Subject Name: Computer Networks

Module 4 : Network Layer

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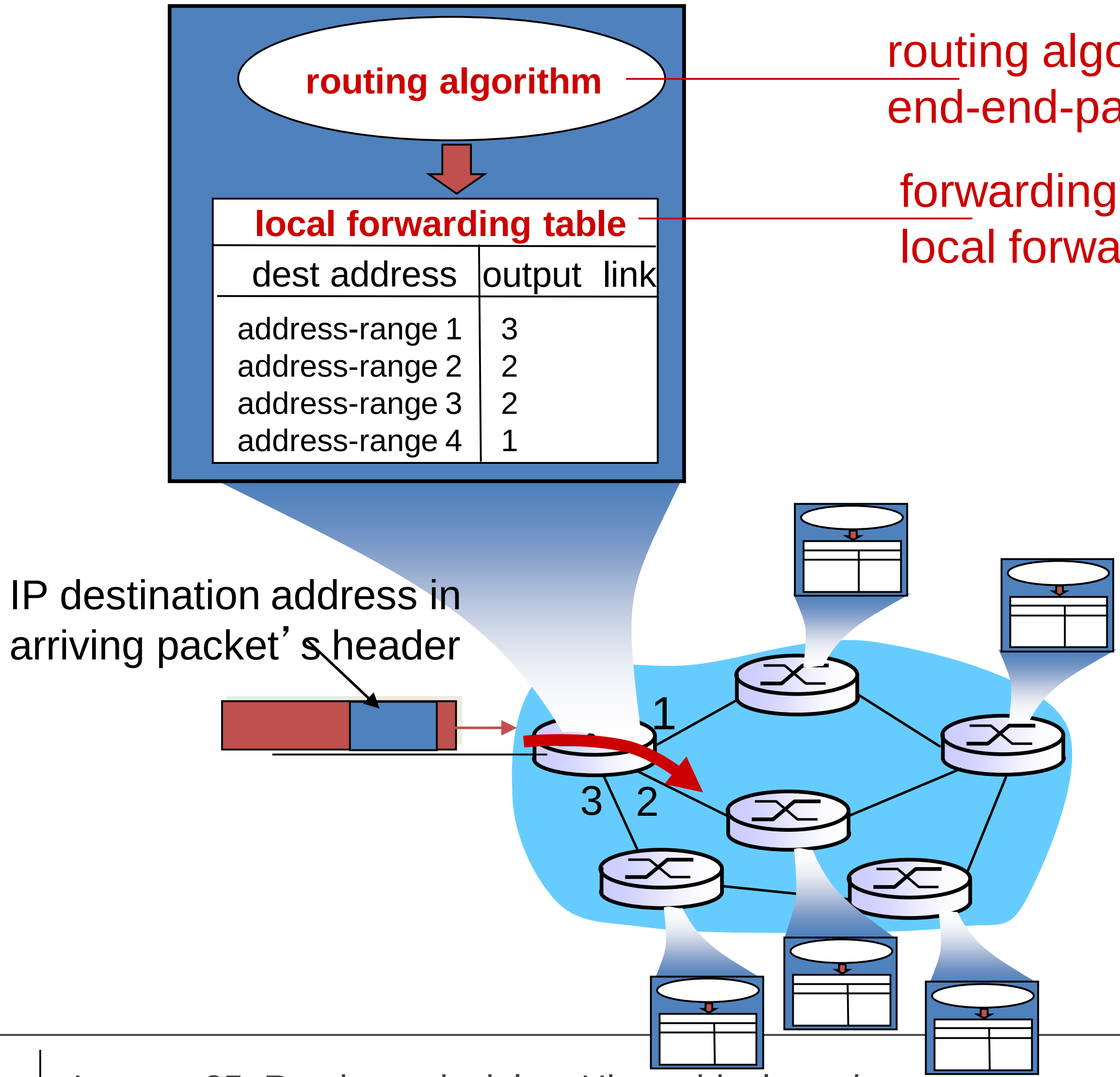
Unit No: 4 Unit name: Network Layer

Lecture No: 25
Routing principles, Hierarchical routing

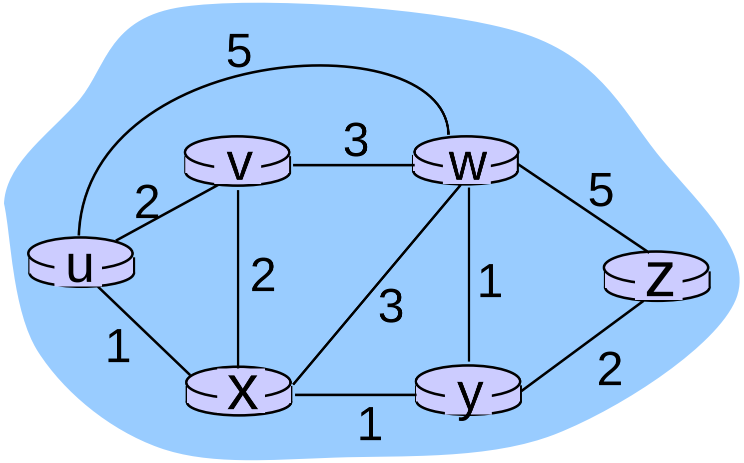
Interplay between routing, forwarding



routing algorithm determines end-end-path through network

forwarding table determines local forwarding at this router

Graph abstraction



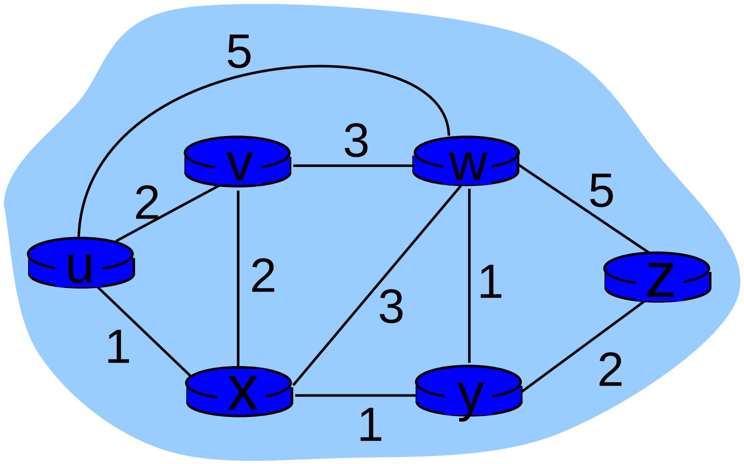
graph: G = (N,E)

N = set of routers = { u, v, w, x, y, z }

E = set of links ={ (u,v), (u,x), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }

aside: graph abstraction is useful in other network contexts, e.g., P2P, where *N* is set of peers and *E* is set of TCP connections

Graph abstraction: costs



$c(x,x')$ = cost of link (x,x')
e.g., $c(w,z) = 5$

cost could always be 1, or inversely related to bandwidth, or inversely related to congestion

cost of path $(x_1, x_2, x_3,\ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$

key question: what is the least-cost path between u and z ?
routing algorithm: algorithm that finds that least cost path

Routing Table

- 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.

Static route and Dynamic route

- **Static route** that the static route uses programmed definitions representing paths through the network. That means, already programmed or already defined routes
- **Dynamic route** algorithms allowed router to automatically discover and maintain the awareness of the paths through the network right.

Routing algorithm classification

Q: global or decentralized information?

global:

- all routers have complete topology, link cost info
- "link state" algorithms

decentralized:

- router knows physically-connected neighbors, link costs to neighbors
- iterative process of computation, exchange of info with neighbors
- "distance vector" algorithms

Q: static or dynamic?

static:

- routes change slowly over time

dynamic:

- routes change more quickly
  - periodic update
  - in response to link cost changes

Hierarchical routing

our routing study thus far - idealization

- all routers identical
- network "flat"

… *not* true in practice

scale: with 600 million destinations:

- can't store all dest's in routing tables!
- routing table exchange would swamp links!

administrative autonomy

- internet = network of networks
- each network admin may want to control routing in its own network

Hierarchical routing

- aggregate routers into regions, "autonomous systems" (AS)
- routers in same AS run same routing protocol
  - "intra-AS" routing protocol
  - routers in different AS can run different intra-AS routing protocol

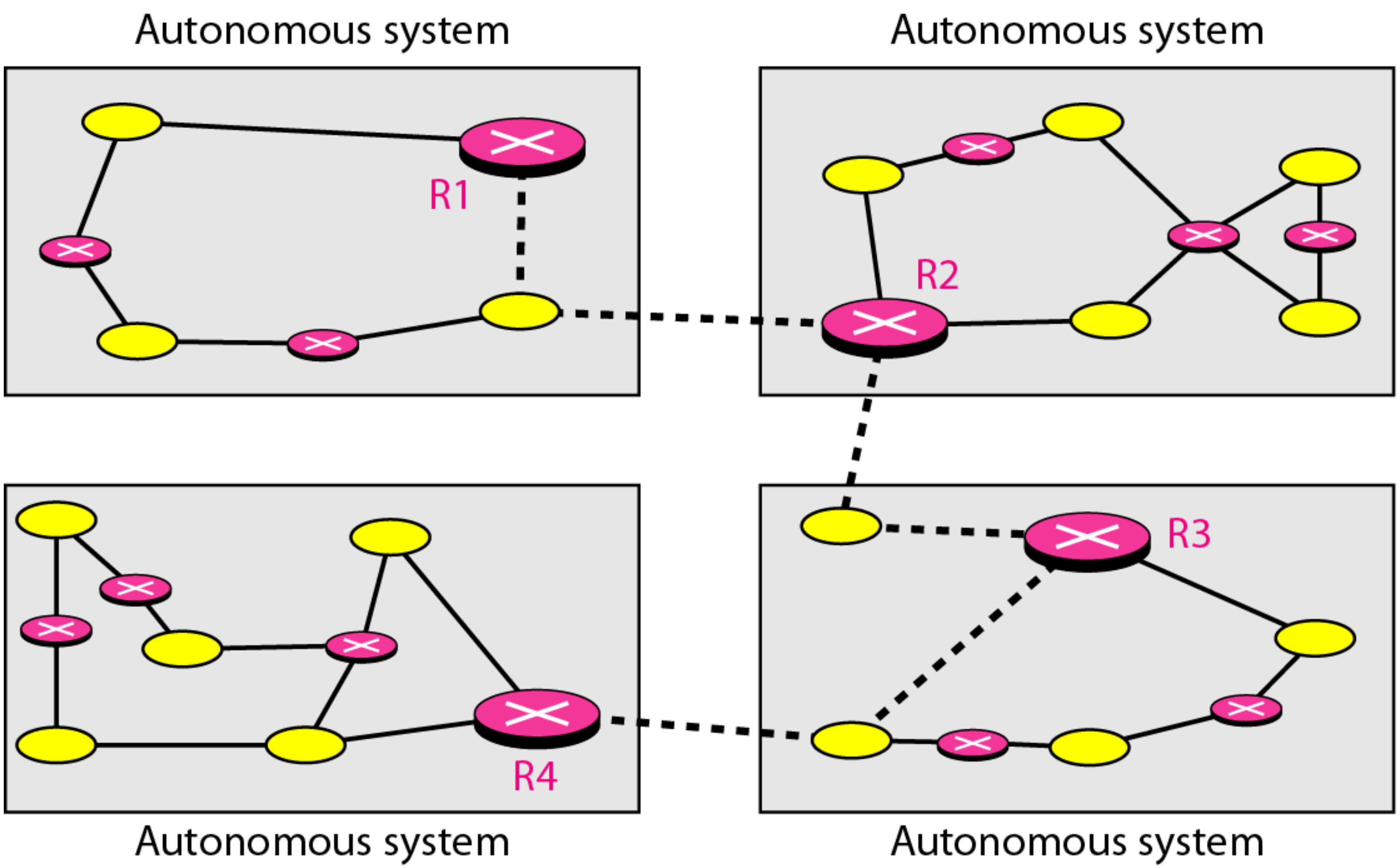
gateway router:

- at "edge" of its own AS
- has link to router in another AS

Autonomous System

- Corresponds to an administrative domain
  - Internet has many networks
  - AS reflects organization of the internet
- Goals:
  - AS wants to choose their own local routing algorithm
  - AS want to set policies about non local routing
  - Each AS assigned unique 16 bit number

Autonomous System



Autonomous System

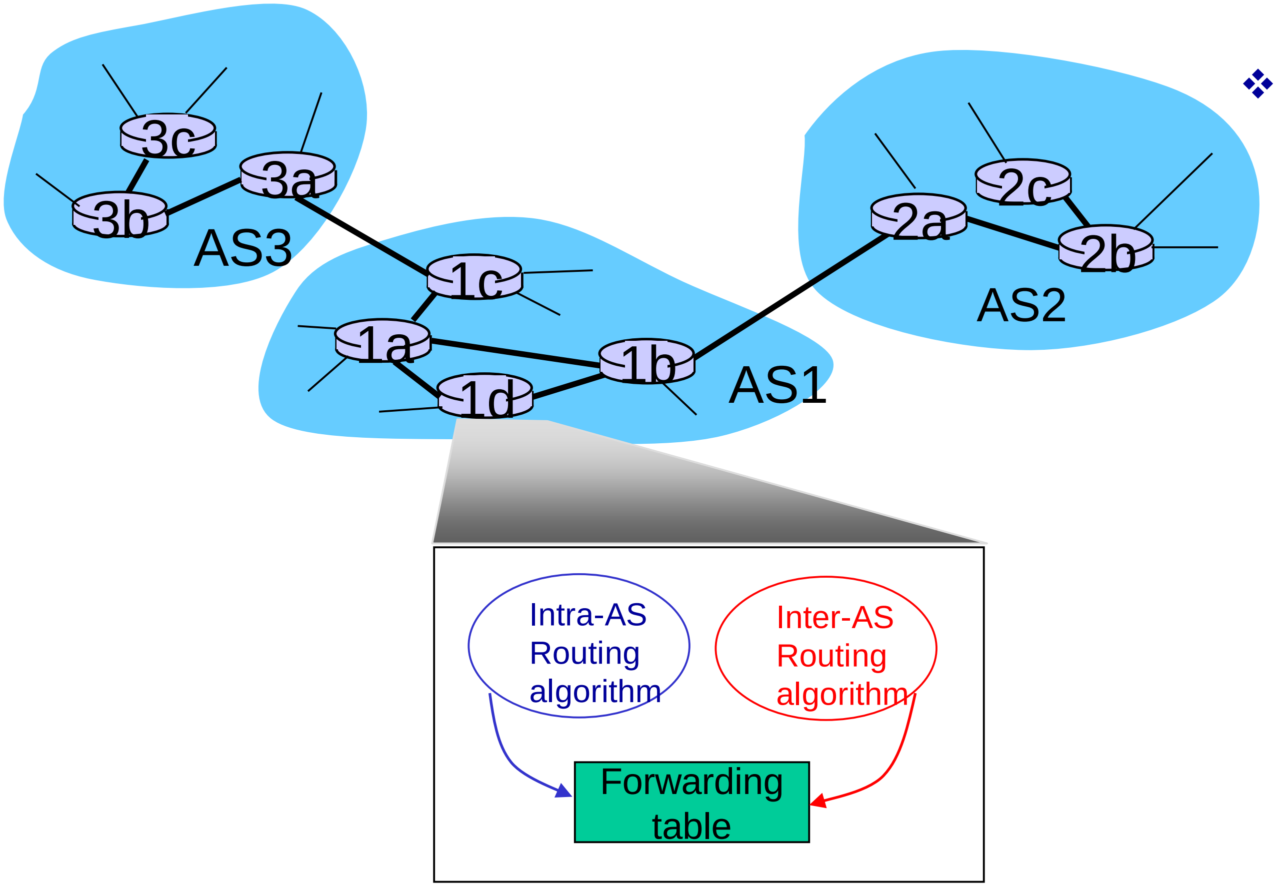
- Types of AS:

  Stub AS – has only one connection to another AS
  - ✓ Data traffic cannot pass through stub AS
  - ✓ A stub AS is either a source or sink
  - ✓ Eg. Small corporation or a small local ISP

  Multihomed –more than one connection to other AS
  - ✓ It can send data traffic to more than one AS ,but no transient traffic
  - ✓ Eg. large corporate office

  Transit AS- It is a multihomed AS that allows transient traffic
  - ✓ Eg. National and international ISPs

Interconnected AS



- forwarding table configured by both intra- and inter-AS routing algorithm
  - intra-AS sets entries for internal dests
  - inter-AS & intra-AS sets entries for external dests

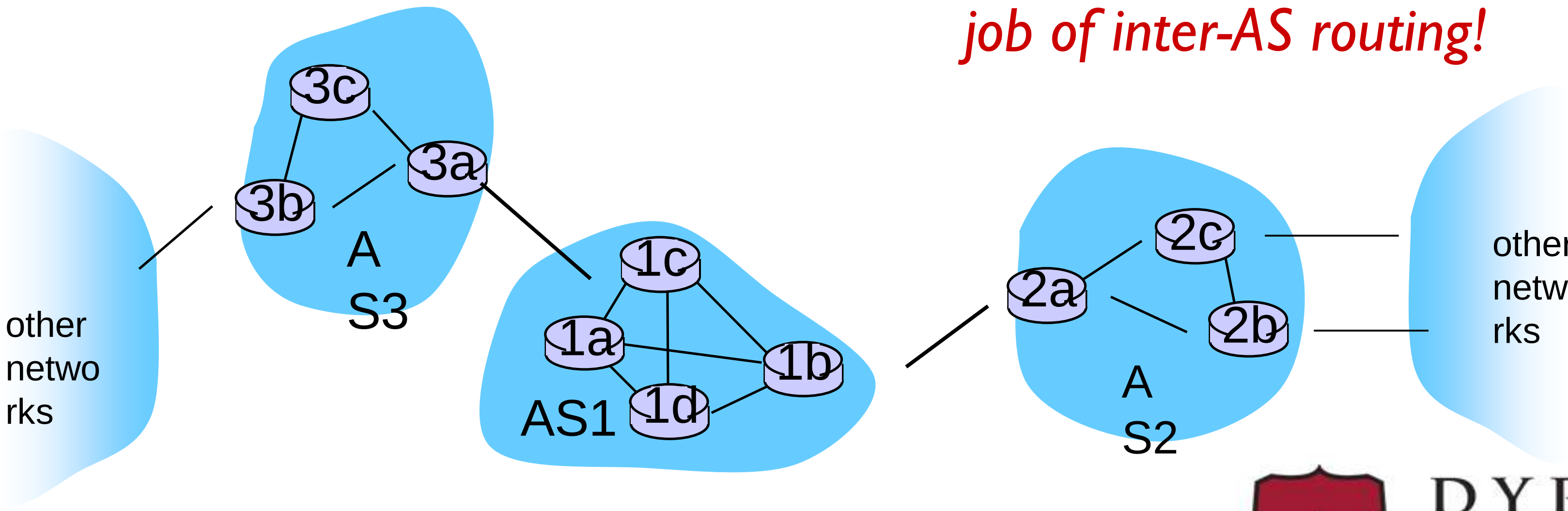
Inter-AS tasks

- suppose router in AS1 receives datagram destined outside of AS1:
  - router should forward packet to gateway router, but which one?

AS1 must:

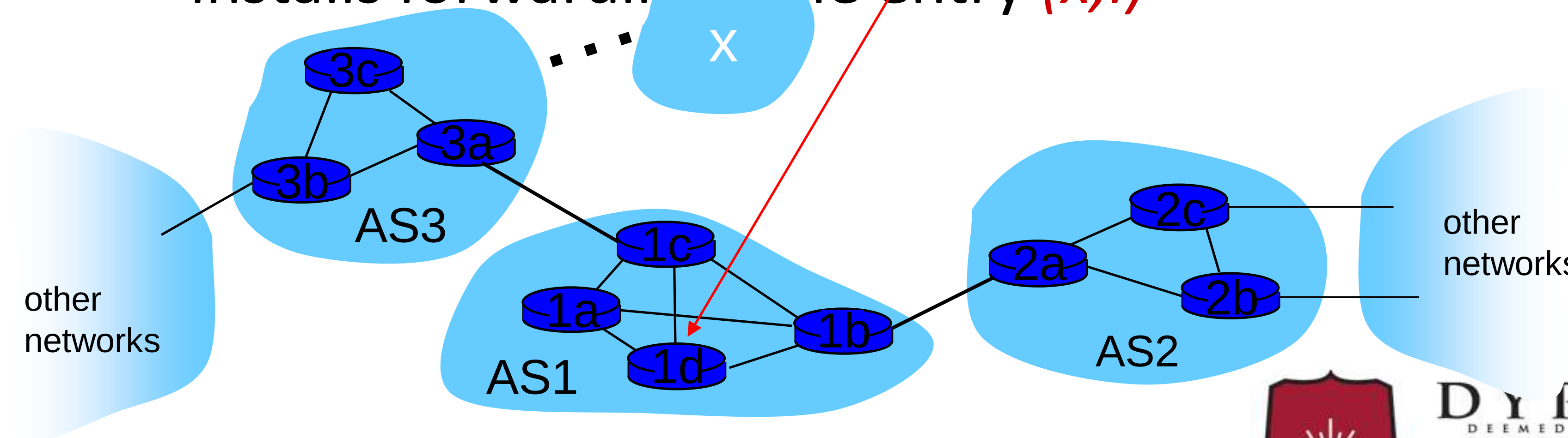
1. learn which dests are reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1

job of inter-AS routing!



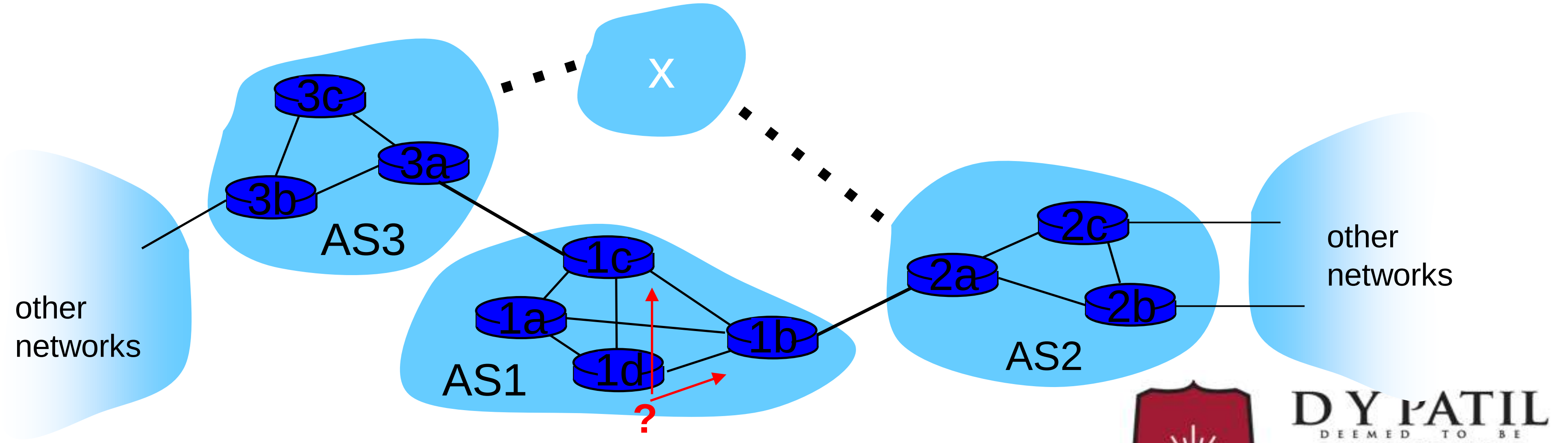
Example: setting forwarding table in router 1d

- suppose AS1 learns (via inter-AS protocol) that subnet *x* reachable via AS3 (gateway 1c), but not via AS2
  – inter-AS protocol propagates reachability info to all internal routers
- router 1d determines from intra-AS routing info that its interface *I* is on the least cost path to 1c
  – installs forwarding table entry *(x,I)*



Example: choosing among multiple ASes

- now suppose AS1 learns from inter-AS protocol that subnet *x* is reachable from AS3 *and* from AS2.
- to configure forwarding table, router 1d must determine which gateway it should forward packets towards for dest x
  - this is also job of inter-AS routing protocol!



Example: choosing among multiple ASes

- now suppose AS1 learns from inter-AS protocol that subnet *x* is reachable from AS3 *and* from AS2.
- to configure forwarding table, router 1d must determine towards which gateway it should forward packets for dest x
  - this is also job of inter-AS routing protocol!
- *hot potato routing: send* packet towards closest of two routers.

learn from inter-AS protocol that subnet *x* is reachable via multiple gateways → use routing info from intra-AS protocol to determine costs of least-cost paths to each of the gateways → hot potato routing: choose the gateway that has the smallest least cost → determine from forwarding table the interface *I* that leads to least-cost gateway. Enter *(x,I)* in forwarding table

Thank You

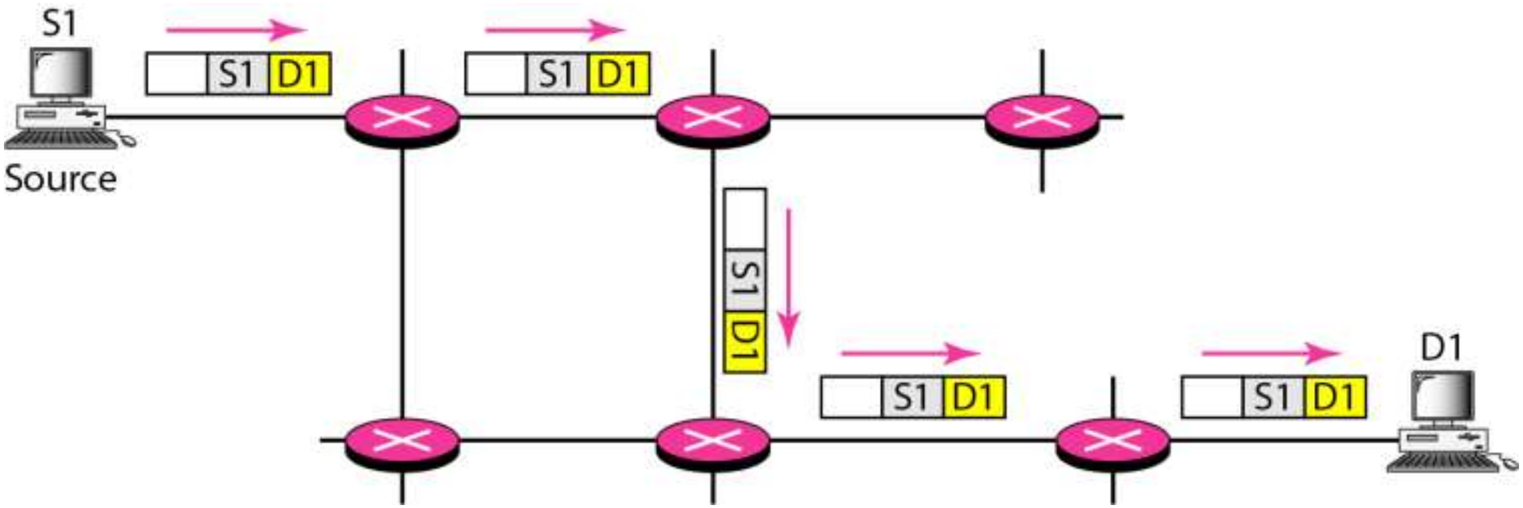
Unit No: 4 Unit name: Network Layer

Lecture No: 26
Routing in the Internet-I

Routing Protocols

- A routing protocol is a combination of rules and procedures that lets routers in the Internet inform each other of changes.
  - ❑ Unicast Routing Protocols
  - ❑ Multicast Routing Protocols

