Chapter 4
Network Layer

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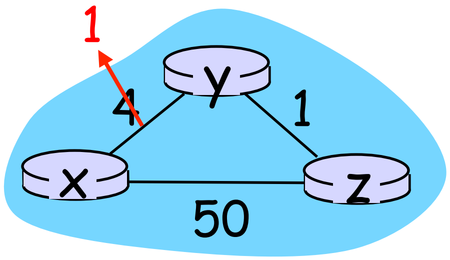
Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach
5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April 2009.

Distance Vector: link cost changes



Link cost changes:

- node detects local link cost change
- updates routing info, recalculates distance vector
- if DV changes, notify neighbors

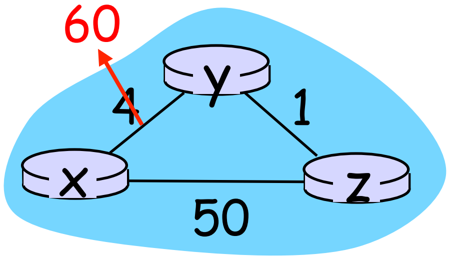
"good news travels fast"

t_0 : *y* detects link-cost change, updates its DV, informs its neighbors.

t_1 : *z* receives update from *y*, updates its table, computes new least cost to *x* , sends its neighbors its DV.

t_2 : *y* receives *z*'s update, updates its distance table. *y*'s least costs do *not* change, so *y* does *not* send a message to *z*.

Distance Vector: link cost increases



node x table

~~4~~ 60
0
4
50

cost to

from	x	y	z
x	0	4	5
y	4	0	1
z	5	1	0

cost to

from	x	y	z
x	0	51	50
y	4	0	1
z	5	1	0

cost to

from	x	y	z
x			
y		idem	
z			

node y table

60
~~4~~
0
1

cost to

from	x	y	z
x	0	4	5
y	4	0	1
z	5	1	0

cost to

from	x	y	z
x	0	4	5
y	6	0	1
z	5	1	0

cost to

from	x	y	z
x	0	51	50
y	6	0	1
z	5	1	0

cost to

from	x	y	z
x	0	4	5
y	8	0	1
z	7	1	0

node z table

50
1
0

cost to

from	x	y	z
x	0	4	5
y	4	0	1
z	5	1	0

cost to

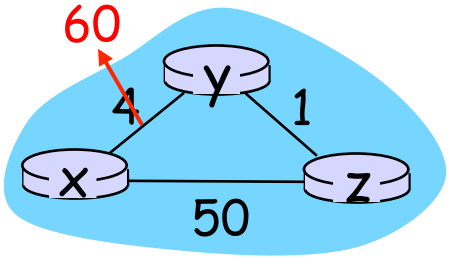
from	x	y	z
x	0	4	5
y	4	0	1
z	5	1	0

cost to

from	x	y	z
x	0	51	50
y	6	0	1
z	7	1	0

time →

Same with poison reverse!



node x table

0
~~4~~ 60
50

cost to (from)

from	x	y	z
x	0	4	5
y	∞	0	1
z	5	1	0

cost to (from)

from	x	y	z
x	0	51	50
y	∞	0	1
z	5	1	0

cost to (from)

from	x	y	z
x			
y		idem	
z			

node y table

~~4~~ 60
0
1

cost to (from)

from	x	y	z
x	0	∞	∞
y	4	0	1
z	∞	∞	0

cost to (from)

from	x	y	z
x	0	∞	∞
y	60	0	1
z	∞	∞	0

cost to (from)

from	x	y	z
x			
y		idem	
z			

node z table

50
1
0

cost to (from)

from	x	y	z
x	0	4	5
y	4	0	∞
z	5	1	0

cost to (from)

from	x	y	z
x	0	4	5
y	4	0	∞
z	5	1	0

cost to (from)

from	x	y	z
x	0	∞	∞
y	60	0	1
z	50	1	0

cost to (from)

from	x	y	z
x	0	51	50
y	51	0	1
z	50	∞	0

time

Comparison of LS and DV algorithms

Message complexity

- LS: with n nodes, E links, O(nE) msgs sent
- DV: exchange between neighbors only
  - convergence time varies

Speed of Convergence

- LS: O(n^2) algorithm requires O(nE) msgs
  - may have oscillations
- DV: convergence time varies
  - may be routing loops
  - count-to-infinity problem

Robustness: what happens if router malfunctions?

