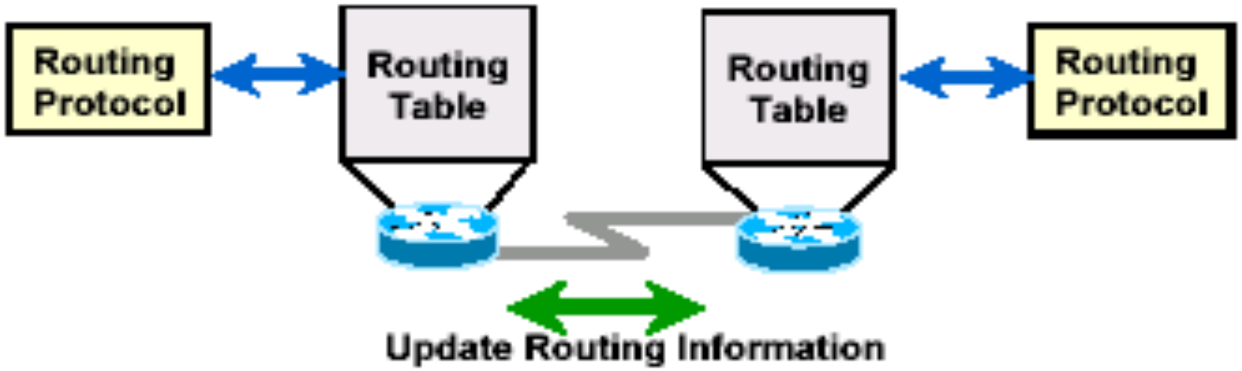
- How to select a "good" path???
  - Good path is the one with **minimum cost** = $\sum$ **Total cost** from **src to dest**

Routing Algorithms Classifications

- Static
  - Routes change **slowly** over time
  - Shortest paths are precomputed offline by a special computer running the routing algorithm
  - Resulted information is entered manually by the administrator into the routing tables
  - **Can not** update automatically if there is a change in the network or failure
  - Used in **small** networks
- Dynamic (adaptive)
  - Each router or host learns the state of the network by **communicating** with its **neighbours (routers that are directly connected to each other).**
  - Based on the collected information, each node (router) can fill its routing table
  - More complexity is added to the router

Routing algorithm: Dynamic Route operation

- Routing protocol maintains and distributes routing information



How to reduce number of entries in the routing table?

could reduce entry number in routing table

- Network-Specific routing (Destination Network IP Address is listed in the table)
- Host Specific Routing (Destination Host IP Address is listed in the table)
- Default Routing

Host-specific versus network-specific method

Host

Destination	Next Hop
N1	Directly Connected
A	R1
B	R1
C	R1
D	R1

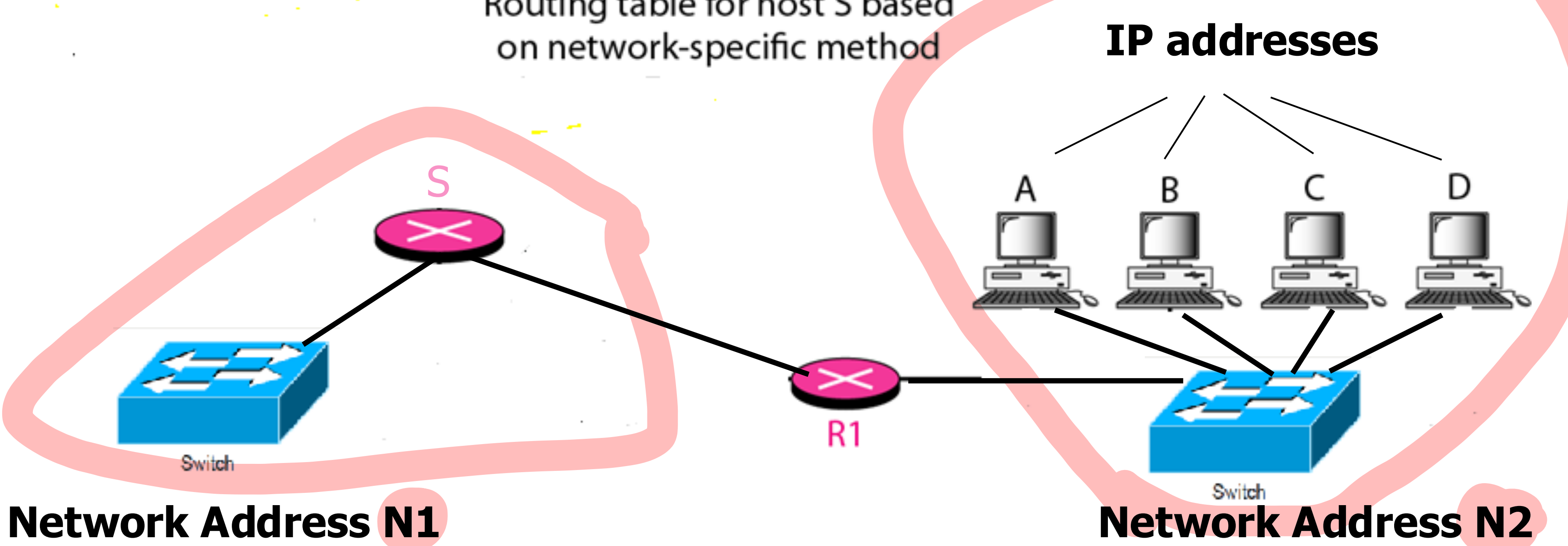
Routing table for host S based on host-specific method

