CS321: Computer Networks

Unicast Routing

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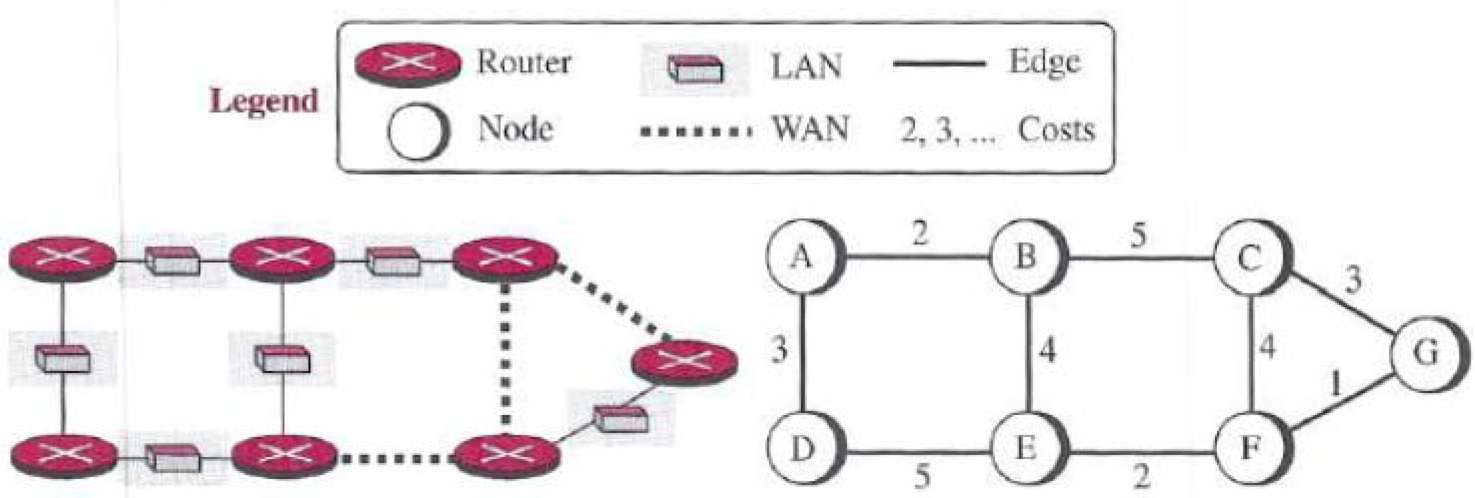
Introduction

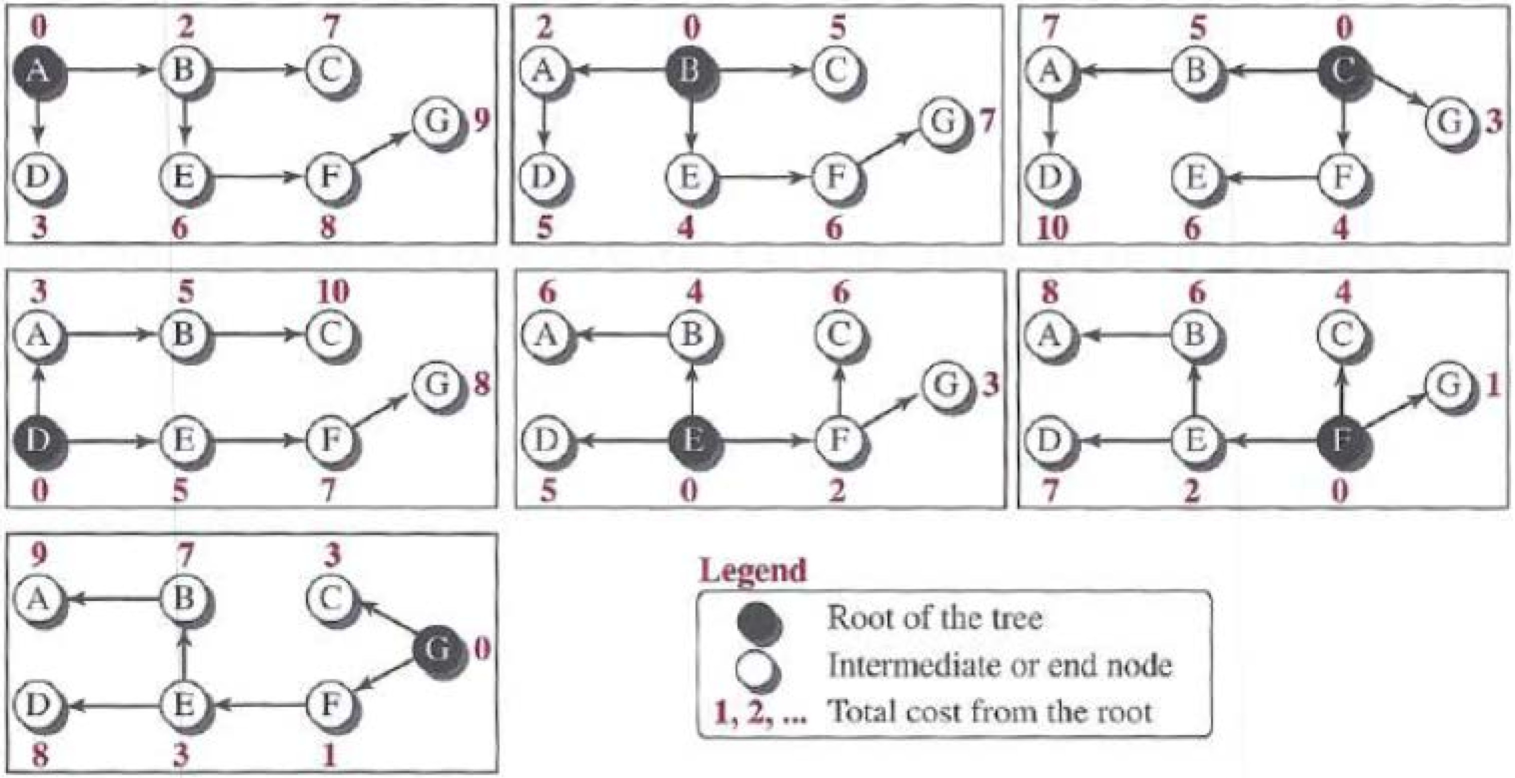
- The goal of the network layer is deliver a datagram from its source to its destination.
- An Internet as a Graph



a. An internet

b. The weighted graph

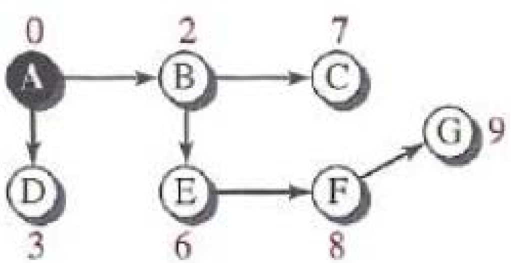
Least cost routing



- one of the ways to interpret the *best* route from the source router to the destination router is to find the *least cost* between the two.
  - Distance vector approach
  - Link state approach

Distance Vector Routing

- a router continuously tells all of its neighbours what it knows about the whole internet (although the knowledge can be incomplete)
- each node creates its own least-cost tree with the (incomplete) information it receives from neighbours
- It is iterative, asynchronous, and distributed
- The heart of distance-vector routing is Bellman-Ford equation: $d_x(y) = \min_v\{c(x,v) + d_v(y)\}$



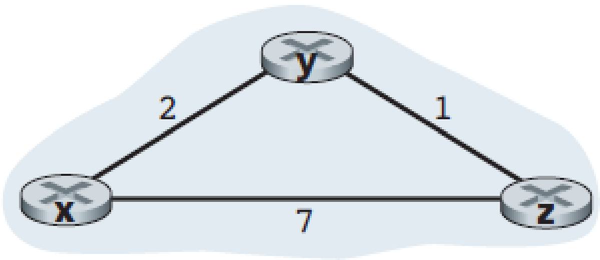
a. Tree for node A

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

b. Distance vector for node A

distance vector:
a one-dimensional array to represent the least-cost tree

Cont…



Node x table

from \ cost to	x	y	z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	7	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