Unicasting

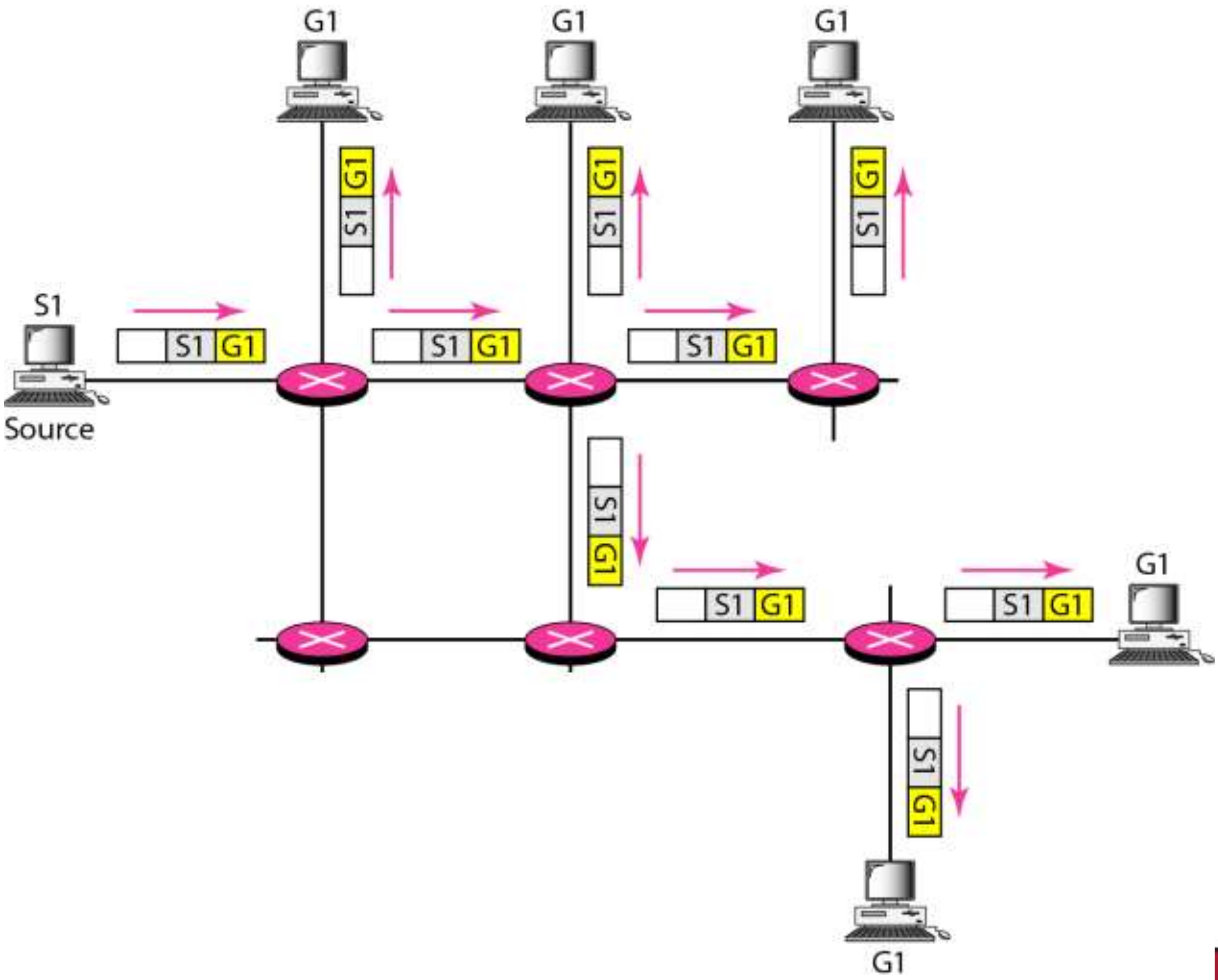


Unicasting

Note

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

Multicasting

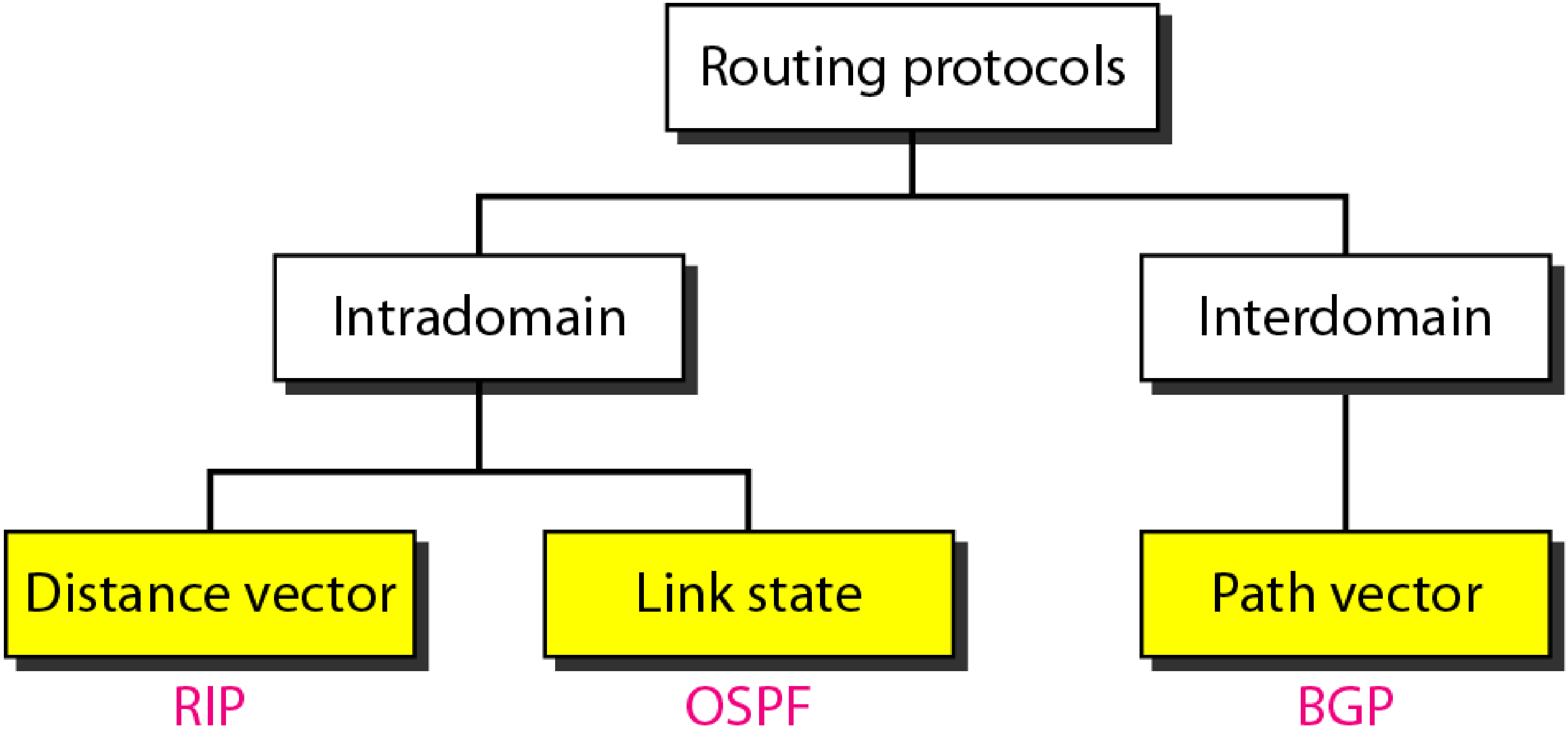


Multicasting

Note

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

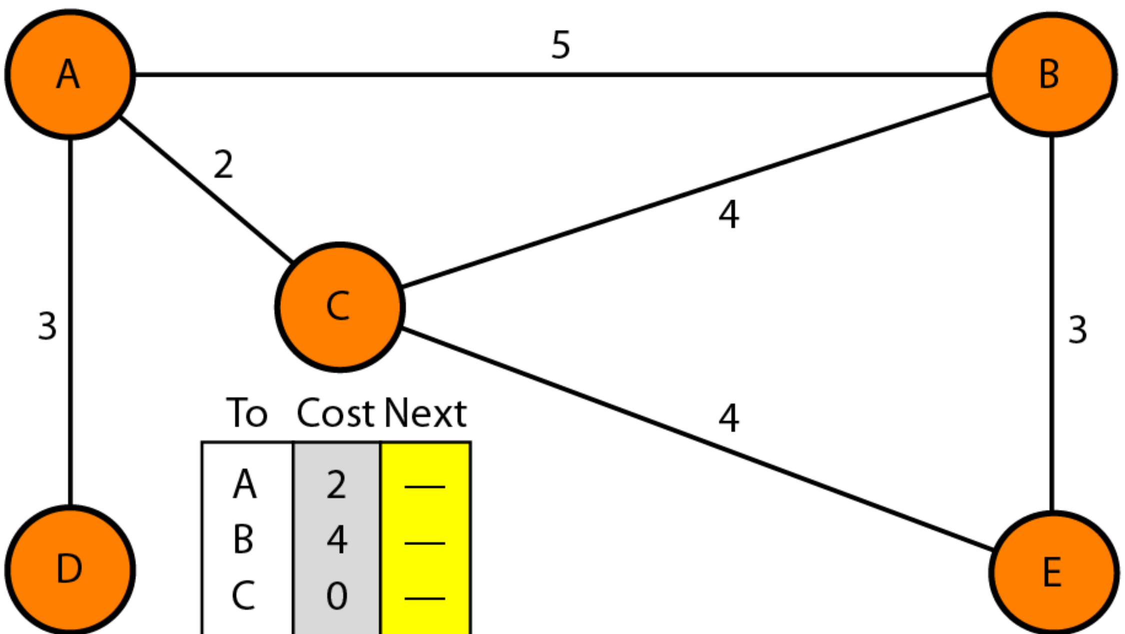
Popular routing protocols



Distance vector

- Each router in the internode maintains a distance or cost from itself to its neighbor.
- So, it is more localized like a router only look at the table or maintains and share the information about its neighbors along with the cost.
- The path represented by the smallest cost become the preferred path to reach the destination right.
- There is a period of advertisement that is how periodically it is done, one maybe one is every 30 seconds and so.

Initialization of tables in distance vector routing



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	—

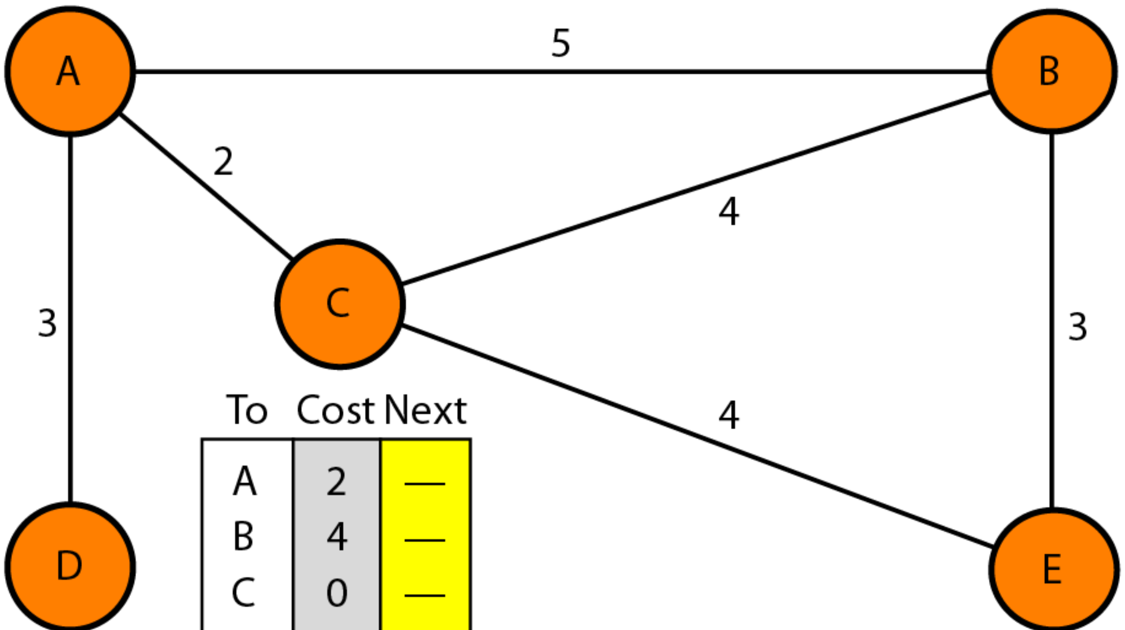
D's table

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

Distance vector routing tables



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	—

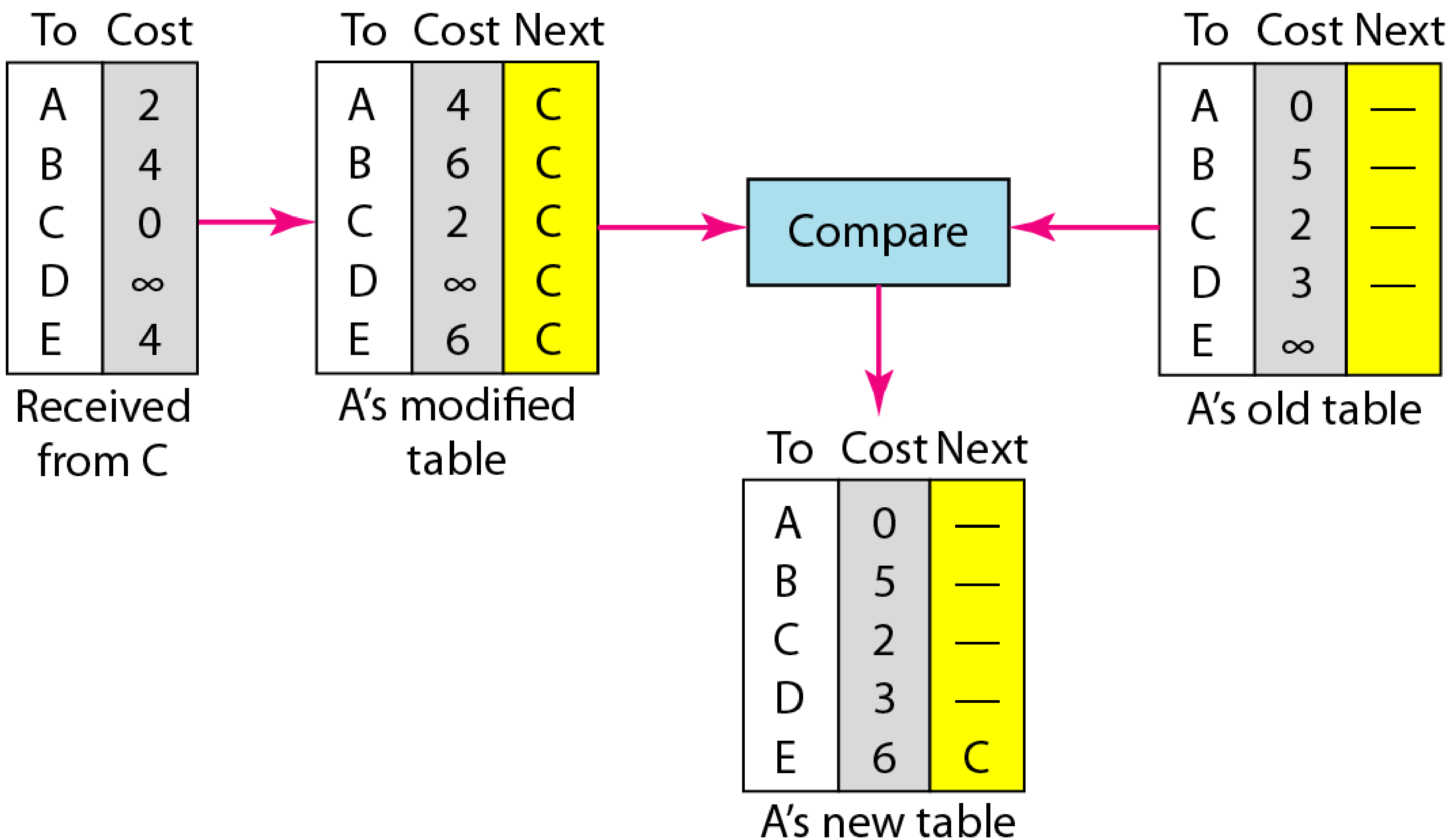
E's table

Distance vector routing

Note

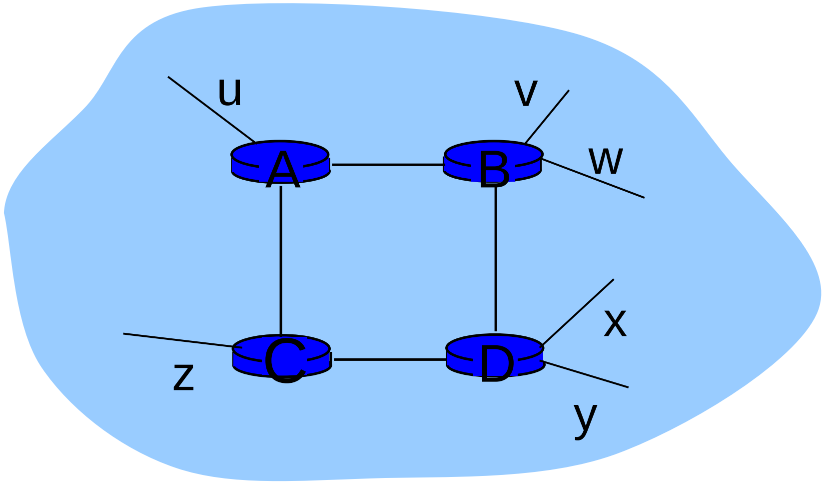
In distance vector routing, each node shares its routing table with its immediate neighbors periodically and when there is a change.