hosts here are computers

Network

Destination	Next Hop
N1	Directly Connected
N2	R1

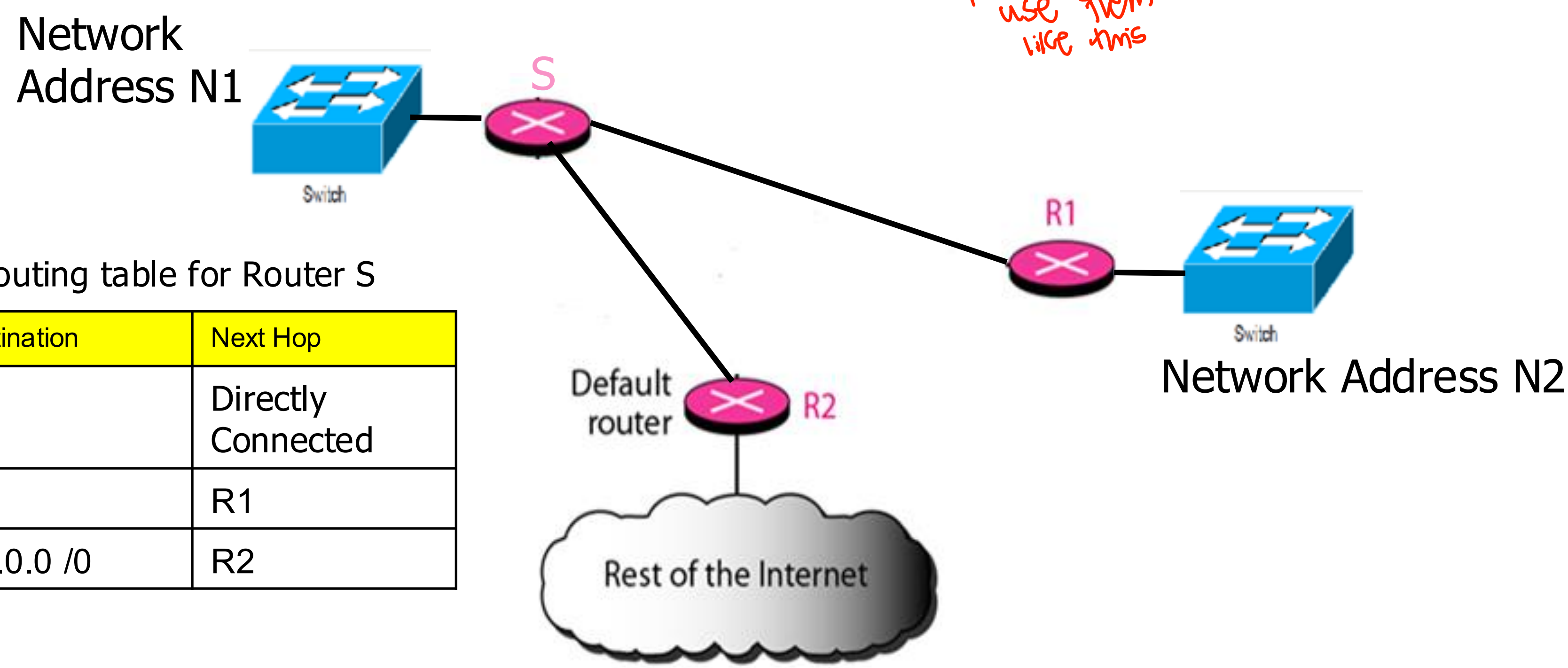
Routing table for host S based on network-specific method



Default Route

- Default route is used if the destination network address is not found in the routing table
- 0.0.0.0 /0 is the address used for default route
- 0.0.0.0 /0 corresponds to any other in the routing table

probably won't use them like this



Routing table for Router S

Destination	Next Hop
N1	Directly Connected
N2	R1
0.0.0.0 /0	R2

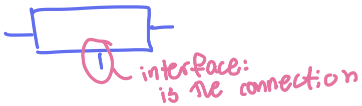
18-5 FORWARDING OF IP PACKETS

We discussed the concept of forwarding at the network layer earlier in this chapter. In this section, we extend the concept to include the role of IP addresses in forwarding. As we discussed before, forwarding means to place the packet in its route to its destination.

Destination Address Forwarding

We first discuss forwarding based on the destination address. This is a traditional approach, which is prevalent today. In this case, forwarding requires a host or a router to have a forwarding 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 next hop to deliver the packet to.

Classful addressing routing table

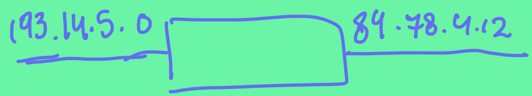


	Mask	Destination address	Next-hop address	Interface
	/8	14.0.0.0	118.45.23.8	m1
Host-specific →	/32	192.16.7.1	202.45.9.3	m0
	/24	193.14.5.0	84.78.4.12	m2
Default →	/0	0.0.0.0	145.11.10.6	m0

- **When a packet arrives:**
  - **Apply all the available masks to the IP destination address**
  - **If a match is found in the destination address column, the packet has to be forwarded to the next hop IP address through the corresponding interface**
  - **If no match is found, send the packet through the default interface**
  - **Otherwise, a message "host unreachable error" is sent back to the sender.**

Example

can extract this info from figure



	Mask	Destination address	Next-hop address	Interface
	/8	14.0.0.0	118.45.23.8	m1
Host-specific →	/32	192.16.7.1	202.45.9.3	m0
	/24	193.14.5.0	84.78.4.12	m2
Default →	/0	0.0.0.0	145.11.10.6	m0

want to find destination from routing table

193.14.5.22 (8, 8, 8)

Network address: 193.14.5.0

Using the table above, the router receives a packet for destination 193.14.5.22. For each row, the mask is applied to the destination address until a match with the next-hop address is found. In this example, the router sends the packet through interface m2 (**network specific**).