Node y table

from \ cost to	x	y	z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

from \ cost to	x	y	z
x	0	2	7
y	2	0	1
z	7	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

Node z table

from \ cost to	x	y	z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

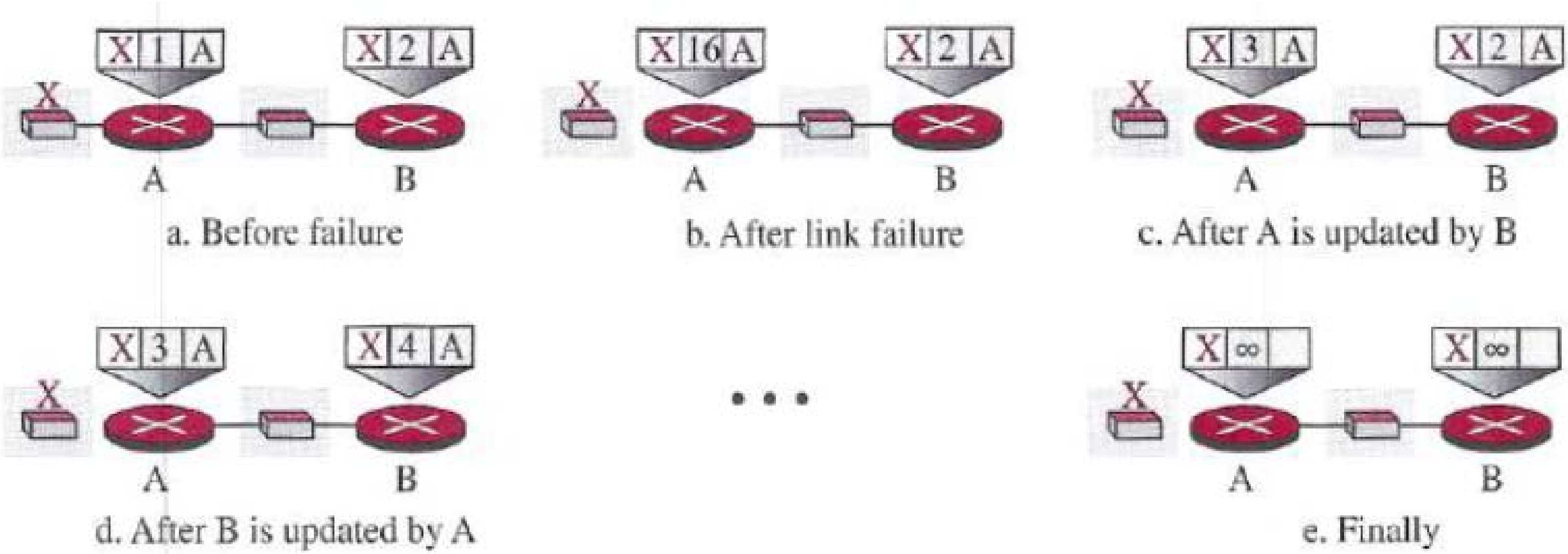
from \ cost to	x	y	z
x	0	2	7
y	2	0	1
z	3	1	0

from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

Time

Problem in DVR

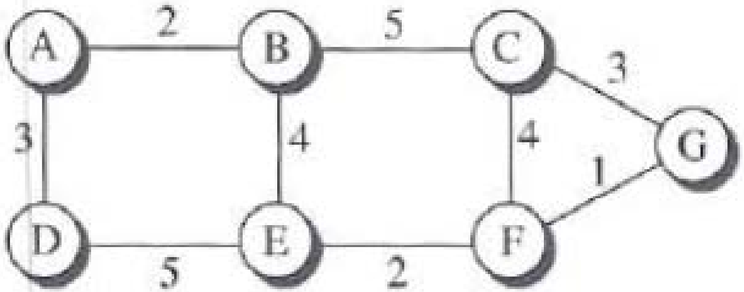
- Count to Infinity problem (for two nodes):



- Solutions:
  - Split Horizon: each node sends only specific part of its table through each interface
    - Route deleted problem due to timer
  - Poison Reverse: "Do not use this value; what I know about this route comes from you"