Updating in distance vector routing



RIP (Routing Information Protocol)

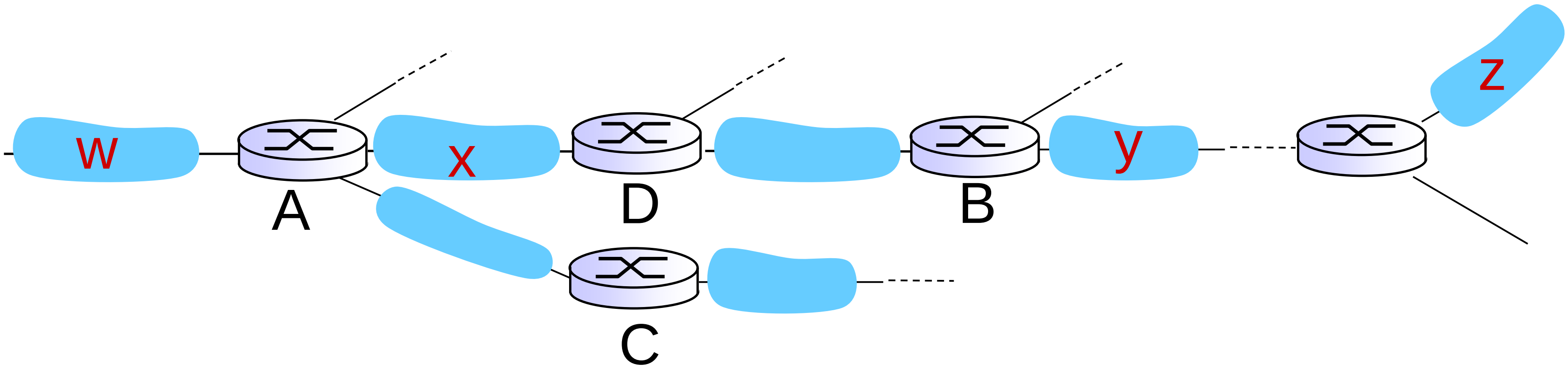
- included in BSD-UNIX distribution in 1982
- distance vector algorithm
  - distance metric: # hops (max = 15 hops), each link has cost 1
  - DVs exchanged with neighbors every 30 sec in response message (aka advertisement)
  - each advertisement: list of up to 25 destination *subnets* *(in IP addressing sense)*



from router A to destination *subnets:*

subnet	hops
u	1
v	2
w	2
x	3
y	3
z	2

RIP: example



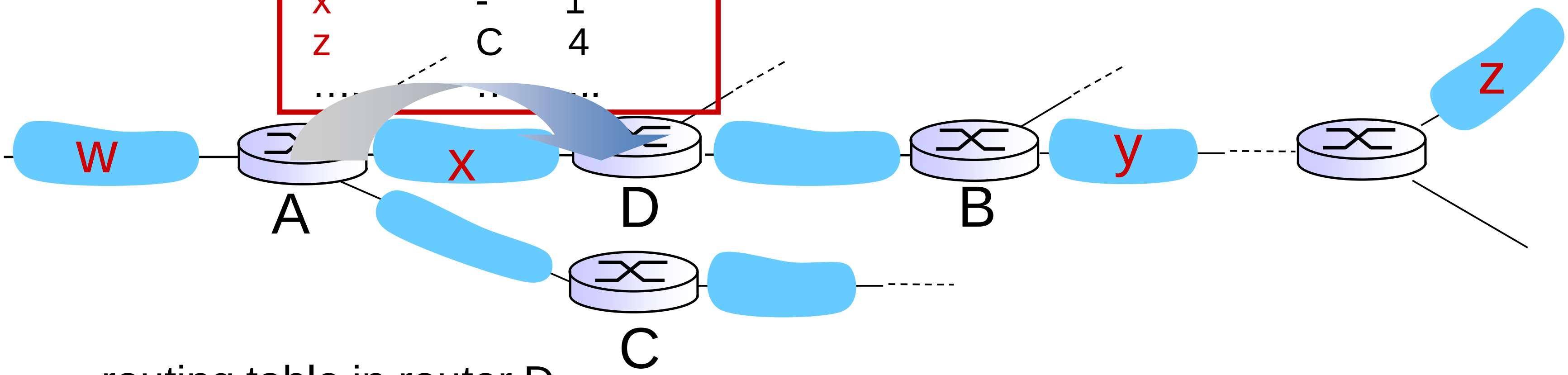
routing table in router D

destination subnet	next router	# hops to dest
w	A	2
y	B	2
z	B	7
x	--	1
….	….	….

RIP: example

A-to-D advertisement

dest	next	hops
w	-	1
x	-	1
z	C	4
….	…	...



routing table in router D

destination subnet	next router	# hops to dest
w	A	2
y	B	2
z	~~B~~ A	~~7~~ 5
x	--	1
….	….	....

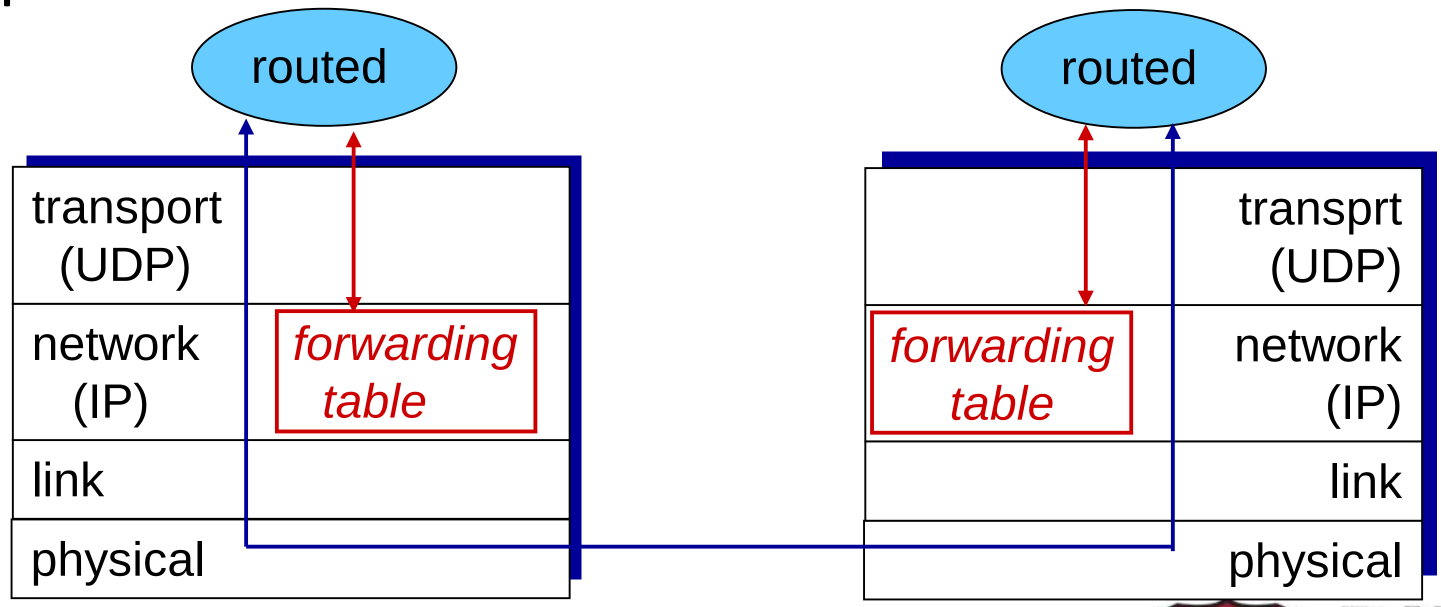
RIP: link failure, recovery

if no advertisement heard after 180 sec --> neighbor/link declared dead

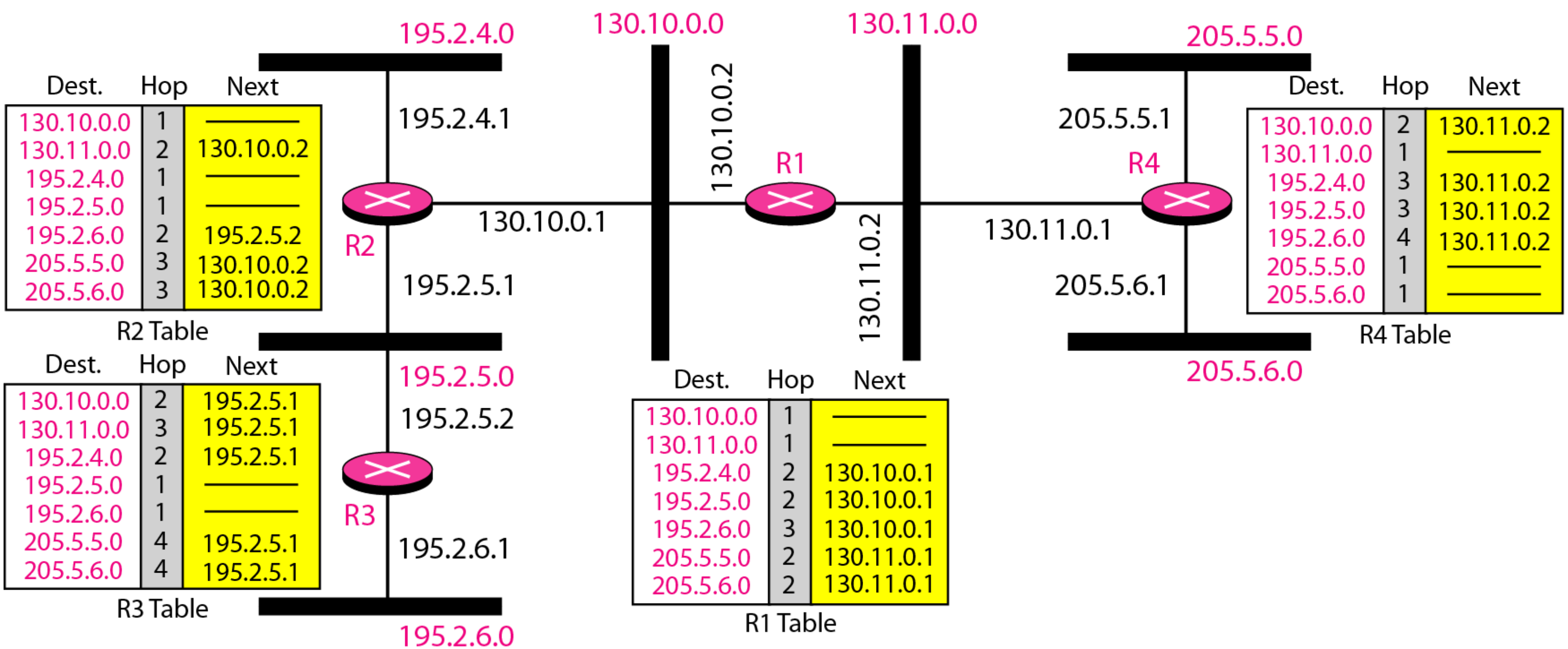
- routes via neighbor invalidated
- new advertisements sent to neighbors
- neighbors in turn send out new advertisements (if tables changed)
- link failure info quickly (?) propagates to entire net

RIP table processing

- RIP routing tables managed by *application-level* process called route-d (daemon)
- advertisements sent in UDP packets, periodically repeated