Example

	Mask	Destination address	Next-hop address	Interface
	/8	14.0.0.0	118.45.23.8	m1
Host-specific →	/32	192.16.7.1	202.45.9.3	m0
	/24	193.14.5.0	84.78.4.12	m2
Default →	/0	0.0.0.0	145.11.10.6	m0

can't find it

Using the table above, the router receives a packet for destination 200.34.12.34. For each row, the mask is applied to the destination address, but no match is found. In this example, the router sends the packet through the **default interface** m0.

Example

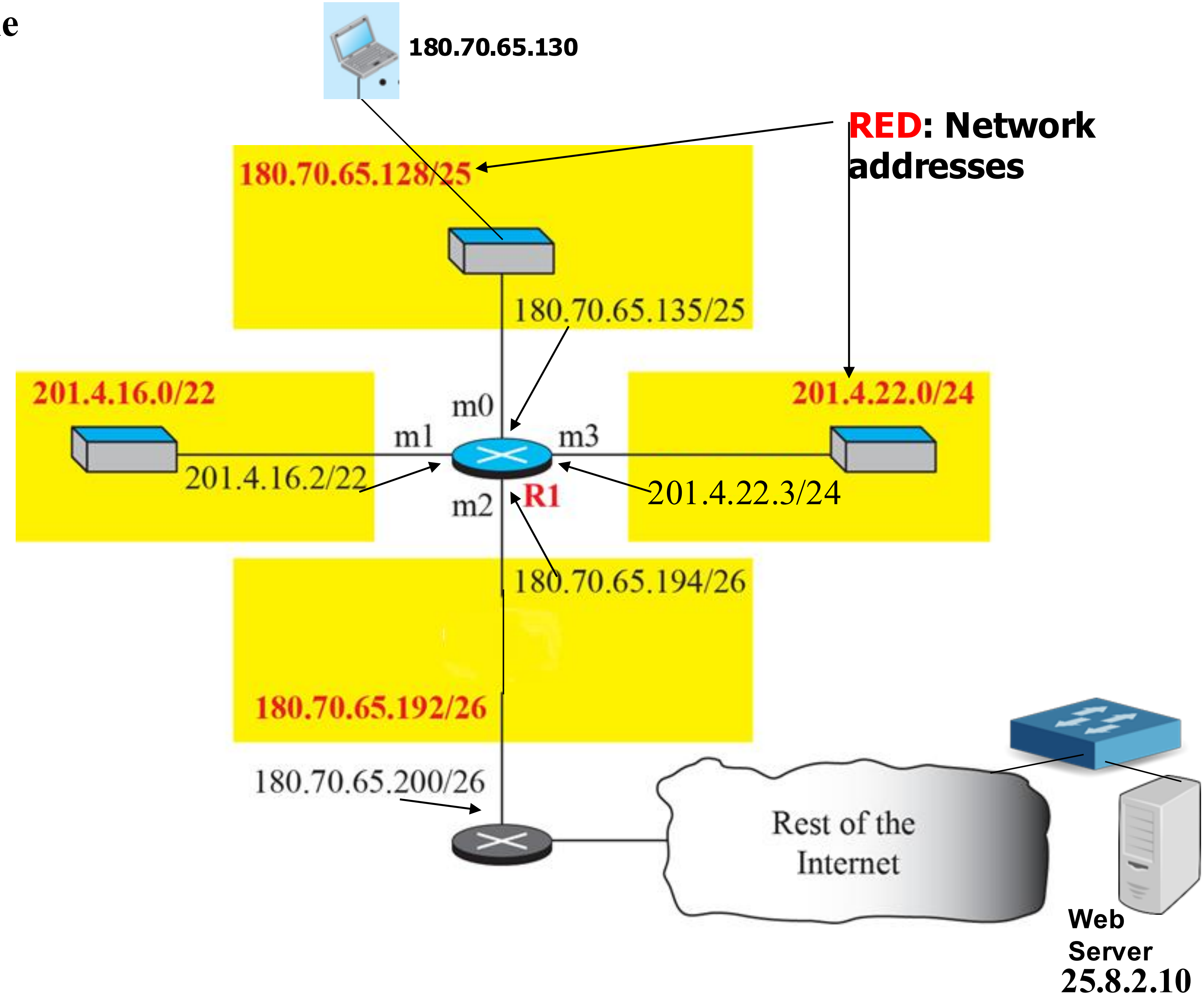
	Mask	Destination address	Next-hop address	Interface
	/8	14.0.0.0	118.45.23.8	m1
Host-specific →	/32	192.16.7.1	202.45.9.3	m0
	/24	193.14.5.0	84.78.4.12	m2
Default →	/0	0.0.0.0	145.11.10.6	m0

shouldn't be exactly the same
must have variation.

we call it
host specific

Using the table above, the router receives a packet for destination **192.16.7.1**. For each row, the mask is applied to the destination address until a match with the destination address is found. In this example, the router sends the packet through interface m0 (**host specific**).

Example



180.70.65.130
RED: Network addresses
180.70.65.128/25
180.70.65.135/25
201.4.16.0/22
m0
m1
m3
201.4.22.0/24
201.4.16.2/22
R1
m2
201.4.22.3/24
180.70.65.194/26
180.70.65.192/26
180.70.65.200/26
Rest of the Internet
Web Server
25.8.2.10

Make a forwarding table for router R1 using the configuration in previous slide

Solution

"-" means Directly connected network

Forwarding table for router R1

Network 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
0.0.0.0 /0	180.70.65.200	m2

Show the forwarding process if a packet arrives at R1 with the **destination address** 180.70.65.130.

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 extracted for forwarding the packet

Show the forwarding process if a packet arrives at R1 with the **destination address** 25.8.2.10.