Link State Routing

- a router continuously tells all nodes what it knows about the neighbours

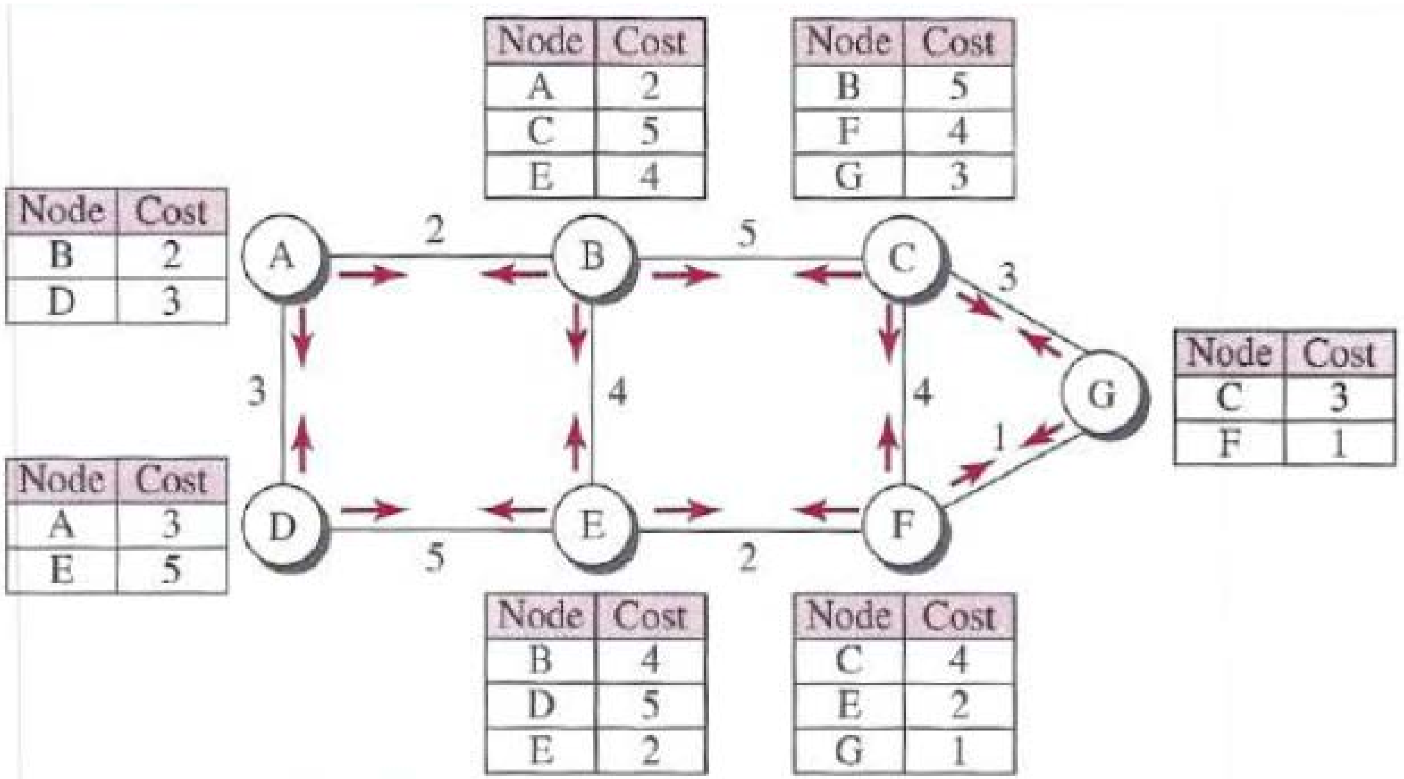


a. The weighted graph

	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

Cont…



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

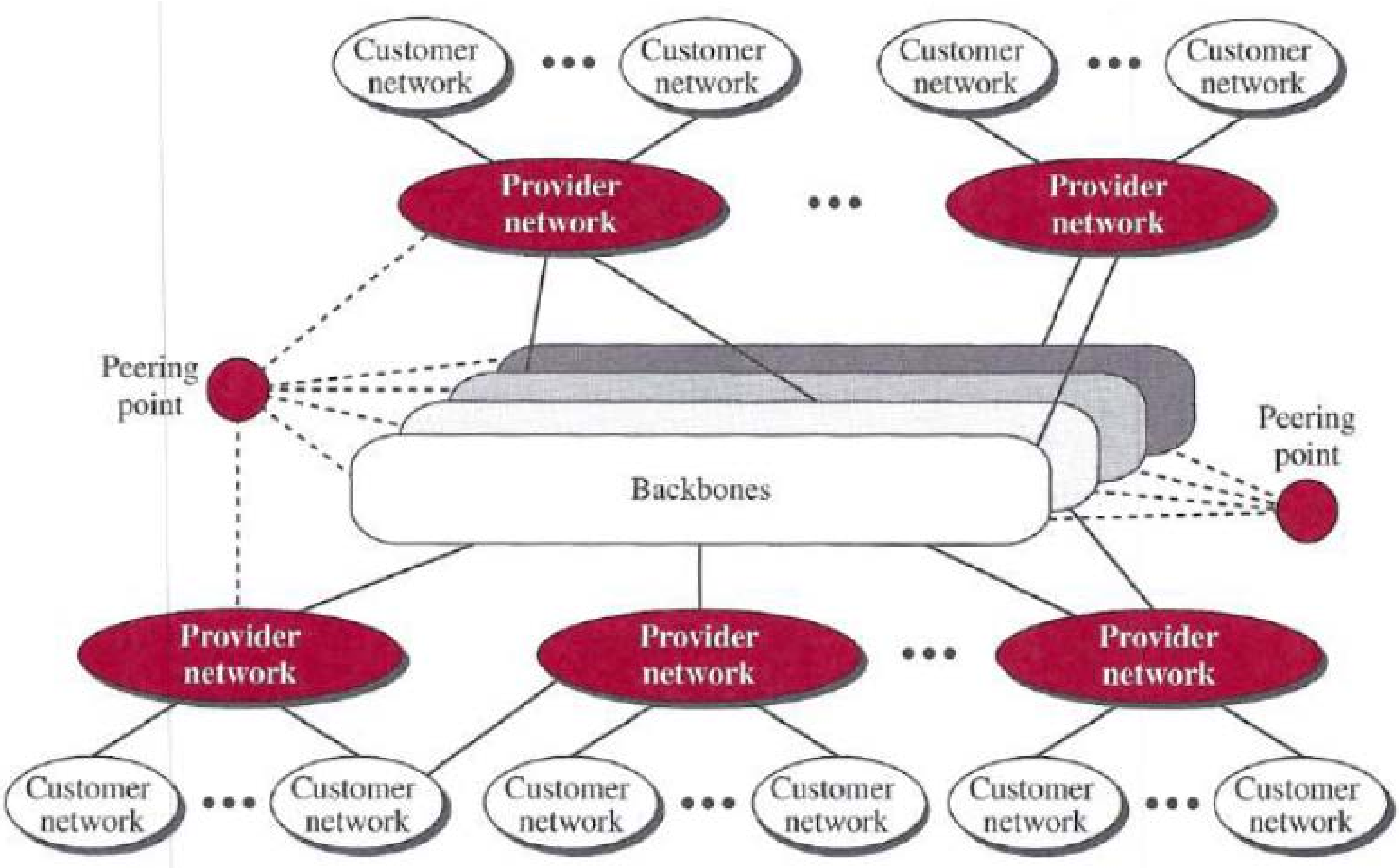
- To create a least-cost tree for itself, each node needs to run the famous Dijkstra Algorithm.

Path-Vector Routing

- LS and DV both are based on least-cost routing
  - Does not allow the sender to apply its own policy
- PV based on best path according to desired policy
  - mainly used in routing between ISPs

- Path is determined from source to destination using spanning tree (might not be least cost)
- Spanning trees are made gradually and asynchronously likewise DVR
- Follow Bellman-Ford, but not the least-cost concept

Internet Structure



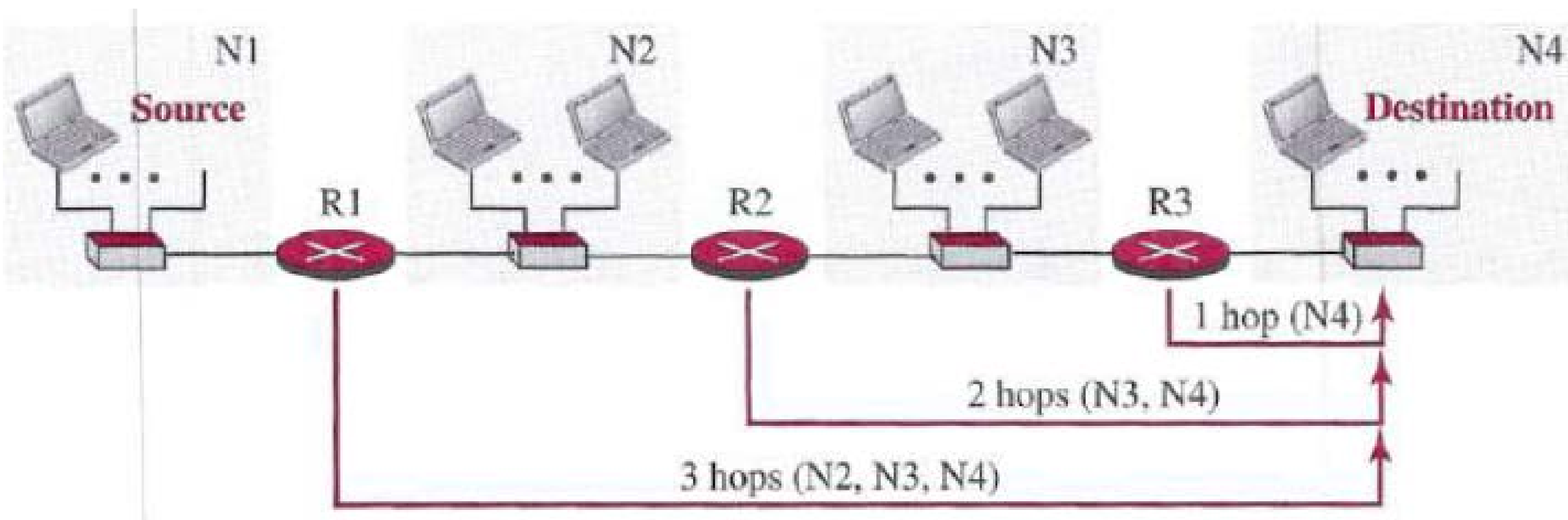
Routing Protocols

- Each ISP is considered as Autonomous System (AS)
  - Stub AS: connects to one other AS only
  - Multihomed AS: connects more than one AS, but refuses to carry transit traffic
  - Transit AS: connects more than one other AS, and carries local and transit traffic

- Two types of routing protocol:
  - Intra-AS / intradomain / Interior Gateway Protocol (IGP)
    - E.g., RIP (Routing Information Protocol) - use DVR
    - OSPF (Open Shortest Path First) - use LSR
  - Inter-AS / interdomain / Exterior Gateway Protocol (EGP)
    - E.g., BGP (Border Gateway Protocol) - use PVR

RIP

- Follow distance-vector routing with the following modifications
  - Router advertise the cost to reach different networks instead of individual node
  - Advertise forwarding table instead of distance-vector
  - Cost is defined as number of hops