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

Thank You

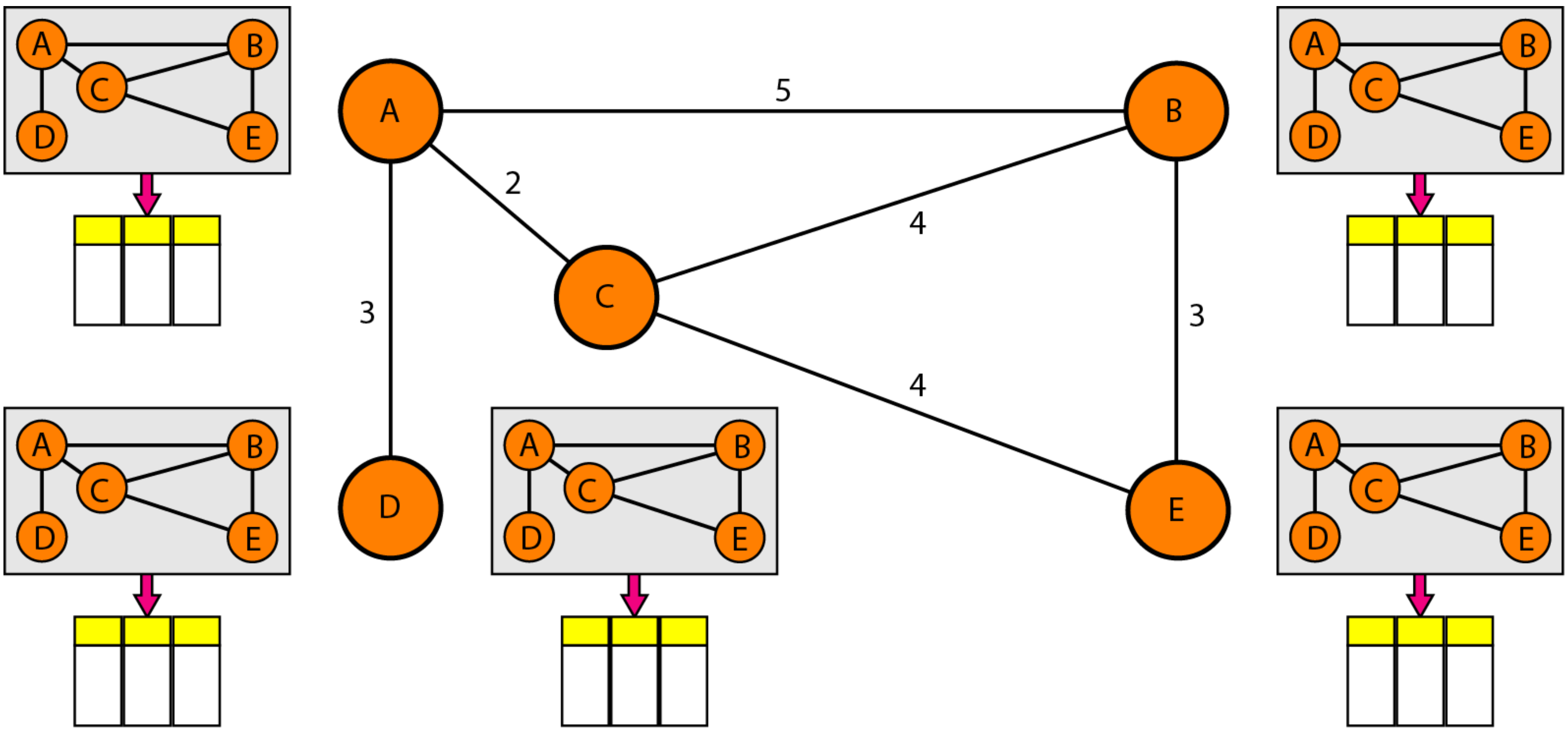
Unit No: 4 Unit name: Network Layer

Lecture No: 27
Routing in the Internet-II

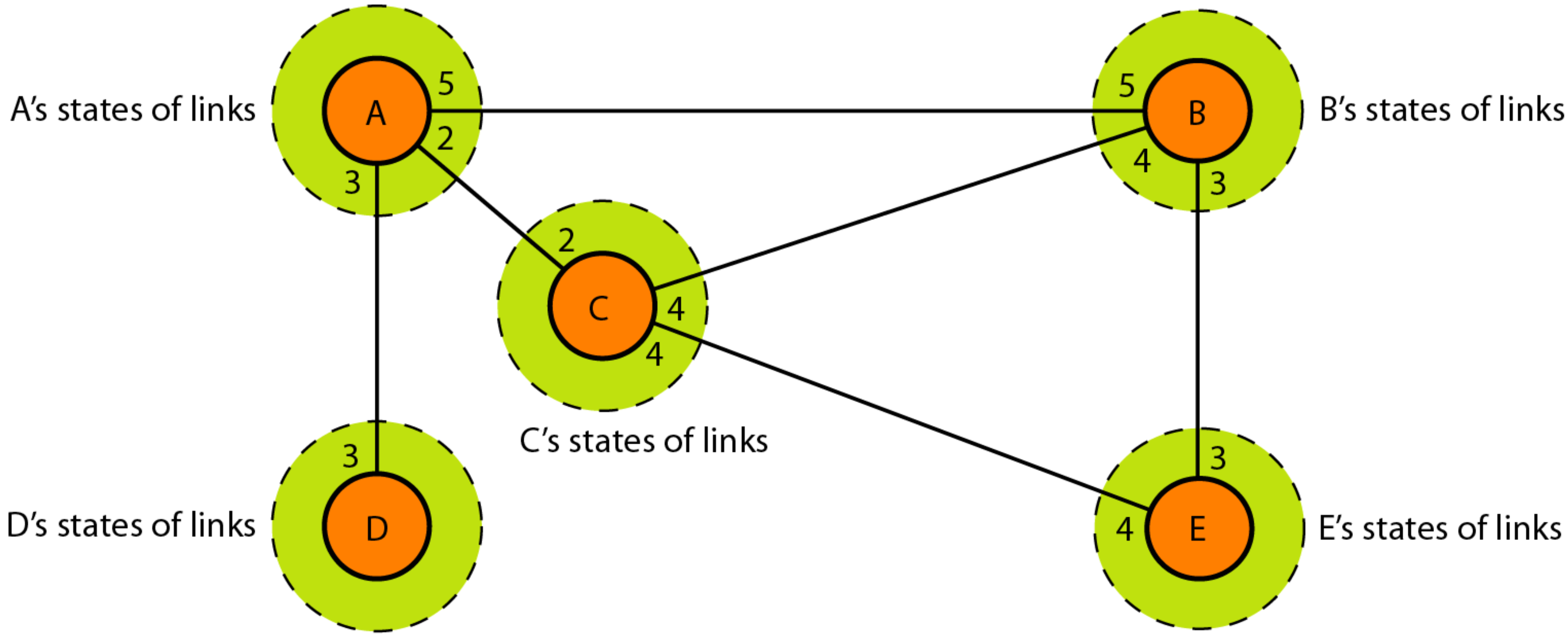
Link state

- Each router advertises a list of all directly connected network and associated cost of the link(list of nodes and links).
- It tries to look at the whole network or the portion of the network in the autonomous systems.
- It advertises the what is the link state .This is performed through exchange of link state advertisements or popularly known as LSAs - LSA with other routers in the network.
- Using these advertisement each router creates a database detailing the current network topology, the topology database in each router is same.

Concept of Link Routing



Link state knowledge



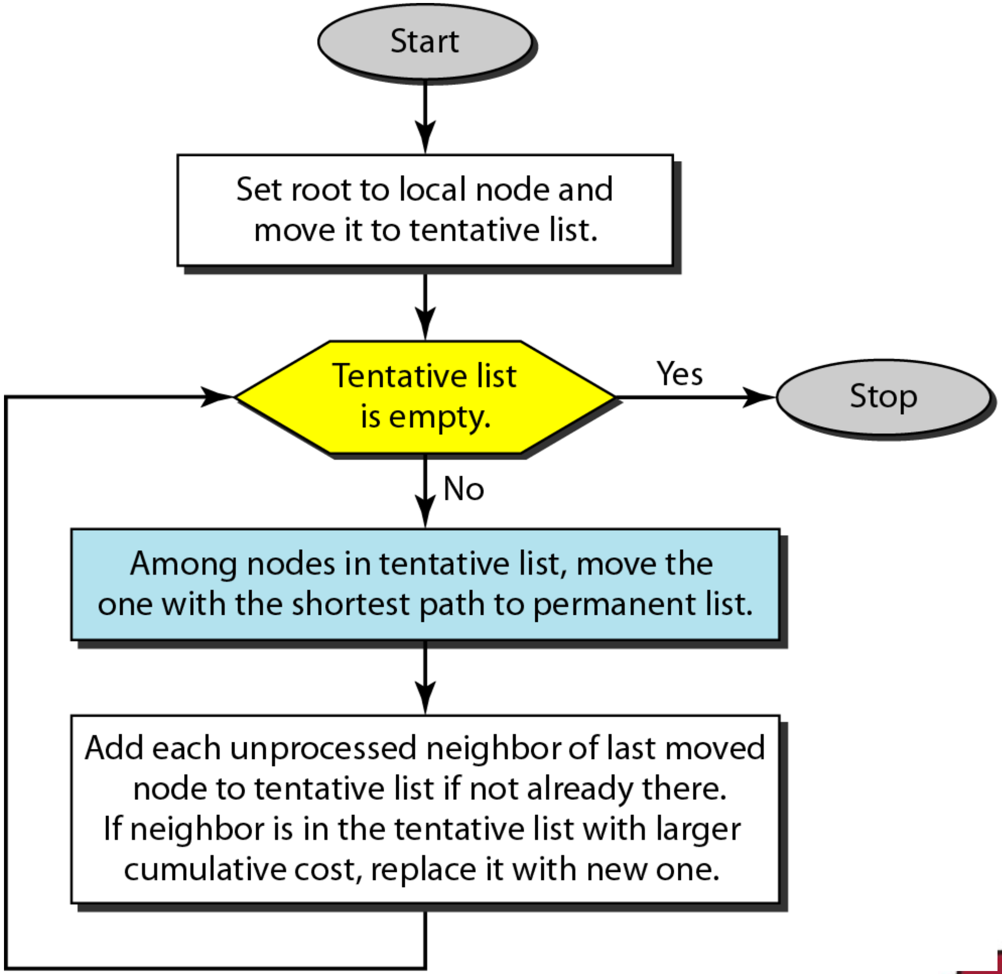
OSPF (Open Shortest Path First)

- "open": publicly available
- uses link state algorithm
  - LS packet dissemination
  - topology map at each node
  - route computation using Dijkstra's algorithm
- OSPF advertisement carries one entry per neighbor
- advertisements flooded to *entire* AS
  - carried in OSPF messages directly over IP (rather than TCP or UDP)

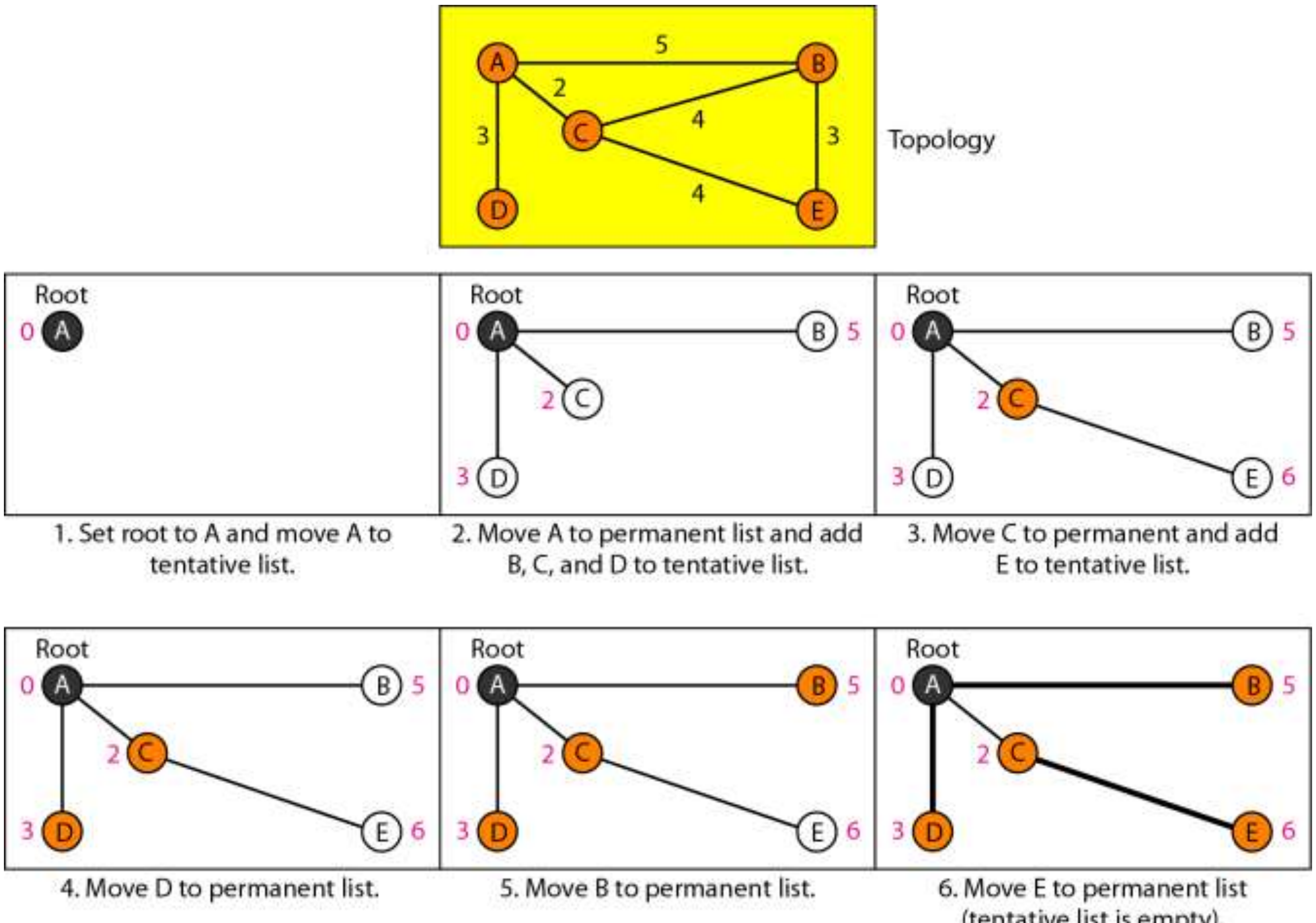
Building routing table

- Creation of states of the links by each node called link state packets(LSP).
  - LSPs are generated on 2 occasions-when change in topology, on a periodic basis-range of 60 mins to 2 hrs
- Flooding- Dissemination of LSPs to every other router
  - At node newly arrives LSP is compared with older one-if it is new then discard old one and send copy of it out of each interface except from which packet has arrived
- Formation of shortest path tree for each node
- Calculation of a routing table based on the shortest path tree