Solution

The router performs the following steps:

1.The first mask (**/26**) is applied to the destination address. The result is **25.8.2.0**, which does not match the corresponding network address.

2. The second mask (**/25**) is applied to the destination address. The result is **25.8.2.0**, which does not match the corresponding network address.

3. The second mask (**/24**) is applied to the destination address. The result is **25.8.2.0**, which does not match the corresponding network address.

4. The second mask (**/22**) is applied to the destination address. The result is **25.8.0.0**, which does not match the corresponding network address.

In this example, the router sends the packet to the **default route**. The **next-hop address will be 180.70.65.200** through **interface** m2.

Sun 12 Apr

Shortest Path Routing

- Algorithms used to determine the shortest path between two nodes according to some cost condition.
- The shortest path is the path with the ***least cost*** (the sum of the cost of the links on the path is minimum over all possible paths between the source and destination)
- Two main algorithms to find the shortest path between any two nodes

  go distance in ford

  - Distance Vector (**Bellman-Ford** Algorithm)
  - Link State – (**Dijkstra's Algorithm**)

Imp to know the names

Distance Vector (DV) Routing

look at below diagram for reference

- Basic idea: each network node maintains a **Distance Vector (DV) table** containing the ***distances from*** itself to **ALL** possible destination nodes in the domain.
- Distances are based on a chosen metric (Metric: *usually number of hops, bandwidth, delay)*
- Router transmits its *distance vector table* to each of its **neighbors (directly connected to it) periodically** or when there is a change.
- A router **recalculates** its distance vector when:
  - It receives a *distance vector table* from a neighbor containing different information than before.
  - It discovers that a link to a neighbor has gone down or up (i.e., a **topology changes**).
- Distances to all destinations are computed using information from thereceived **neighbors'** distance vectors.
- The DV calculation is based on minimizing the cost to each destination.
- From its DV, a router can directly derive its **routing table**.
- **Enhanced Interior Gateway Routing Protocol (EIGRP) and Routing Information Protocol (RIP) are examples of distance vector protocols**

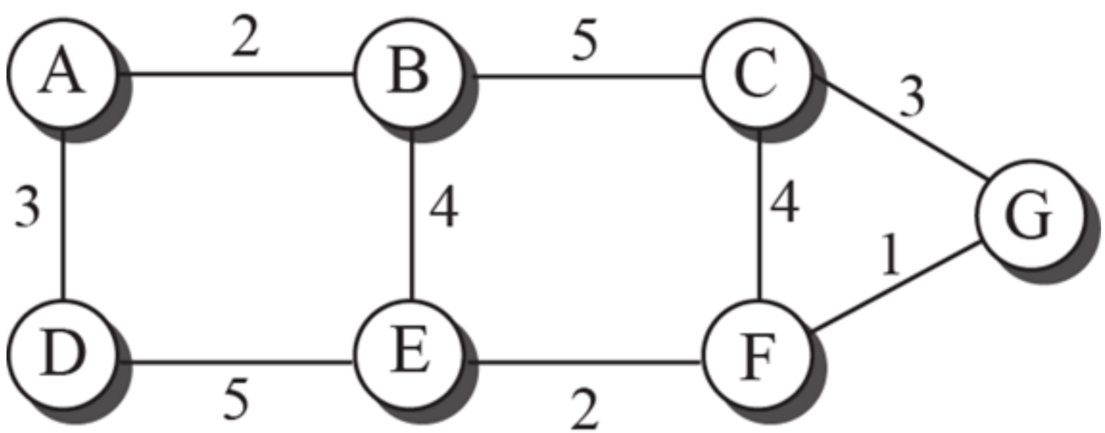
The **first round** distance vector for an internet

It has only the cost to the directly connected neighbors

read above at the same time

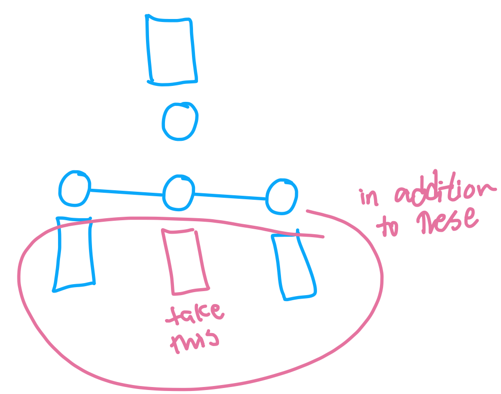
0 → itself
∞ → unreachable

	A	B	C	D	E	F	G
A	0	2	∞	3	∞	∞	∞
B	2	0	5	∞	4	∞	∞
C	∞	5	0	∞	∞	4	3
D	3	∞	∞	0	5	∞	∞
E	∞	4	∞	5	0	2	∞
F	∞	∞	4	∞	2	0	1
G	∞	∞	3	∞	∞	1	0



∞: means not reachable

don't know distance



Updating distance vectors (case for node B)

	New B	Old B	A
A	2	2	0
B	0	0	2
C	5	5	∞
D	5	∞	3
E	4	4	∞
F	∞	∞	∞
G	∞	∞	∞

B[ ] = min (B[ ] , 2 + A[ ])

a. First event: B receives a copy of A's vector.