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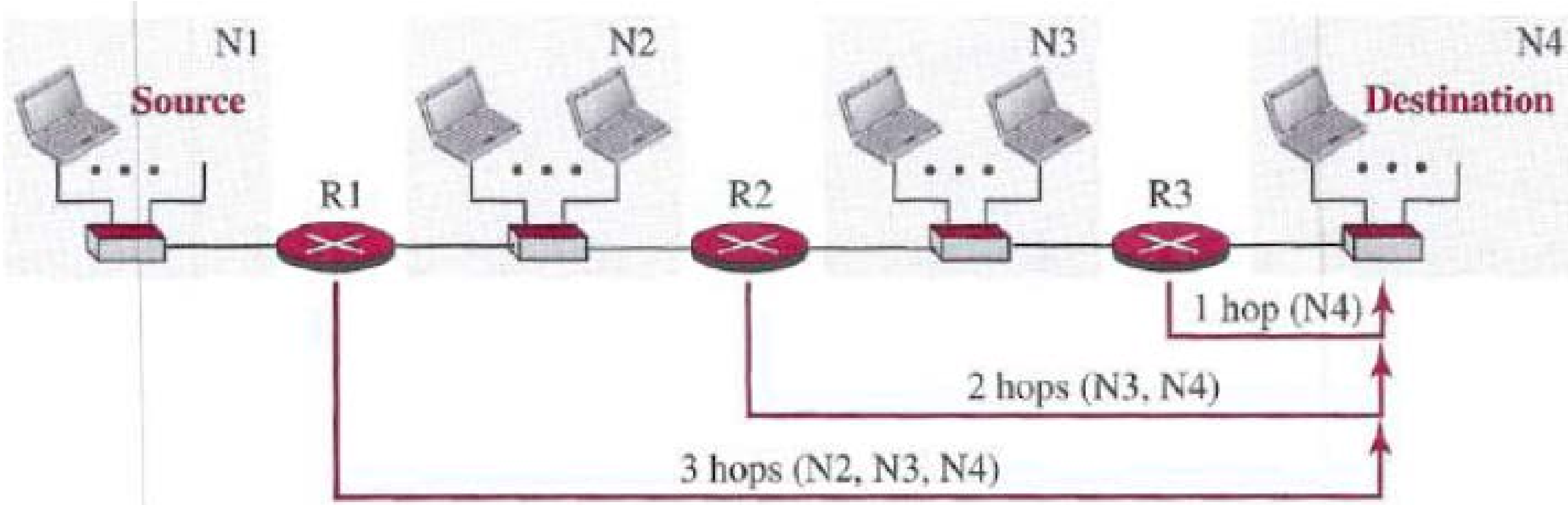


Forwarding table for R1

Destination network	Next router	Cost in hops
N1	—	1
N2	—	1
N3	R2	2
N4	R2	3

Forwarding table for R2

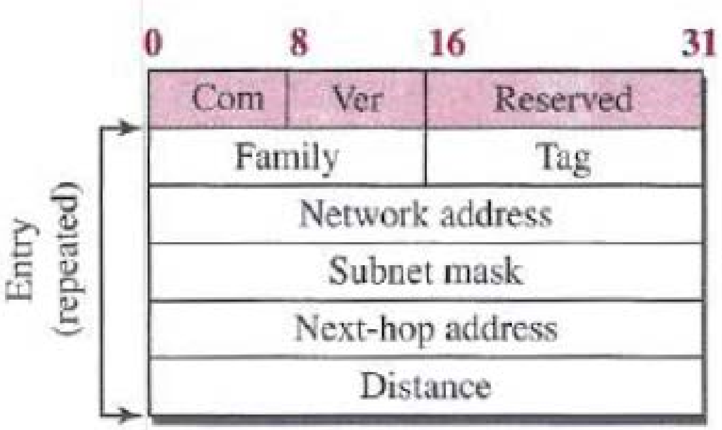
Destination network	Next router	Cost in hops
N1	R1	2
N2	—	1
N3	—	1
N4	R3	2

Forwarding table for R3

Destination network	Next router	Cost in hops
N1	R2	3
N2	R2	2
N3	—	1
N4	—	1

RIP Implementation

- RIP runs at the application layer but creates forwarding table for network layer
- Uses the service of UDP on port 520
- Runs as background process
  - Two processes : a client and a server
- RIP uses two types of messages: request and response
- Runs as background process

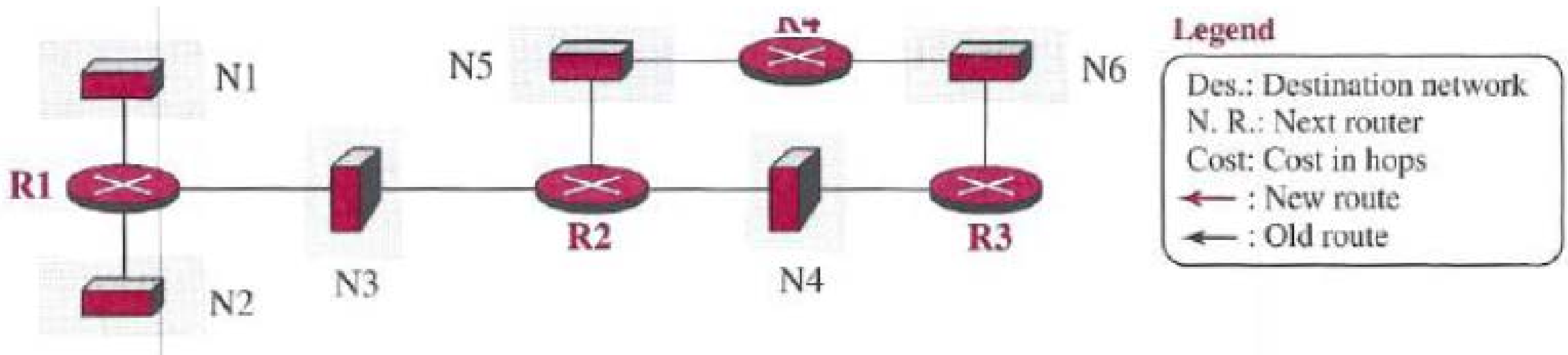


Fields

Com: Command, request (1), response (2)
Ver: Version, current version is 2
Family: Family of protocol, for TCP/IP value is 2
Tag: Information about autonomous system
Network address: Destination address
Subnet mask: Prefix length
Next-hop address: Address length
Distance: Number of hops to the destination

RIP Algorithm

- RIP uses three timers:
  - Periodic timer: for advertising update message regularly
  - Expiration timer: governs the validity of a route