LS:

- node can advertise incorrect *link* cost
- each node computes only its *own* table

DV:

- DV node can advertise incorrect *path* cost
- each node's table used by others
  - error propagate thru network

Chapter 4: Network Layer

4. 1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router

4.4 IP: Internet Protocol
  - Datagram format
  - IPv4 addressing
  - ICMP
  - IPv6

4.5 Routing algorithms
  - Link state
  - Distance Vector
  - Hierarchical routing

4.6 Routing in the Internet
  - RIP
  - OSPF
  - BGP

4.7 Broadcast and multicast routing

Hierarchical Routing

Our routing study thus far - idealization
- all routers identical
- network "flat"

… *not* true in practice

scale: with 200 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

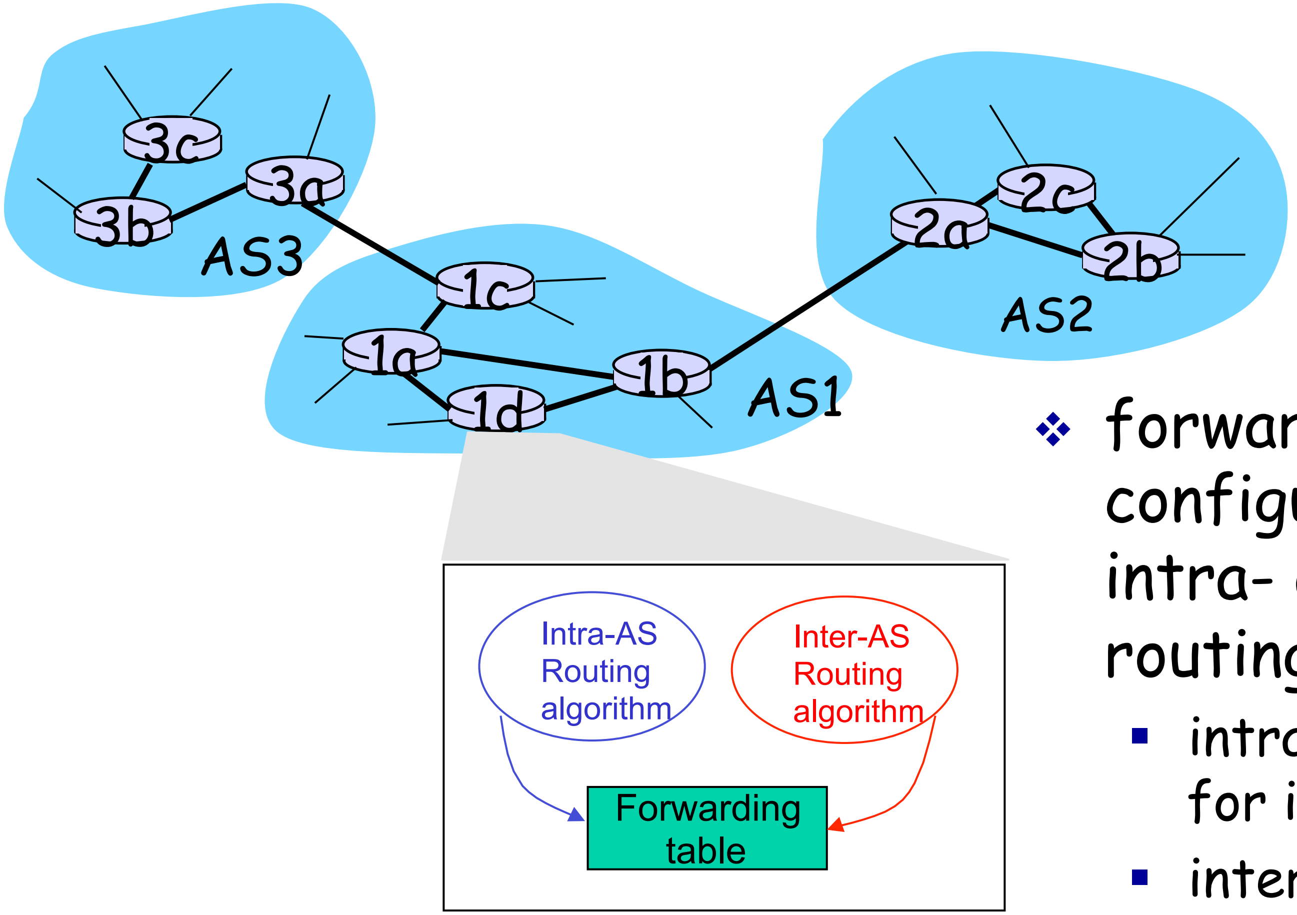
Hierarchical Routing

- 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

Interconnected ASes



- 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

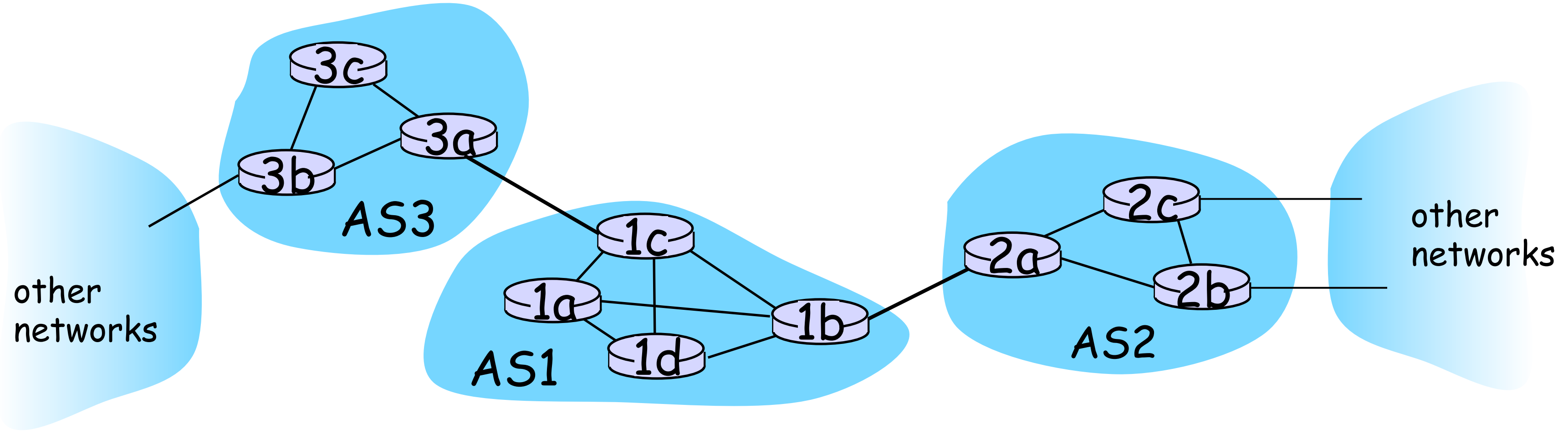
Inter-AS tasks

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

AS1 must:

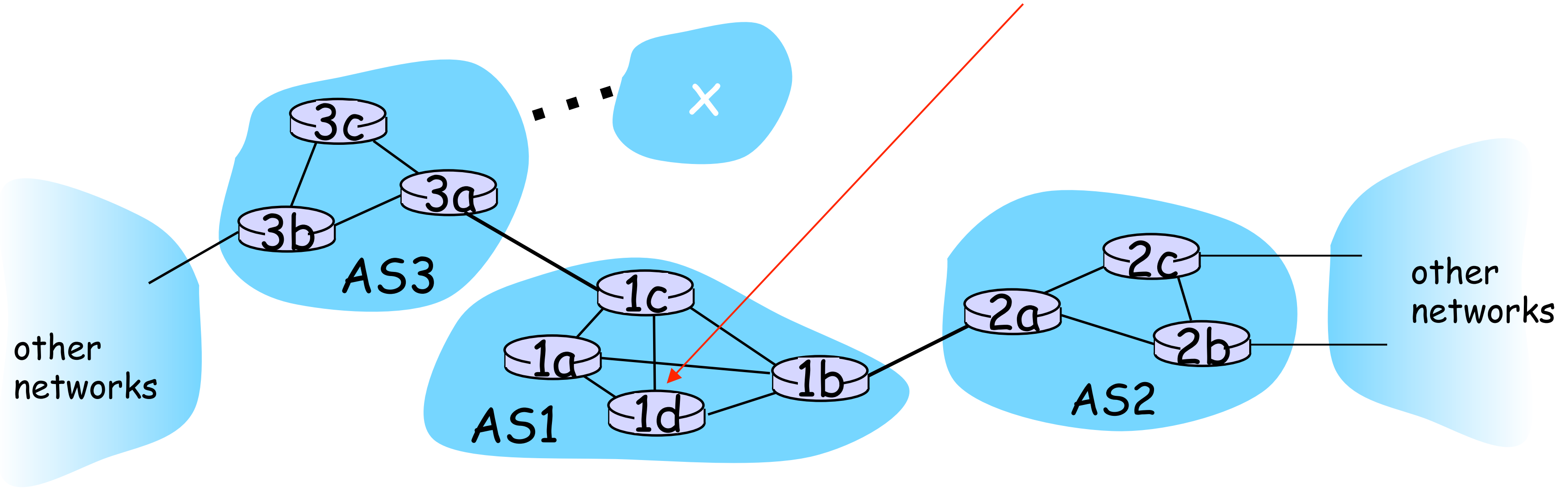
1. learn which dests are reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1

job of inter-AS routing!



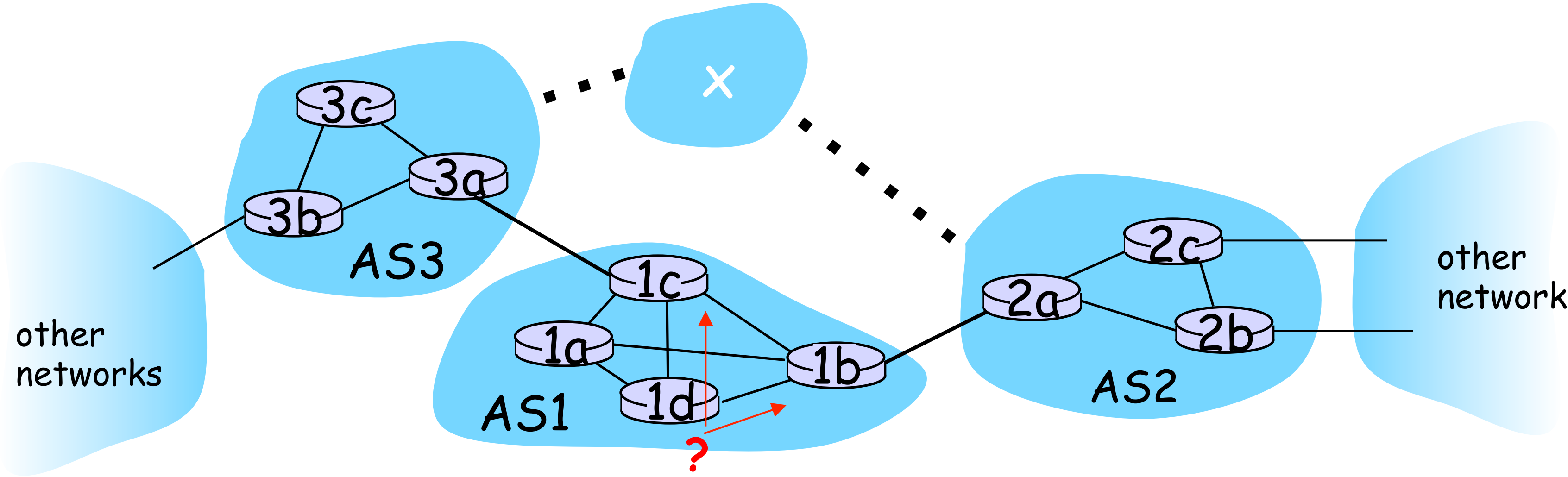
Example: Setting forwarding table in router 1d