Minimum Cost from B to A is 2

① Find min distance in path

②

A sends its distance vector table to B

Note: X[ ]: the whole vector

checking out options

E sends its distance vector table to B

	New B	Old B	E
A	2	2	∞
B	0	0	4
C	5	5	∞
D	5	5	5
E	4	4	0
F	6	∞	2
G	∞	∞	∞

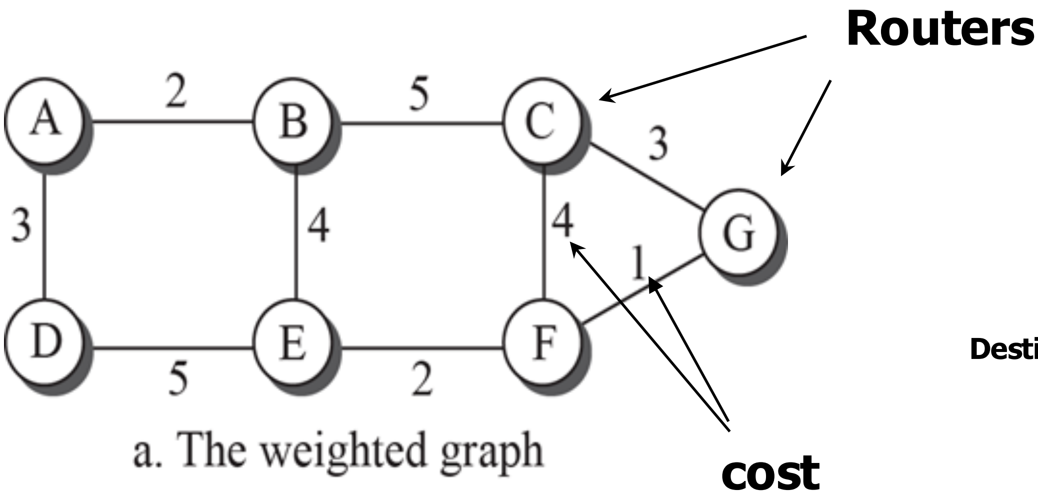
B[ ] = min (B[ ] , 4 + E[ ])

b. Second event: B receives a copy of E's vector.

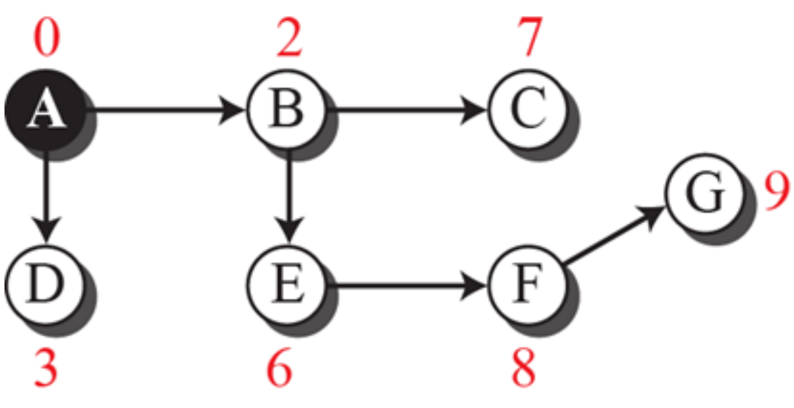
Minimum Cost from B to E is 4

The distance vector corresponding to a tree

based on best path shape of tree will be effected



a. The weighted graph



a. Tree for node A

Source: A
Destination

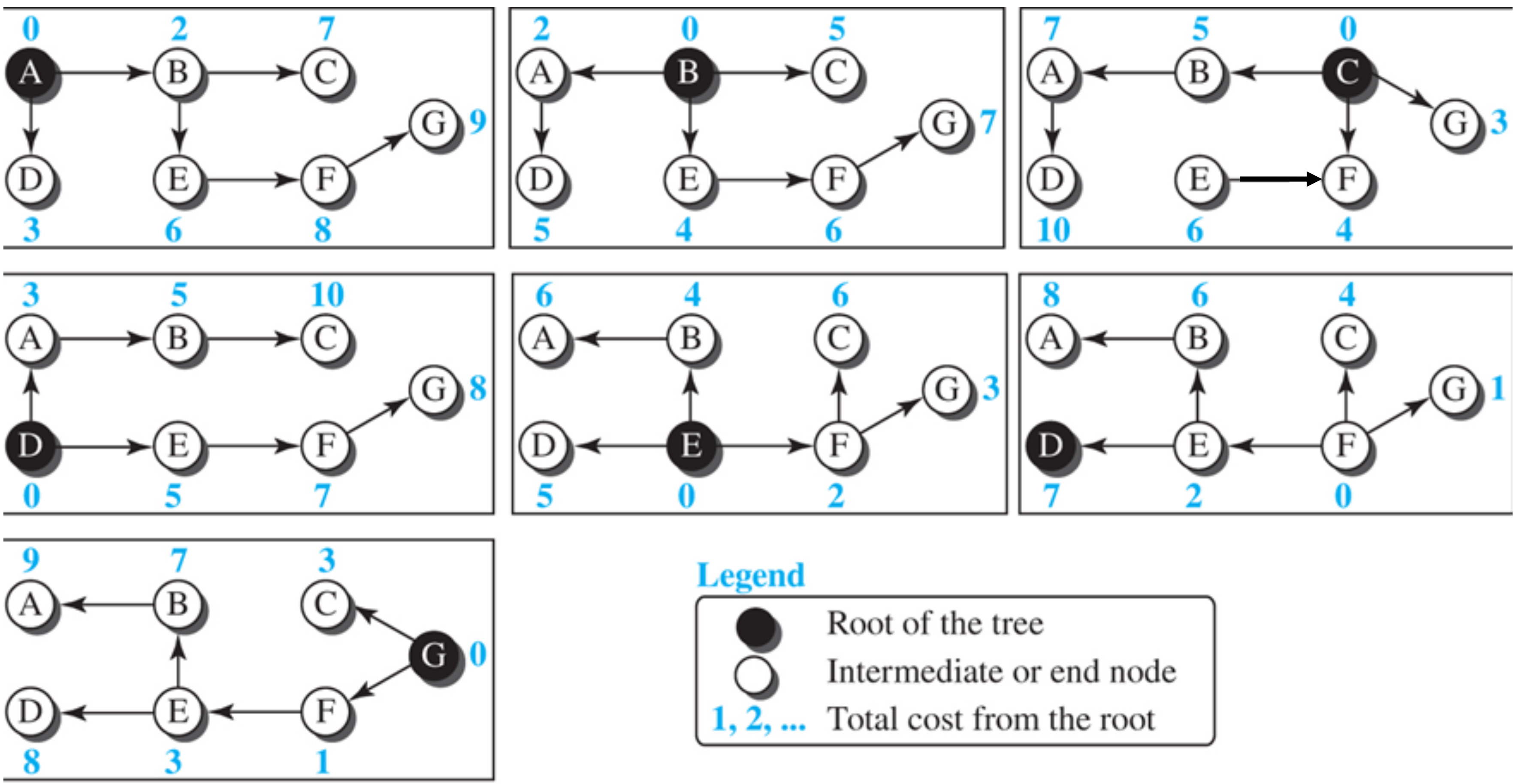
Destination	A
A	0
B	2
C	7
D	3
E	6
F	8
G	9