Dijkstra algorithm- formation of shortest path tree



Example of formation of shortest path tree



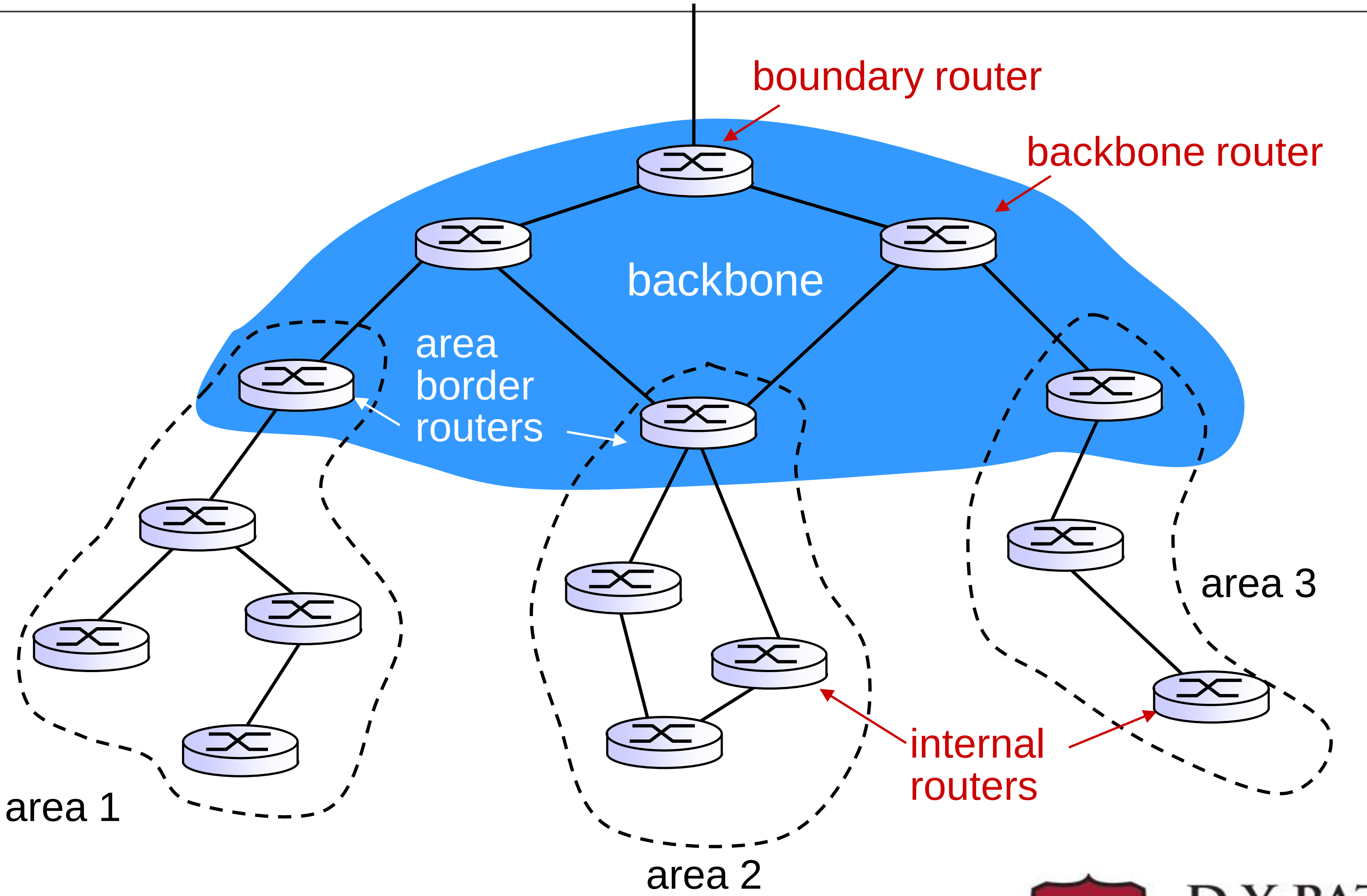
Routing table for node A

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

OSPF “advanced” features (not in RIP)

- *security:* all OSPF messages authenticated (to prevent malicious intrusion)
- multiple same-cost paths allowed (only one path in RIP)
- for each link, multiple cost metrics for different ToS (e.g., satellite link cost set “low” for best effort ToS; high for real time ToS)
- integrated unicast and multicast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- hierarchical OSPF in large domains.

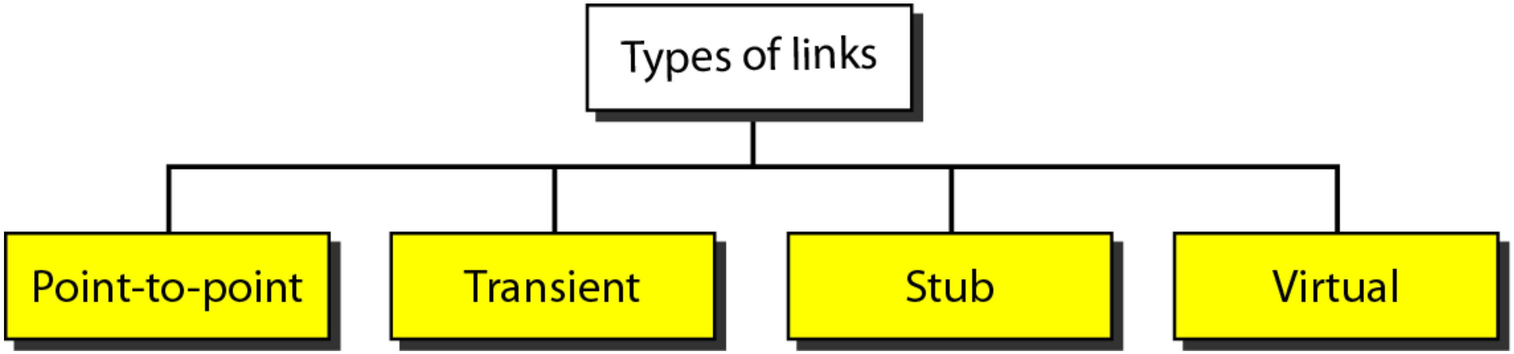
Hierarchical OSPF



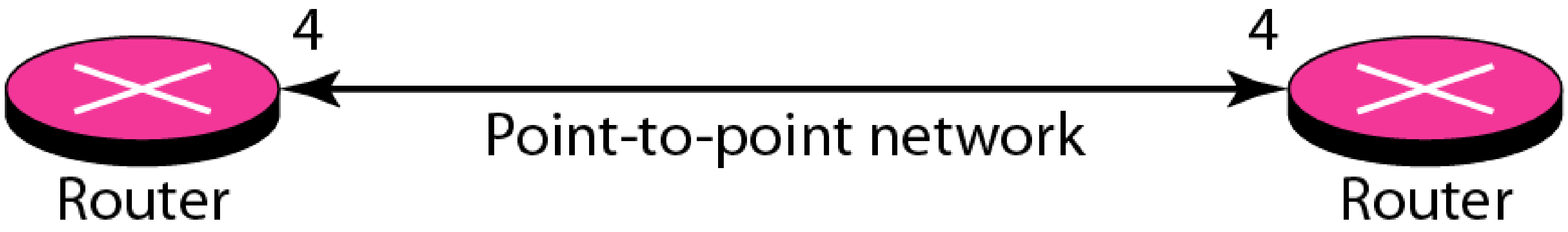
Hierarchical OSPF

- *two-level hierarchy:* local area, backbone.
  - link-state advertisements only in area
  - each nodes has detailed area topology; only know direction (shortest path) to nets in other areas.
- *area border routers:* "summarize" distances to nets in own area, advertise to other Area Border routers.
- *backbone routers:* run OSPF routing limited to backbone.
- *boundary routers:* connect to other AS' s.