R1

Des.	N. R.	Cost
N1	—	1
N2	—	1
N3	—	1

R2

Des.	N. R.	Cost
N3	—	1
N4	—	1
N5	—	1

R3

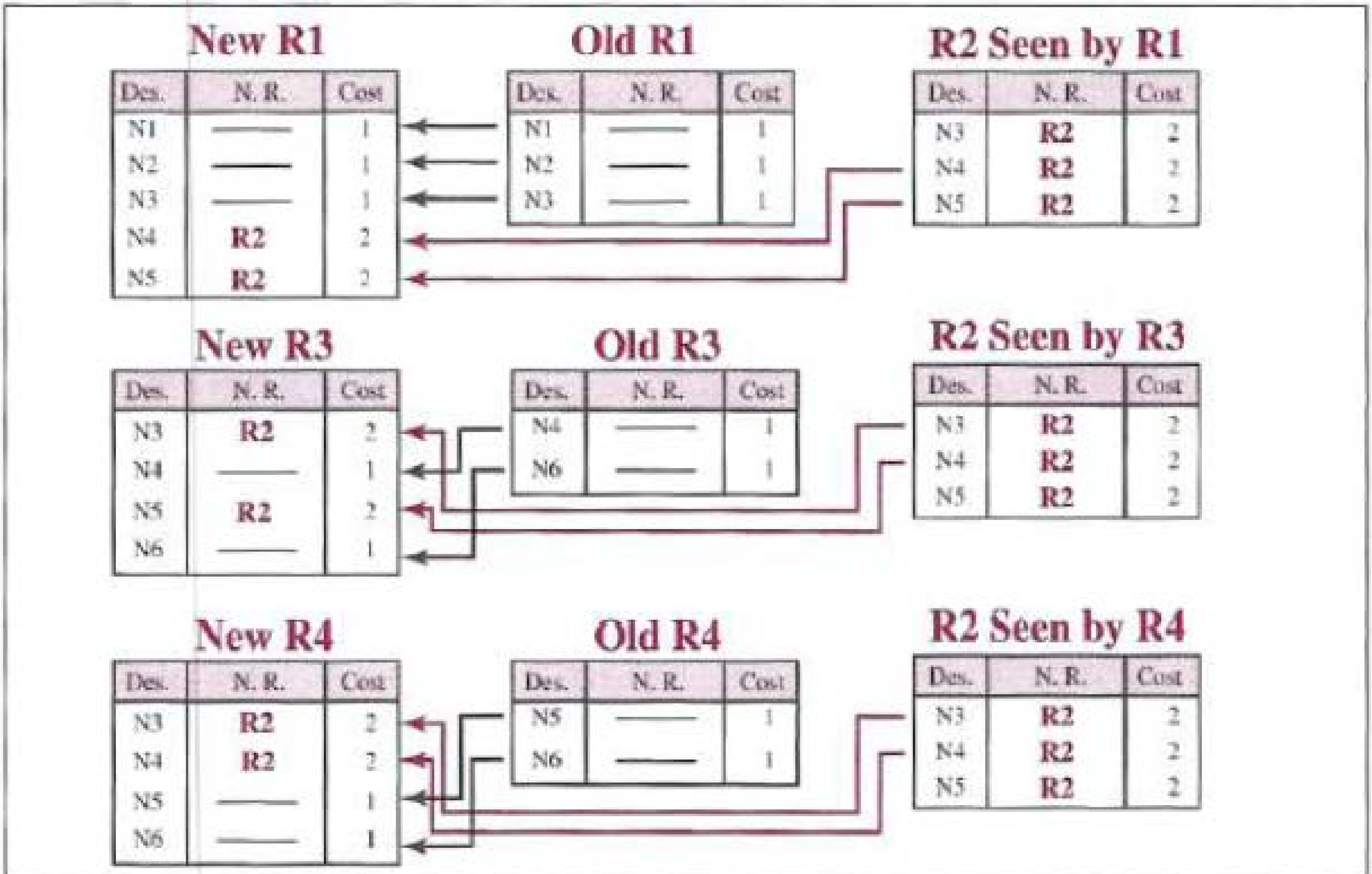
Des.	N. R.	Cost
N4	—	1
N6	—	1

R4

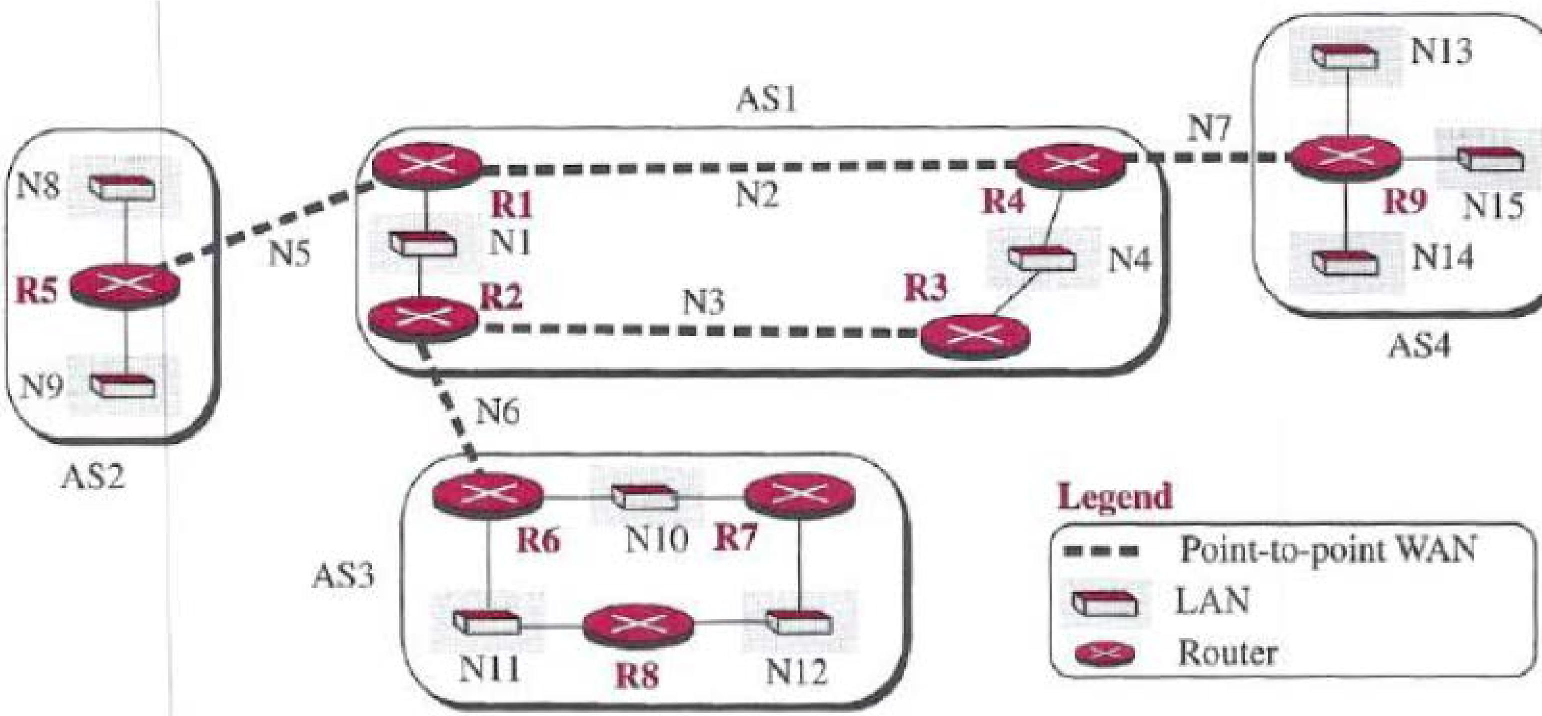
Des.	N. R.	Cost
N5	—	1
N6	—	1

Forwarding tables after all routers booted

Cont…

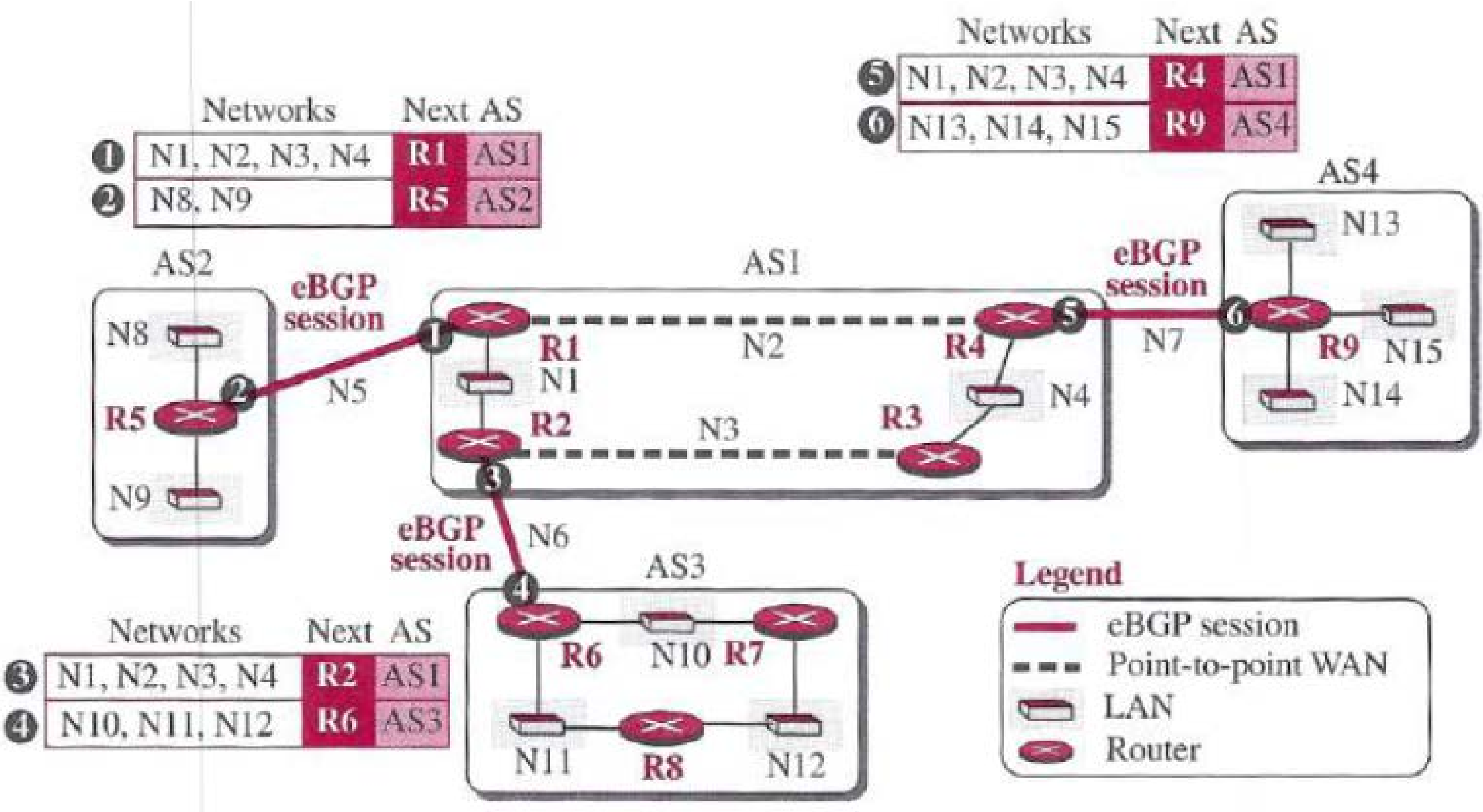

New R1
Des. N. R. Cost
N1 1
N2 1
N3 1
N4 R2 2
N5 R2 2
Old R1
Des. N. R. Cost
N1 1
N2 1
N3 1
R2 Seen by R1
Des. N. R. Cost
N3 R2 2
N4 R2 2
N5 R2 2
New R3
Des. N. R. Cost
N3 R2 2
N4 1
N5 R2 2
N6 1
Old R3
Des. N. R. Cost
N4 1
N6 1
R2 Seen by R3
Des. N. R. Cost
N3 R2 2
N4 R2 2
N5 R2 2
New R4
Des. N. R. Cost
N3 R2 2
N4 R2 2
N5 1
N6 1
Old R4
Des. N. R. Cost
N5 1
N6 1
R2 Seen by R4
Des. N. R. Cost
N3 R2 2
N4 R2 2
N5 R2 2

BGP



- AS2, AS3, AS4 : stub AS;   AS1 : transient AS