Minimum costs from A to others

b. Distance vector for node A

IMP

Least-cost trees for nodes for the previous network



Mon 13 Apr

Link State Routing

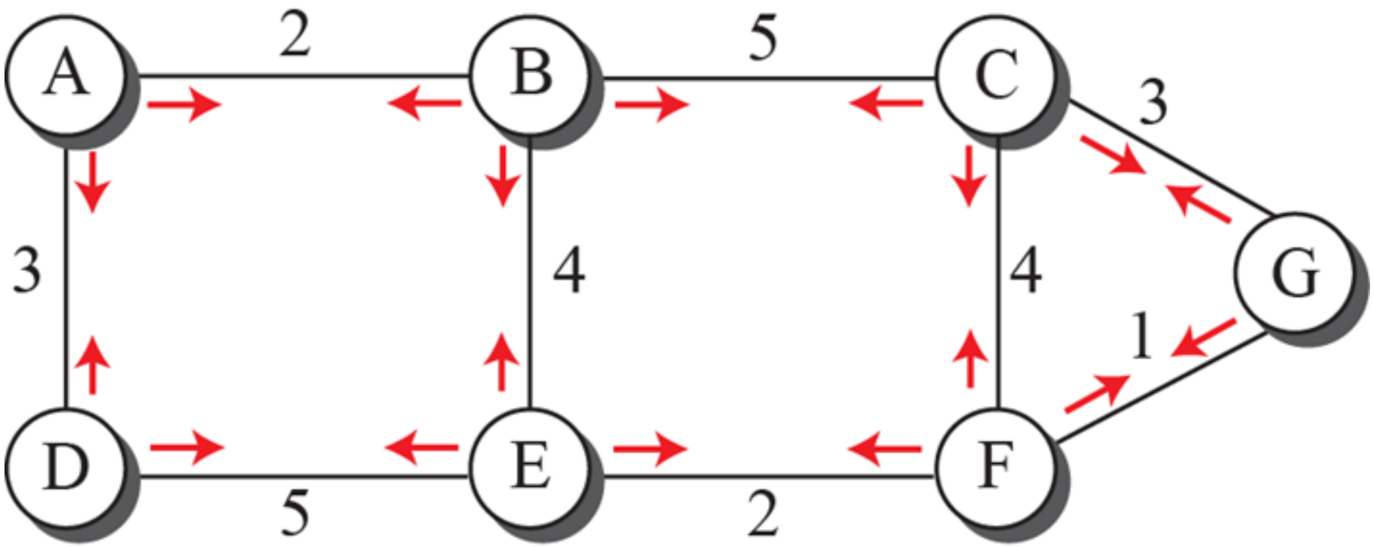
- Each router measures the cost (in either delay, Bandwidth) between itself and its neighbour routers (directly connected)
- The router builds a packet containing all these costs.
- Each router distributes these packets using **flooding** to **ALL** other routers in **the routing area**
- Information is then sent when **there a change** in the link between the router and its neighbours (to reduce traffic)
- Each router builds map (database) of the **entire network**, uses a **shortest-path algorithm** (usually Dijkstra algorithm) to compute a shortest path between itself and any other node in the area (creates the routing table)
- **OSPF** (Open Shortest Path first is an Example)