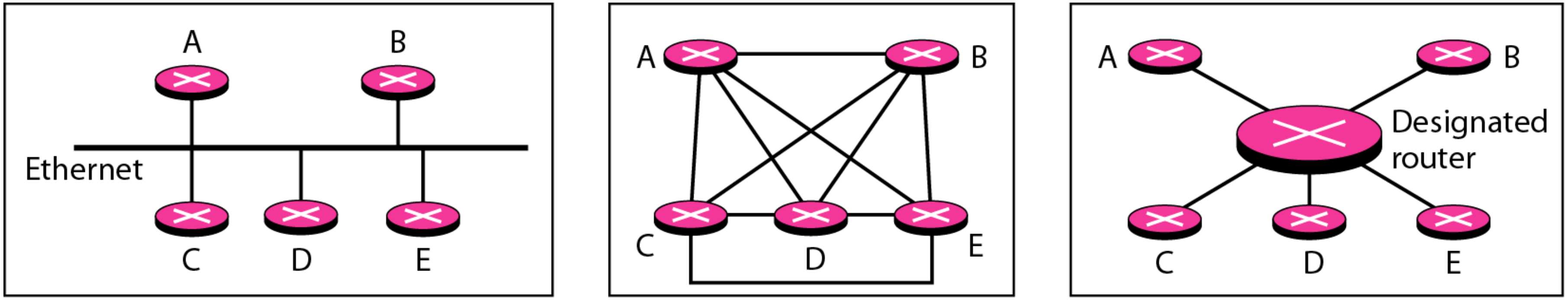
Types of links



Point-to-Point Link

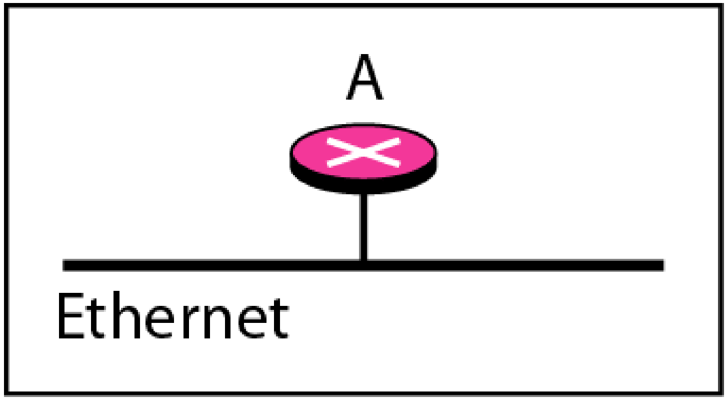


Transient link

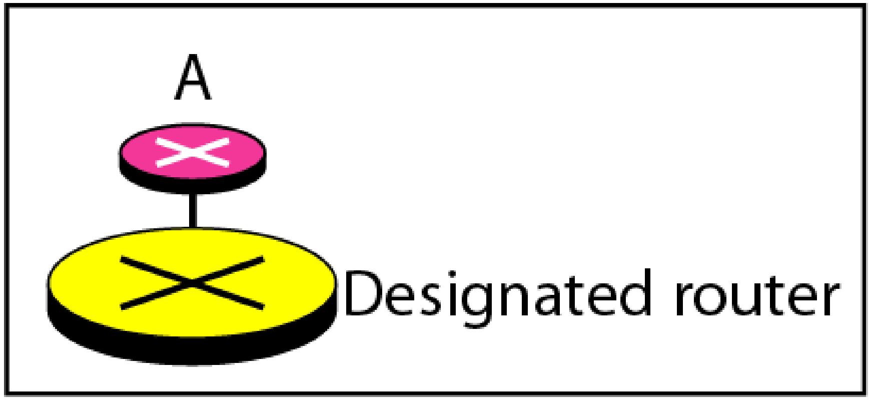


a. Transient network b. Unrealistic representation c. Realistic representation

Stub Link

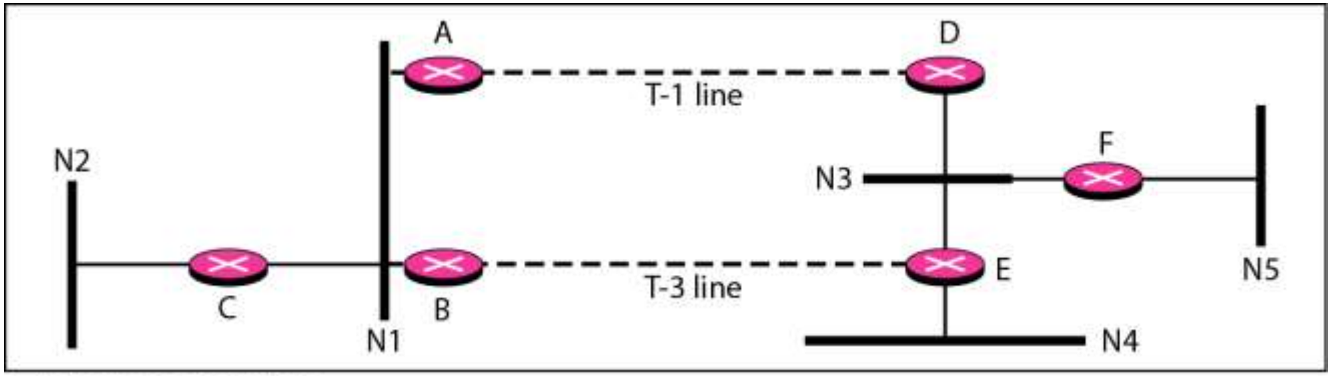


a. Stub network

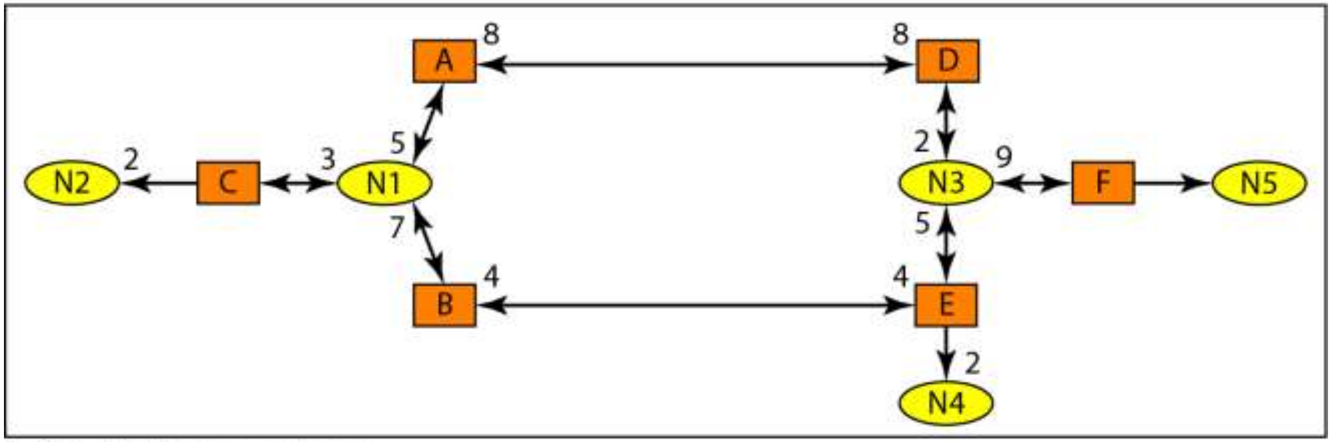


b. Representation

Example of an AS and its graphical representation in OSPF



a. Autonomous system



b. Graphical representation

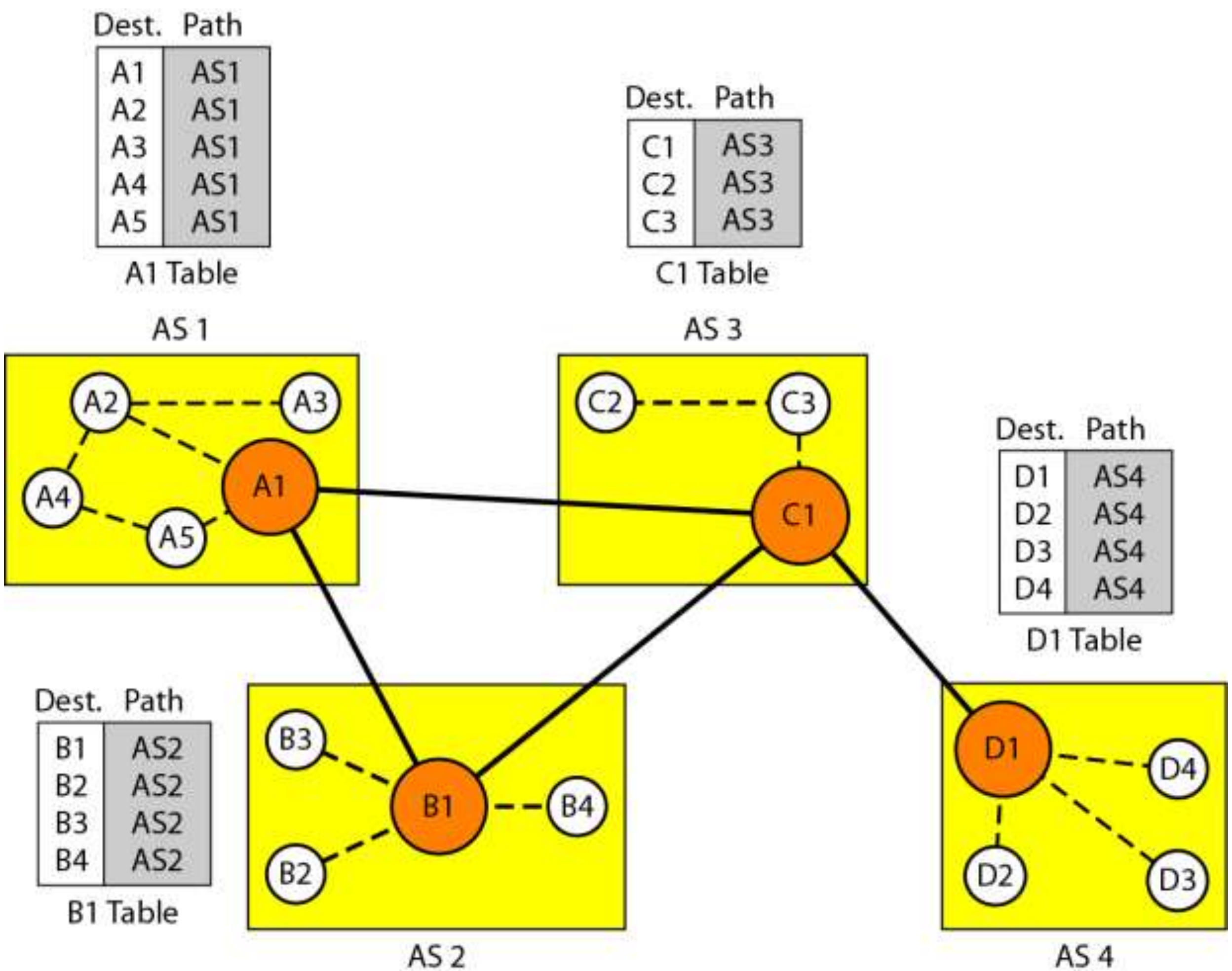
Path vector routing

- Interdomain
- It is somewhat similar to distance vector, but not exactly.
- Speaker node- one node in each AS acts on behalf on the entire AS
- The speaker node in the AS creates a routing table and advertises to the neighboring AS
- A speaker node advertises the path ,not the metric of the nodes , ints AS or other AS

Path vector routing

- Initialization- at the beginning
- Sharing- sharing of routing table with its neighbor
- Updating-when two column table is received from the neighbor, add the nodes not present in routing table
- Optimum path- path that fits the organization

Initial routing tables in path vector routing



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

Border Gateway protocol (BGP)

- Allow exchange of a summary information between the autonomous systems.
- Two sets of routing protocols:

    1.Interior gateway protocol IGPs, interior gateway protocols allows routers to exchange information within the AS.

    Eg. Open Shortest Path First (OSPF)

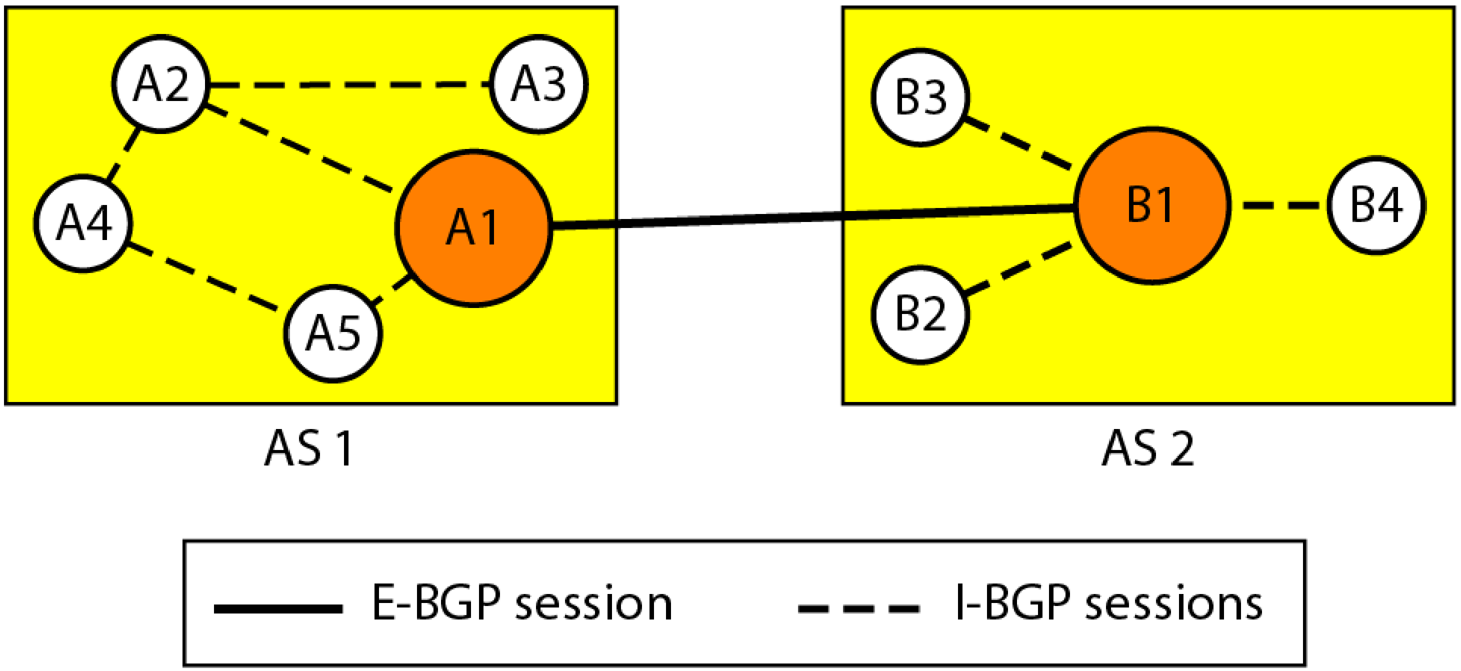
    2. Exterior Gateway Protocols EGPs, allow the exchange of information between two speaker nodes belonging to two different autonomous systems.

    Eg. Border Gateway protocol (BGP)

Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): *the* de facto inter-domain routing protocol
  - "glue that holds the Internet together"
- BGP provides each AS a means to:
  - eBGP: obtain subnet reachability information from neighboring ASs.
  - iBGP: propagate reachability information to all AS-internal routers.
  - determine "good" routes to other networks based on reachability information and policy.
- allows subnet to advertise its existence to rest of Internet: *"I am here"*

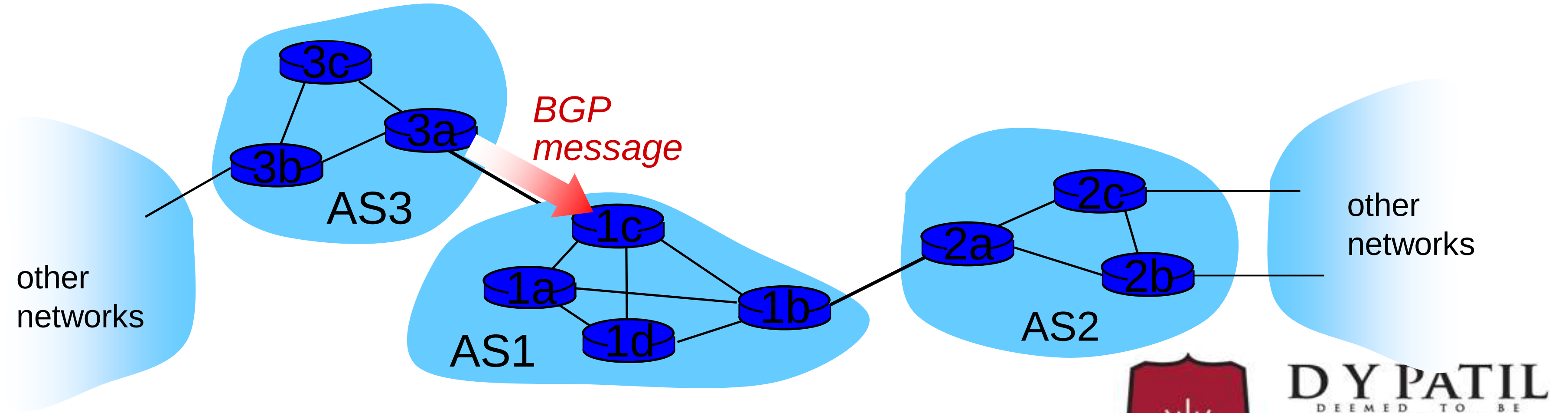
Internal and external BGP sessions



BGP basics

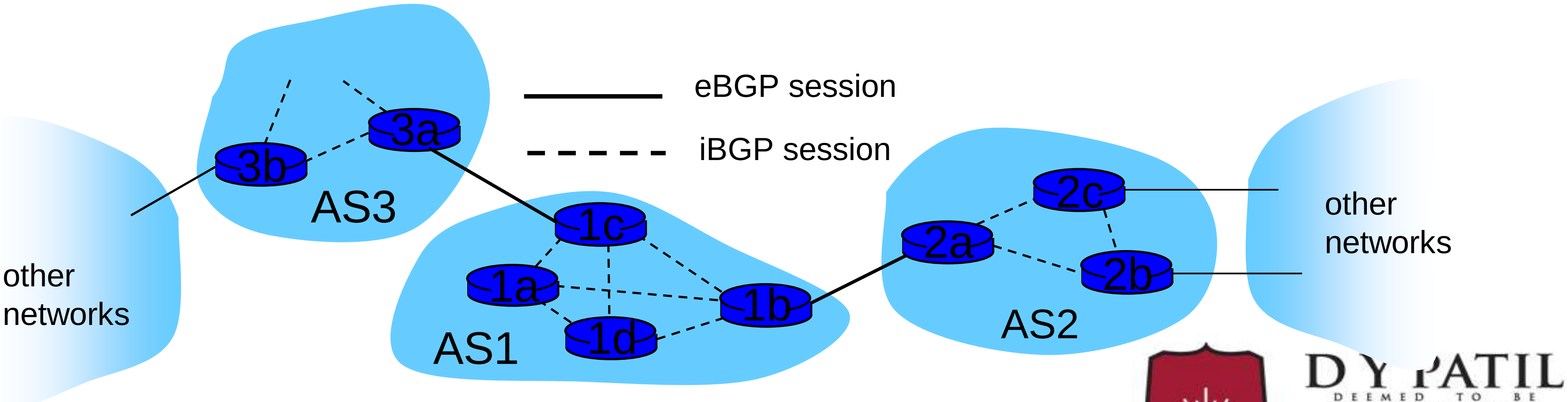
- BGP session: two BGP routers ("peers") exchange BGP messages:
  - advertising *paths* to different destination network prefixes ("path vector" protocol)
  - exchanged over semi-permanent TCP connections

- when AS3 advertises a prefix to AS1:
  - AS3 *promises* it will forward datagrams towards that prefix
  - AS3 can aggregate prefixes in its advertisement



BGP basics: distributing path information

- using eBGP session between 3a and 1c, AS3 sends prefix reachability info to AS1.
  - 1c can then use iBGP do distribute new prefix info to all routers in AS1
  - 1b can then re-advertise new reachability info to AS2 over 1b-to-2a eBGP session
- when router learns of new prefix, it creates entry for prefix in its forwarding table.



Path attributes and BGP routes

- advertised prefix includes BGP attributes
  - prefix + attributes = "route"
- two important attributes:
  - AS-PATH: contains ASs through which prefix advertisement has passed: e.g., AS 67, AS 17
  - NEXT-HOP: indicates specific internal-AS router to next-hop AS. (may be multiple links from current AS to next-hop-AS)
- gateway router receiving route advertisement uses import policy to accept/decline
  - e.g., never route through AS x
  - *policy-based* routing

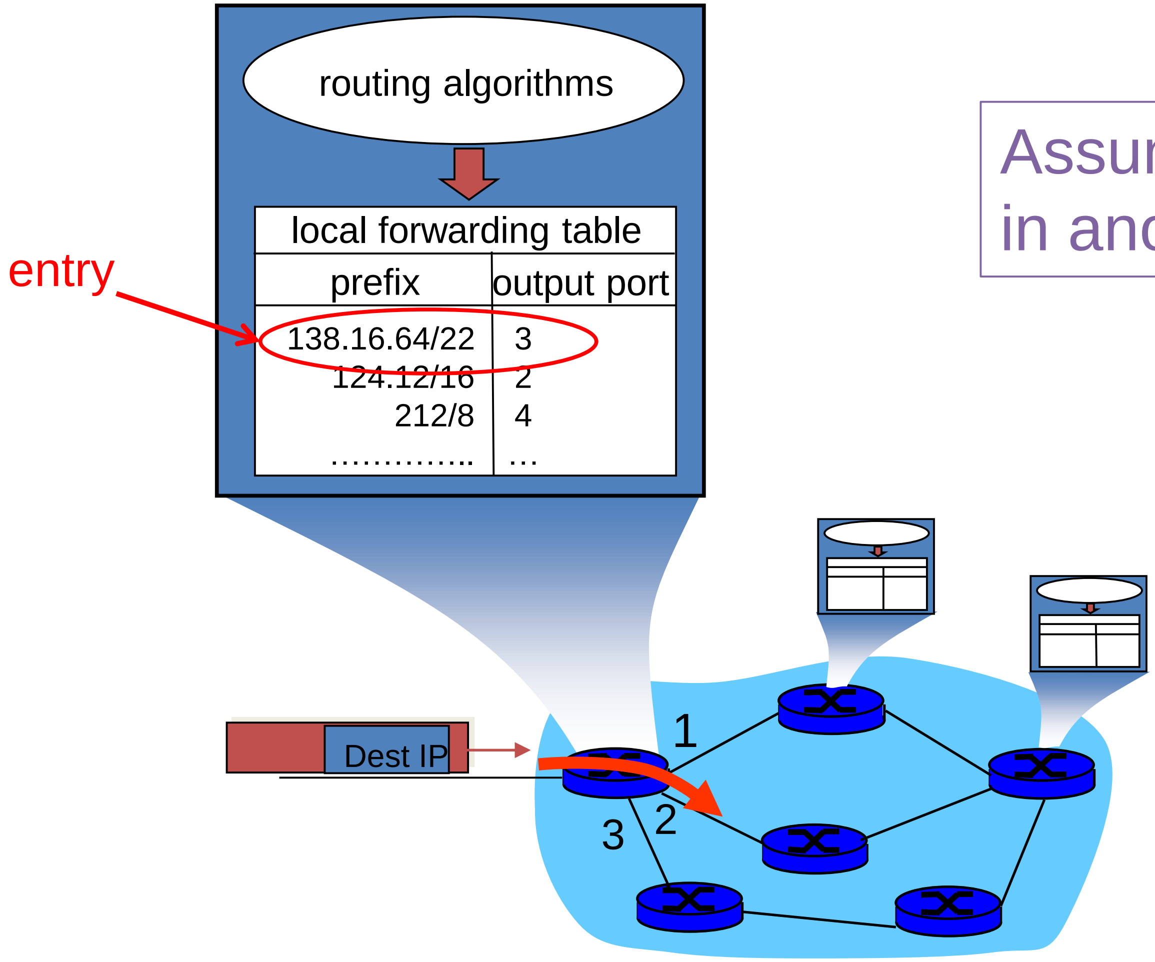
BGP route selection

- router may learn about more than one route to destination AS, selects route based on:
  1. local preference value attribute: policy decision
  2. shortest AS-PATH
  3. closest NEXT-HOP router
  4. additional criteria

BGP messages

- BGP messages exchanged between peers over TCP connection
- BGP messages:
  - OPEN: opens TCP connection to peer and authenticates sender
  - UPDATE: advertises new path (or withdraws old)
  - KEEPALIVE: keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - NOTIFICATION: reports errors in previous msg; also used to close connection

How does entry get in forwarding table?