- Each AS use RIP / OSPF for intra-domain routing
- BGP for inter-domain routing used by all AS
  - eBGP: on each border router
  - iBGP: on all routers

External BGP (eBGP)



- 3 pairs: R1-R5, R4-R9, R2-R6 => 3 eBGP sessions (using TCP)
- Message 1 is sent by router R1 and tells router R5 that N1, N2, N3, and N4 can be reached through router R1. Then, R5 updates its table.

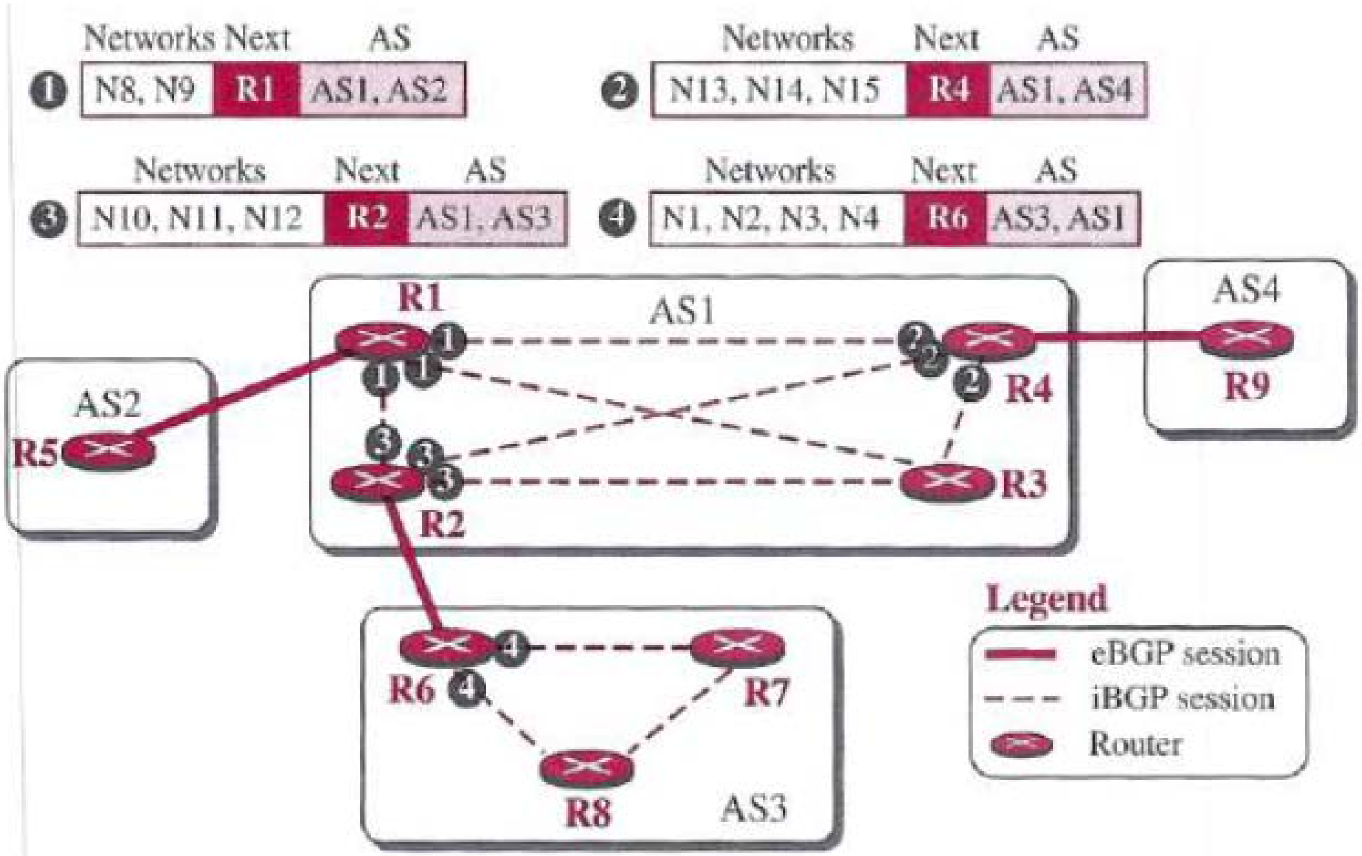
Limitation in eBGP

1. Border router does not know how to route a packet destined for non-neighbour AS.
   - E.g., R5 does not know about networks in AS3, AS4

2. None of the non-border routers know how to route a packet destined for any network in other ASs.
   - E.g., R3 does not know about networks in AS2, AS3, AS4

Solution: Internal BGP (iBGP)