Link Statae Packets (LSPs) created and sent out by each node to build LSDB

Node	Cost
B	2
D	3

Node	Cost
A	2
C	5
E	4

Node	Cost
B	5
F	4
G	3



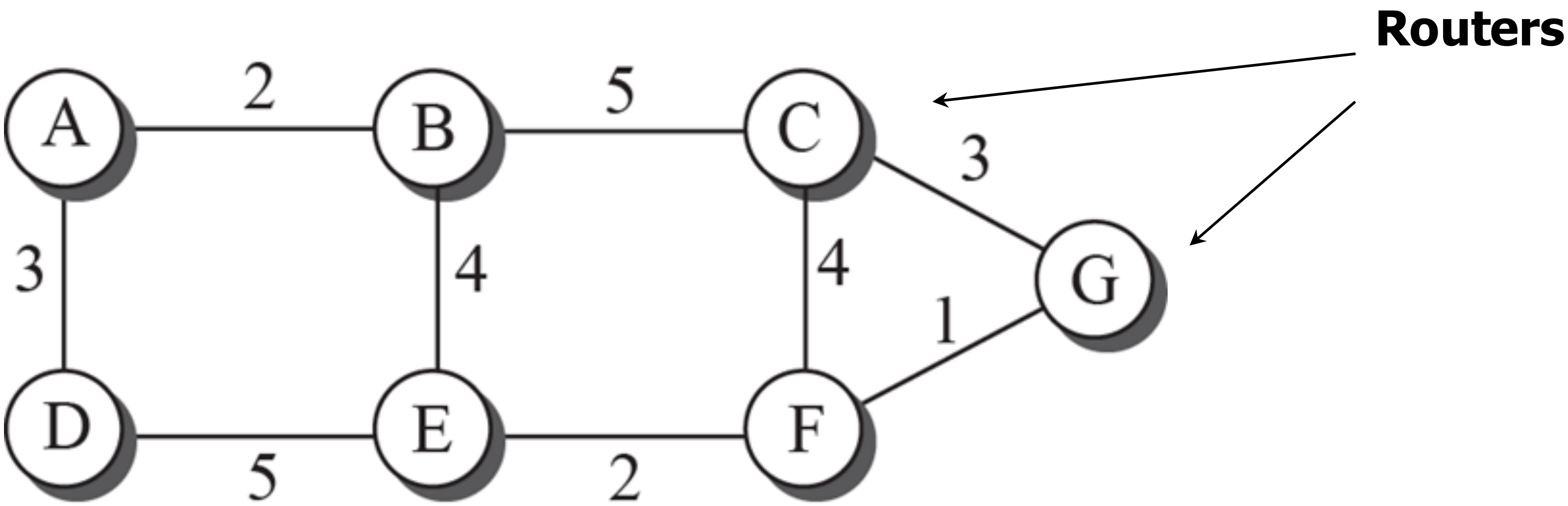
Node	Cost
C	3
F	1

Node	Cost
A	3
E	5

Node	Cost
B	4
D	5
E	2

Node	Cost
C	4
E	2
G	1

Example of a link-state database (LSDB)



a. The weighted graph

Each router will have the <u>same</u> link state database

	A	B	C	D	E	F	G
A	0	2	∞	3	∞	∞	∞
B	2	0	5	∞	4	∞	∞
C	∞	5	0	∞	∞	4	3
D	3	∞	∞	0	5	∞	∞
E	∞	4	∞	5	0	2	∞
F	∞	∞	4	∞	2	0	1
G	∞	∞	3	∞	∞	1	0

b. Link state database

Comparison between distance vector & Link state

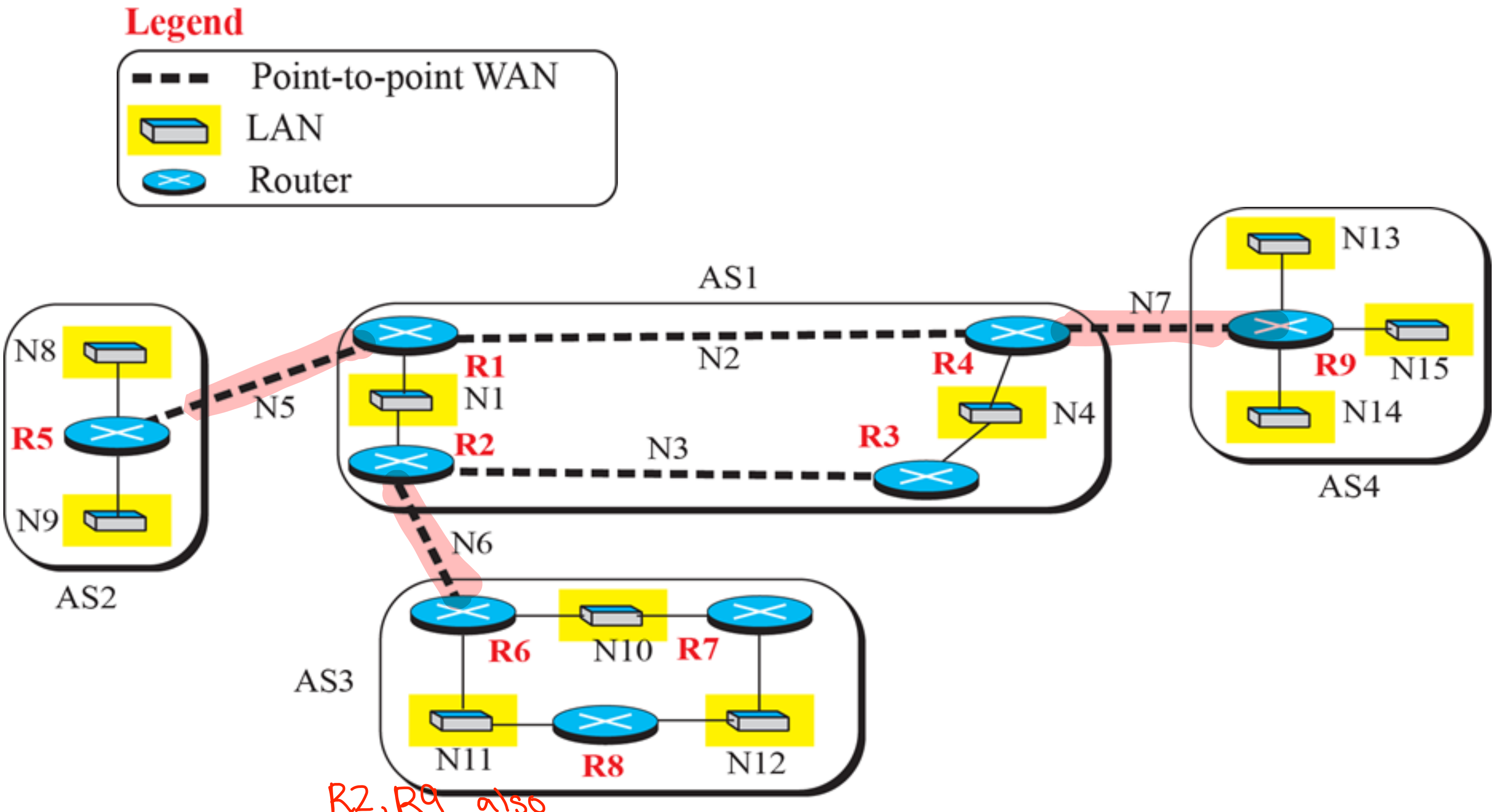
- Distance vector routing
- Each router Sends routing information to its neighbours
- The information sent is an estimate of the path cost to all known destinations in the area
- Information is sent periodically (every 30 s) by the router's own timer
- React to link failure very slowly