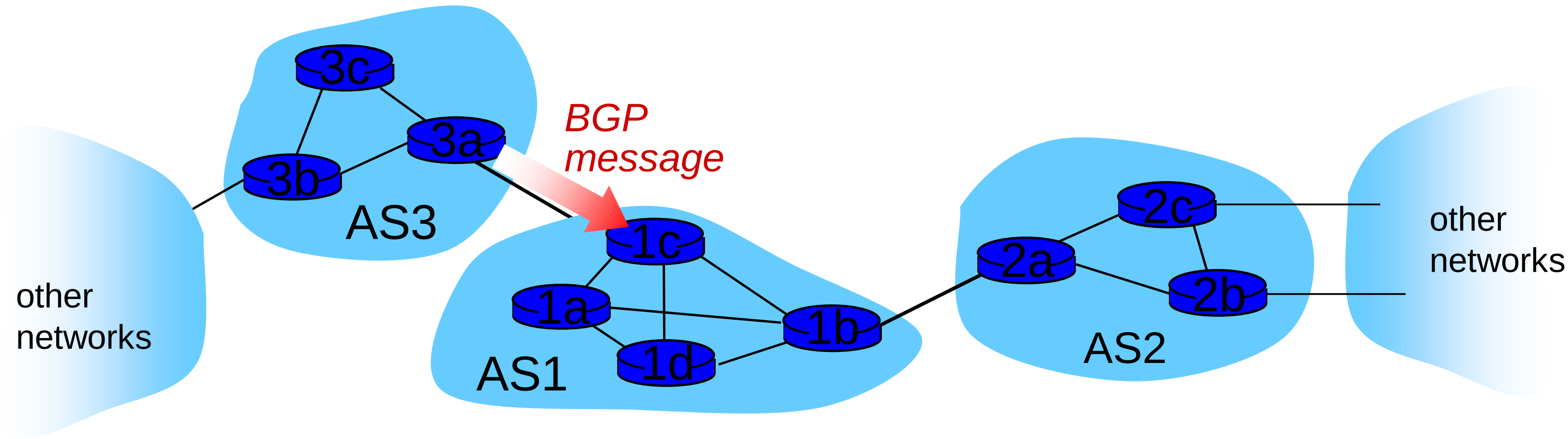


Assume prefix is in another AS.

How does entry get in forwarding table?

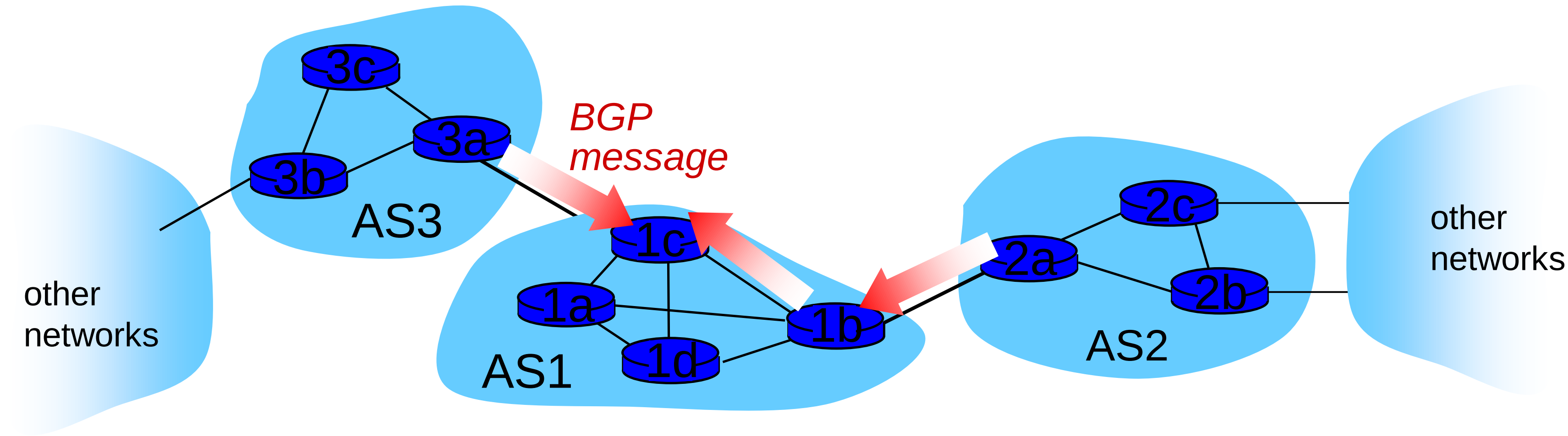
1. Router becomes aware of prefix
2. Router determines output port for prefix
3. Router enters prefix-port in forwarding table

Router becomes aware of prefix



- BGP message contains "routes"
- "route" is a prefix and attributes: AS-PATH, NEXT-HOP,…
- Example: route:
  - Prefix:138.16.64/22 ; AS-PATH: AS3 AS131 ; NEXT-HOP: 201.44.13.125

Router may receive multiple routes



- Router may receive multiple routes for <u>same</u> prefix
- Has to select one route

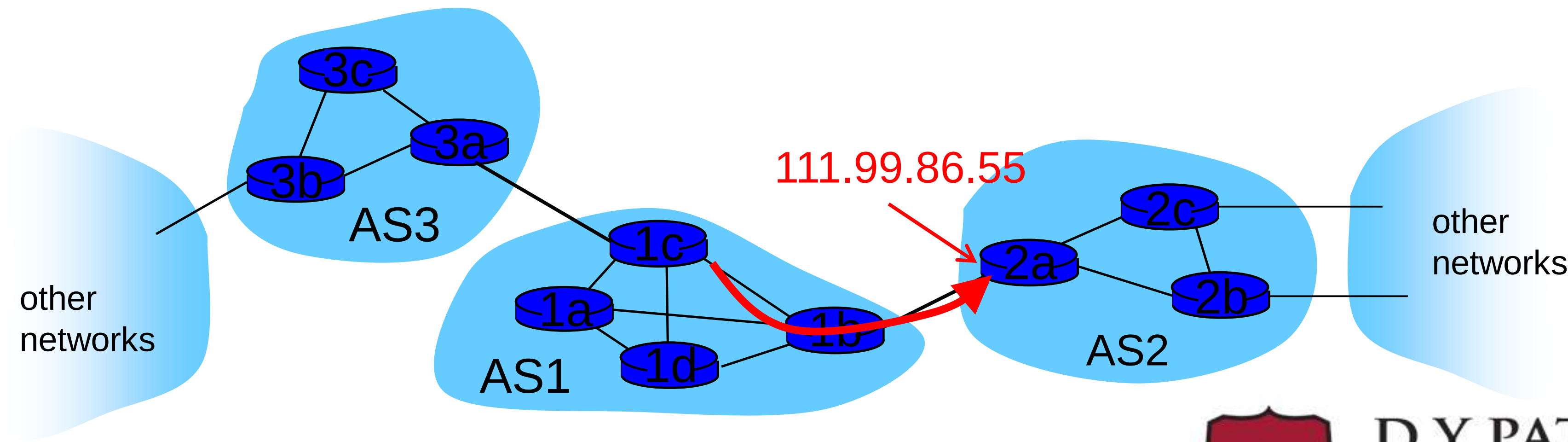
Select best BGP route to prefix

- Router selects route based on shortest AS-PATH

- Example:
  - AS2 AS17 to 138.16.64/22
  - AS3 AS131 AS201 to 138.16.64/22

Find best intra-route to BGP route

- Use selected route's NEXT-HOP attribute
  - Route's NEXT-HOP attribute is the IP address of the router interface that begins the AS PATH.
- Example:
  - AS-PATH: AS2 AS17 ; NEXT-HOP: 111.99.86.55
- Router uses OSPF to find shortest path from 1c to 111.99.86.55



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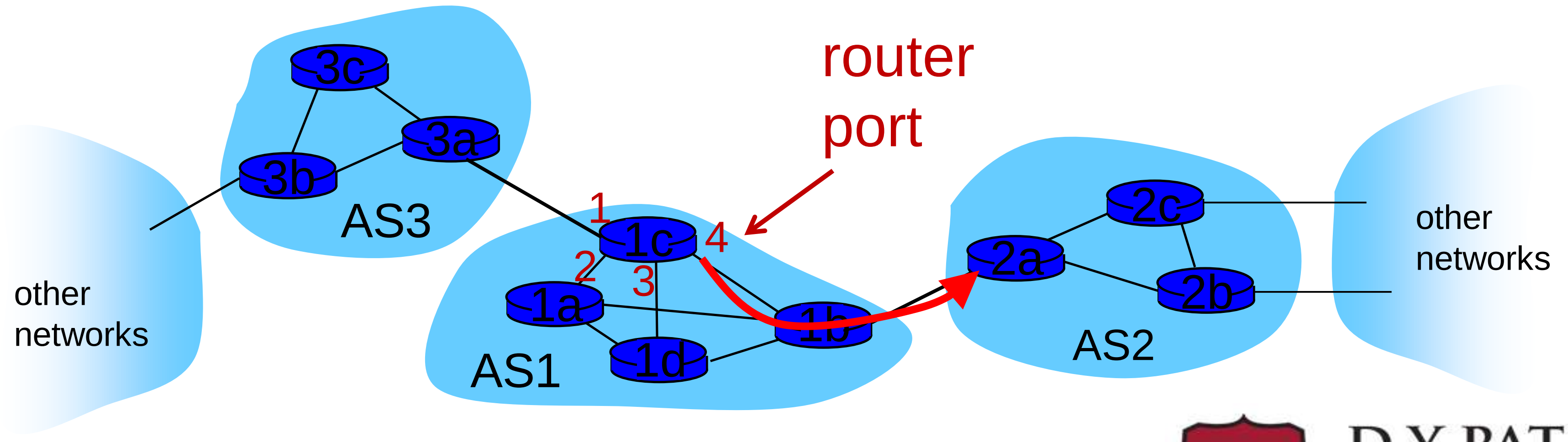
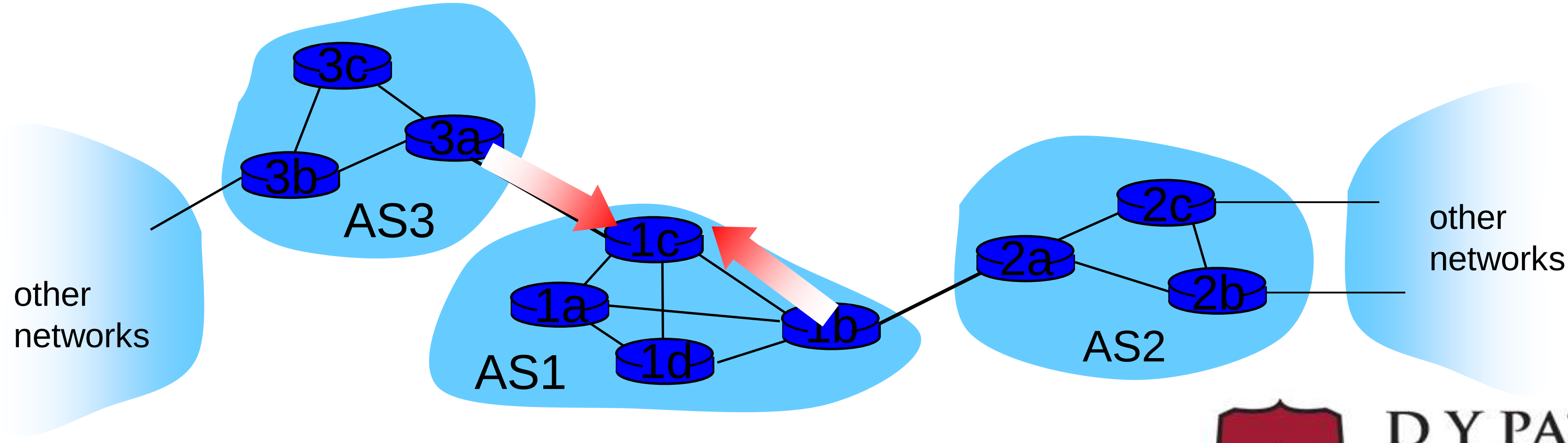
Router identifies port for route

- Identifies port along the OSPF shortest path
- Adds prefix-port entry to its forwarding table:
  - (138.16.64/22 , port 4)



Hot Potato Routing

- Suppose there two or more best inter-routes.
- Then choose route with closest NEXT-HOP
  - Use OSPF to determine which gateway is closest
  - Q: From 1c, chose AS3 AS131 or AS2 AS17?
  - A: route AS3 AS201 since it is closer



How does entry get in forwarding table?

Summary

1. Router becomes aware of prefix
   - via BGP route advertisements from other routers
2. Determine router output port for prefix
   - Use BGP route selection to find best inter-AS route
   - Use OSPF to find best intra-AS route leading to best inter-AS route
   - Router identifies router port for that best route
3. Enter prefix-port entry in forwarding table

Thank You