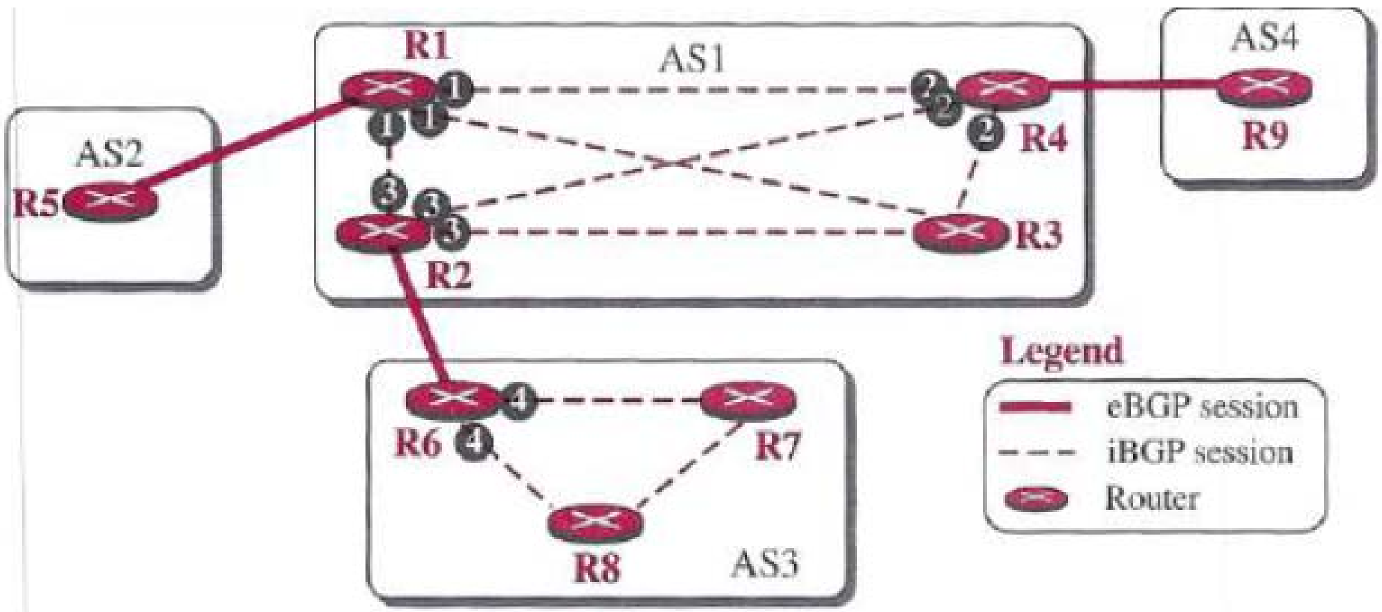
Internal BGP (iBGP)



No message for R3, R7, R8

- No iBGP session for single router in an AS.
- For n router in an AS: n(n-1)/2 sessions
- Message 1 sent by R1 tells that N8 and N9 are reachable through the path AS1-AS2, but the next router is R1.

Finalizing BGP path table



- R1 receives:

Networks	Next	AS
N8, N9	R5	AS2

Networks	Next	AS
N10, N11, N12	R2	AS1, AS3

Networks	Next	AS
N13, N14, N15	R4	AS1, AS4

Networks	Next	Path
N8, N9	R5	AS1, AS2
N10, N11, N12	R2	AS1, AS3
N13, N14, N15	R4	AS1, AS4

Path table for R1

Cont…

Networks	Next	Path
N8, N9	R5	AS1, AS2
N10, N11, N12	R2	AS1, AS3
N13, N14, N15	R4	AS1, AS4

Path table for R1

Networks	Next	Path
N8, N9	R1	AS1, AS2
N10, N11, N12	R6	AS1, AS3
N13, N14, N15	R1	AS1, AS4

Path table for R2

Networks	Next	Path
N8, N9	R2	AS1, AS2
N10, N11, N12	R2	AS1, AS3
N13, N14, N15	R4	AS1, AS4

Path table for R3

Networks	Next	Path
N8, N9	R1	AS1, AS2
N10, N11, N12	R1	AS1, AS3
N13, N14, N15	R9	AS1, AS4

Path table for R4

Networks	Next	Path
N1, N2, N3, N4	R1	AS2, AS1
N10, N11, N12	R1	AS2, AS1, AS3
N13, N14, N15	R1	AS2, AS1, AS4

Path table for R5

Networks	Next	Path
N1, N2, N3, N4	R2	AS3, AS1
N8, N9	R2	AS3, AS1, AS2
N13, N14, N15	R2	AS3, AS1, AS4

Path table for R6

Networks	Next	Path
N1, N2, N3, N4	R6	AS3, AS1
N8, N9	R6	AS3, AS1, AS2
N13, N14, N15	R6	AS3, AS1, AS4

Path table for R7

Networks	Next	Path
N1, N2, N3, N4	R6	AS3, AS1
N8, N9	R6	AS3, AS1, AS2
N13, N14, N15	R6	AS3, AS1, AS4

Path table for R8

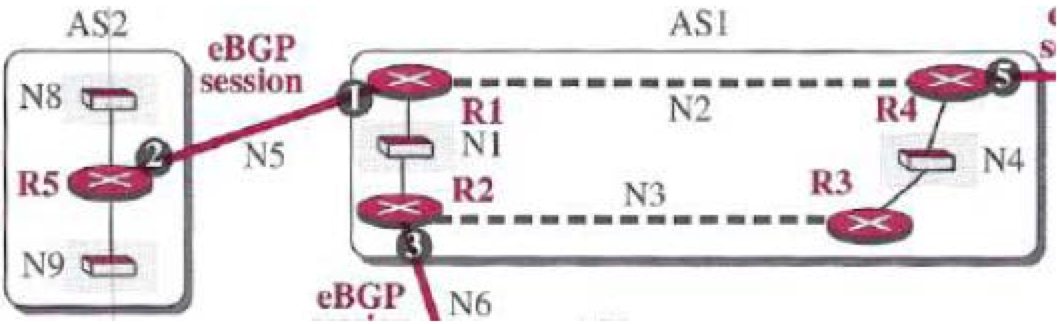
Networks	Next	Path
N1, N2, N3, N4	R4	AS4, AS1
N8, N9	R4	AS4, AS1, AS2
N10, N11, N12	R4	AS4, AS1, AS3

Path table for R9

Injection of Information into Forwarding Table

- The role of BGP is to help the routers inside the AS to augment their routing table
- Cost update problem for mixing of RIP and OSPF

- For stub AS:



Des.	Next	Cost
N8	—	1
N9	—	1

Table for R5

Networks	Next	Path
N1, N2, N3, N4	R1	AS2, AS1
N10, N11, N12	R1	AS2, AS1, AS3
N13, N14, N15	R1	AS2, AS1, AS4

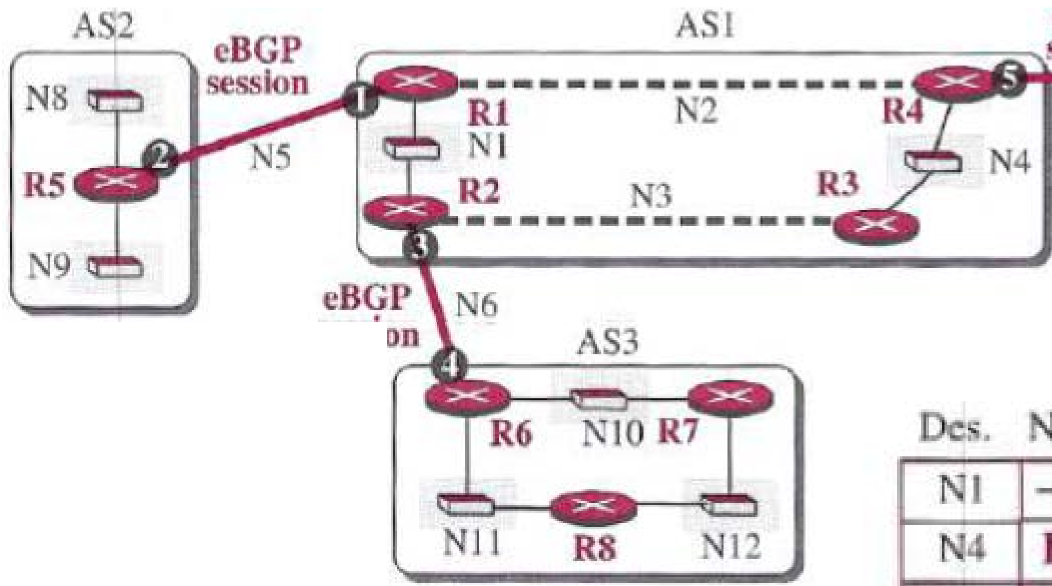
Path table for R5

Des.	Next	Cost
N8	—	1
N9	—	1
0	R1	1

Table for R5

Cont…

For transient AS:



Des.	Next	Cost
N1	—	1
N4	R4	2

Table for R1

Networks	Next	Path
N8, N9	R5	AS1, AS2
N10, N11, N12	R2	AS1, AS3
N13, N14, N15	R4	AS1, AS4

Path table for R1

Des.	Next	Cost
N1	—	1
N4	R4	2
N8	R5	1
N9	R5	1
N10	R2	2
N11	R2	2
N12	R2	2
N13	R4	2
N14	R4	2
N15	R4	2

Table for R1

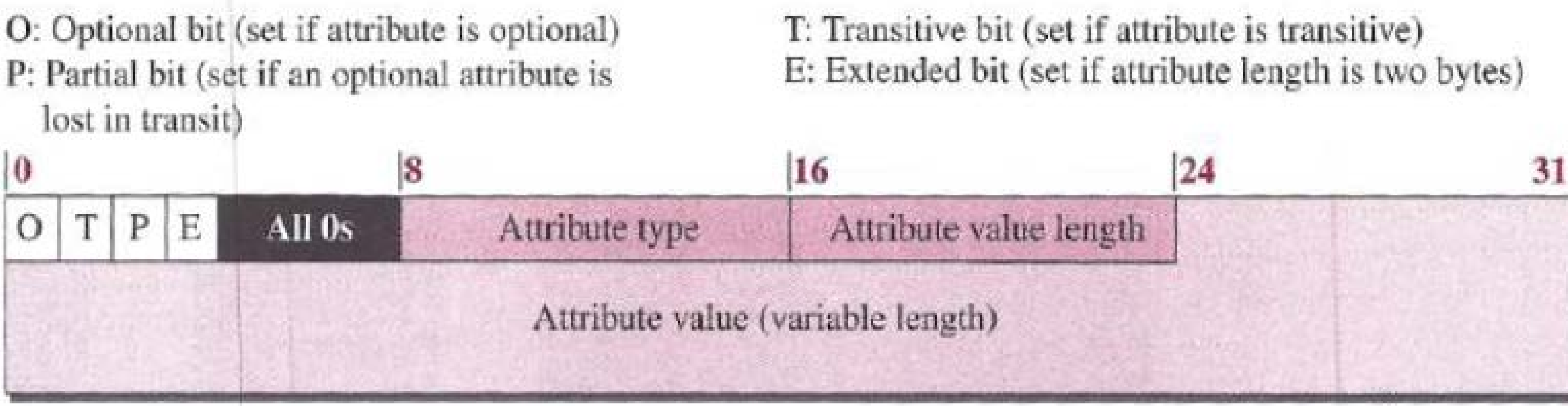
Messages

- BGP uses 4 types of messages
  - Open Message : for creating neighbourhood relationship. Router creates a TCP connection with neighbour router and sends Open message.
  - Update Message: to withdraw destinations that have been advertised previously <u>or</u> to announce a route to a new destination
  - Keepalive Message: BGP peers exchange this message to tell each other that they are alive
  - Notification: when an error is detected <u>or</u> the router wants to close the session

Path Attributes

- In RIP/OSPF a destination has two associated with two information: next hop and cost
- But, inter-domain routing needs more information
- In BGP, those information are called path attributes
  - Destination can be associated with 7 attributes
  - Two types of attribute: mandatory and optional
  - Mandatory attributes must be present in each UPDATE message
  - Optional attributes type: transitive and nontransitive

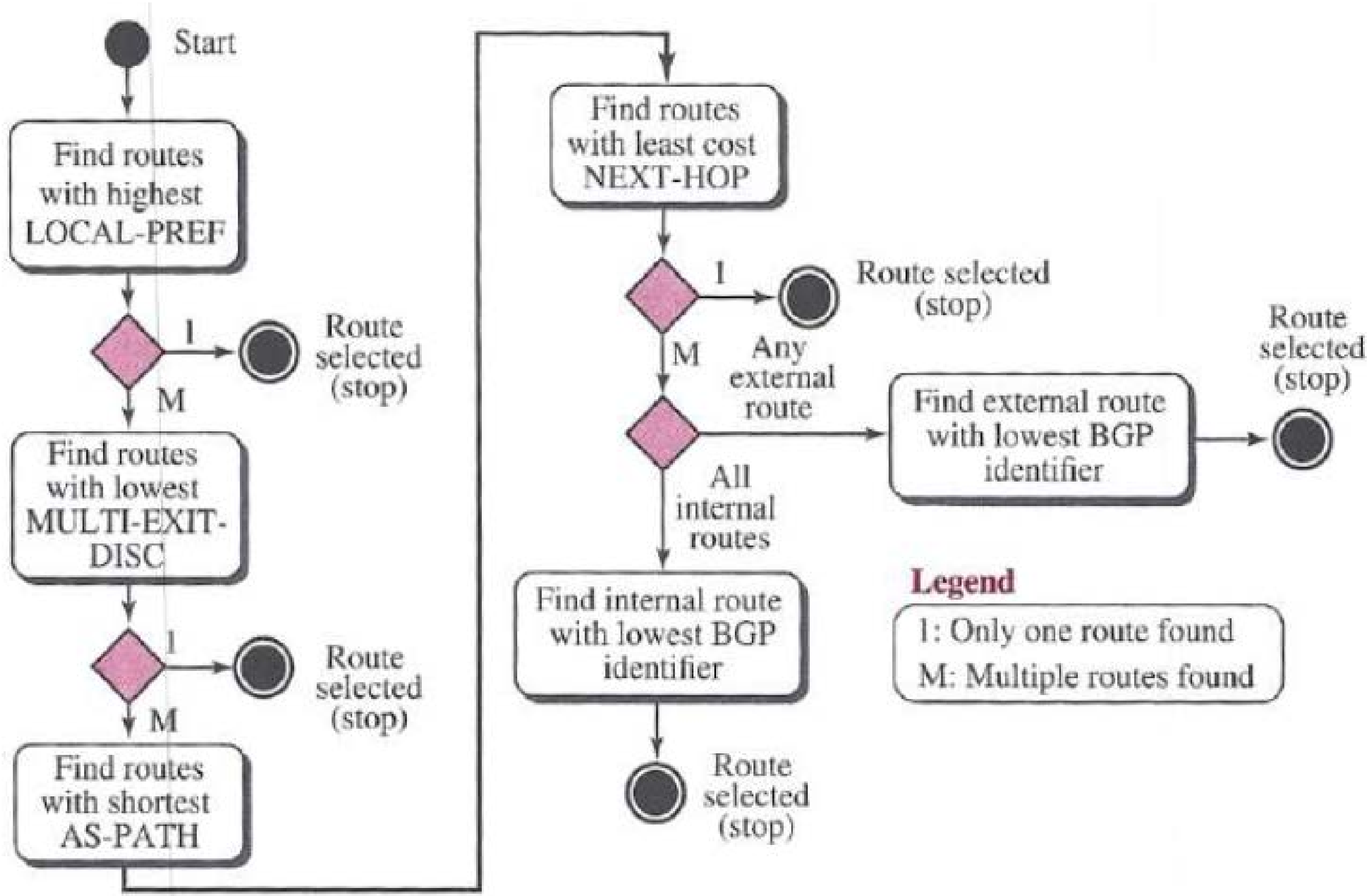
Cont…



- ORIGIN (Type 1): This is mandatory attribute.
  - Value=1: path information comes from RIP/OSPF
  - Value=2: information comes from BGP
  - Value=3: information comes from other sources

- MULTI-EXIT-DISC (Type 4): This is optional intransitive attribute
  - discriminates among multiple exit paths to a destination
  - This is intransitive as the best exit path (e.g. shortest path) is different from one AS to other

Route Selection



Thanks!