- Link state routing
- Each router sends routing information to ALL routers in the area
- The information sent is the exact value of the links cost that connect the router to its neighbours
- Information is sent when there is a change
- React to network failure quickly

Autonomous systems (AS)

- On the Internet, Autonomous system (AS) is either a **single network** or a **group of networks** that is controlled by a **common network administrator**
- An autonomous system is assigned **a globally unique number**, sometimes called an Autonomous System Number (ASN).
- AS systems are connected by special routers called **boarder routers or gateways routers.**
- Routers in **same** AS run **same** routing protocol this is called "intra-AS" (interior) routing protocol
- Routing between autonomous systems is called **inter-AS** or **exterior routing**
- Gateways routers (boarder routers) are special routers in AS that run intra-AS" routing protocol and also responsible for routing to destinations outside AS by running inter-AS (exterior) routing protocol with other gateway (boarder) routers

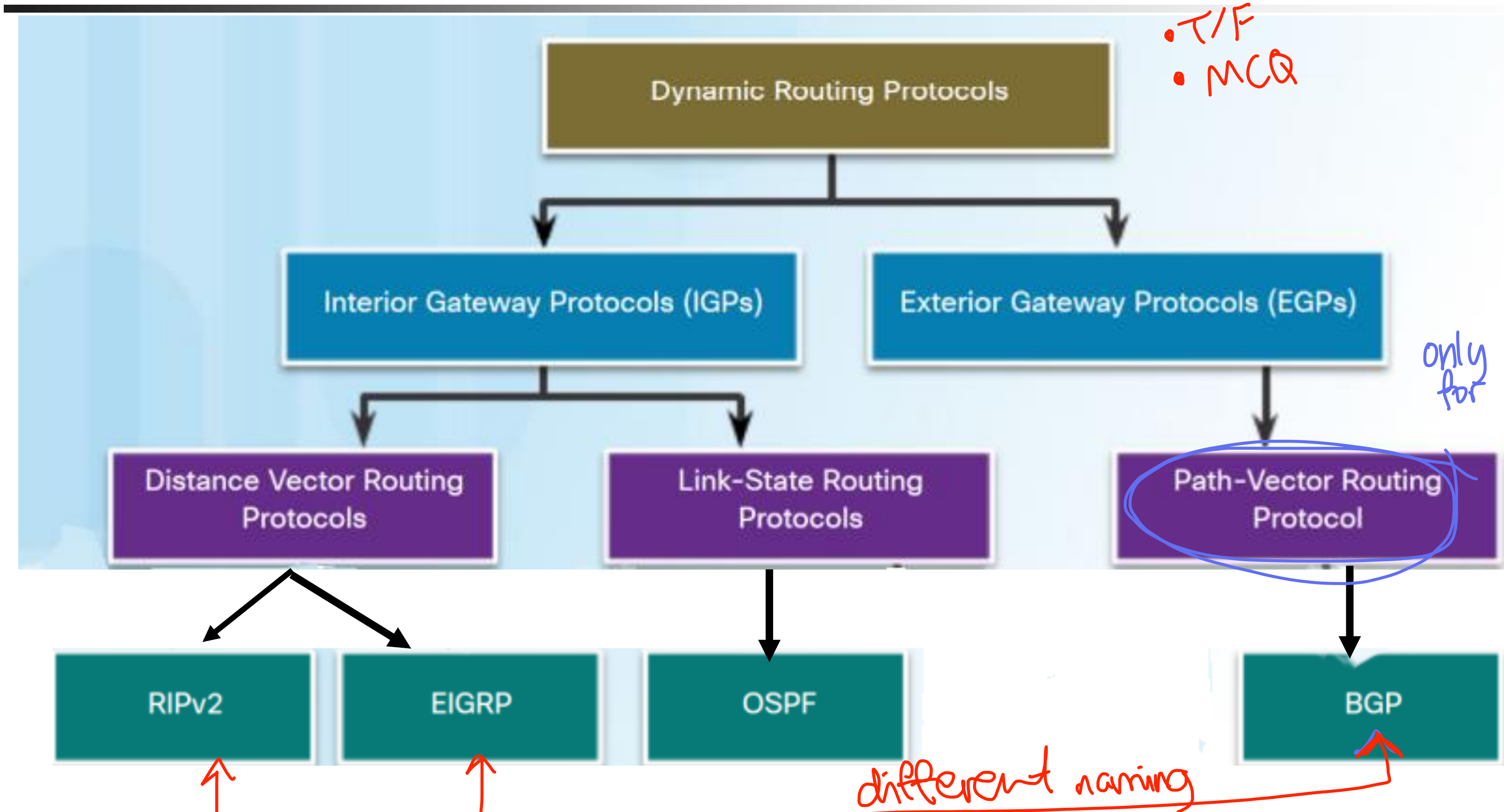
A sample internet with four ASs



- Routers R1,R4,R5,R6 are designated as border gateway routers
- These routers run both interior and exterior routing protocols

Popular routing protocols

- Fill in blank
- T/F
- MCQ



- **Interior routing (RIP, OSPF,EIGRP): between routers inside a single AS**
- **Exterior routing (BGP): between routers connecting several AS**
  - **BGP stands for Border Gateway Protocol Routing**