- 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

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  - Distance Vector
  - Hierarchical routing

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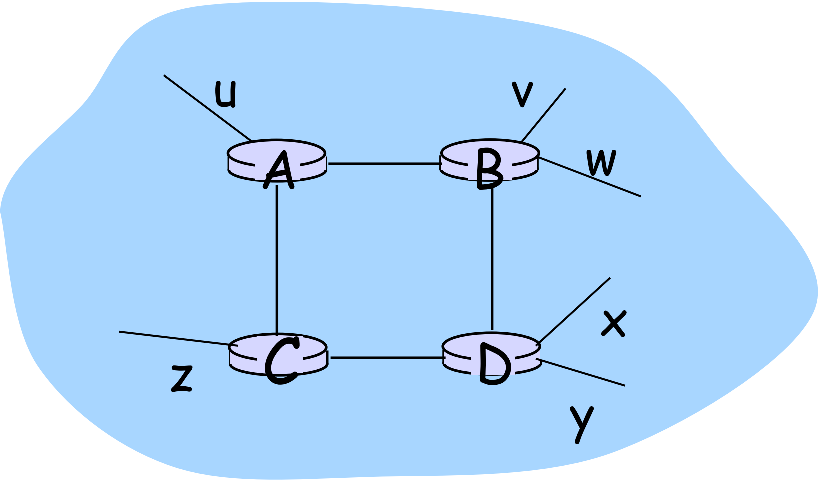
Intra-AS Routing

- also known as Interior Gateway Protocols (IGP)
- most common Intra-AS routing protocols:
  - RIP: Routing Information Protocol
  - OSPF: Open Shortest Path First
  - IGRP: Interior Gateway Routing Protocol (Cisco proprietary)

RIP (Routing Information Protocol)

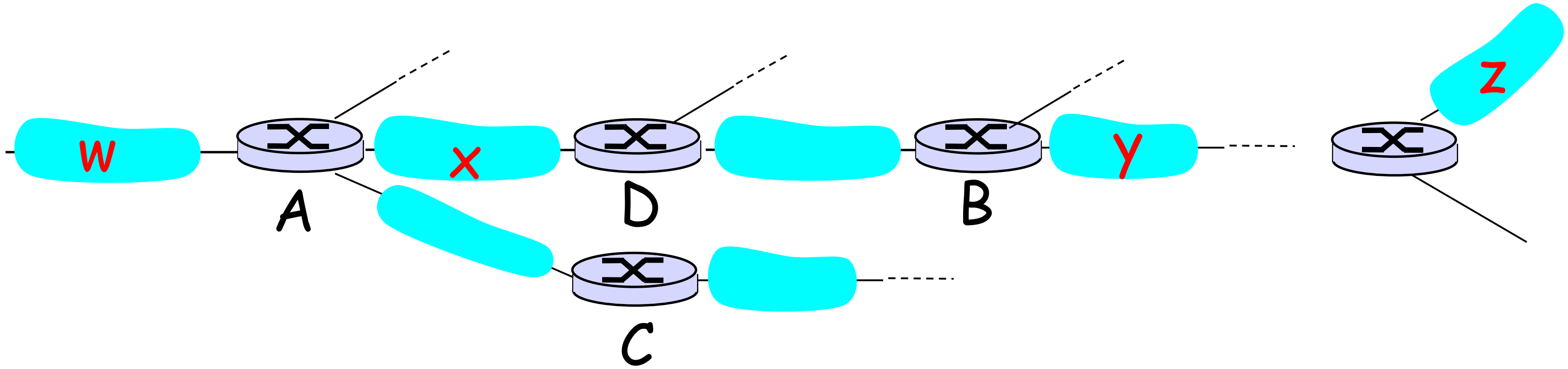
- included in BSD-UNIX distribution in 1982
- distance vector algorithm
    - distance metric: # hops (max = 15 hops), each link has cost 1
    - DVs exchanged with neighbors every 30 sec in response message (aka advertisement)
    - each advertisement: list of up to 25 destination *subnets* *(in IP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



from router A to destination subnets:

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

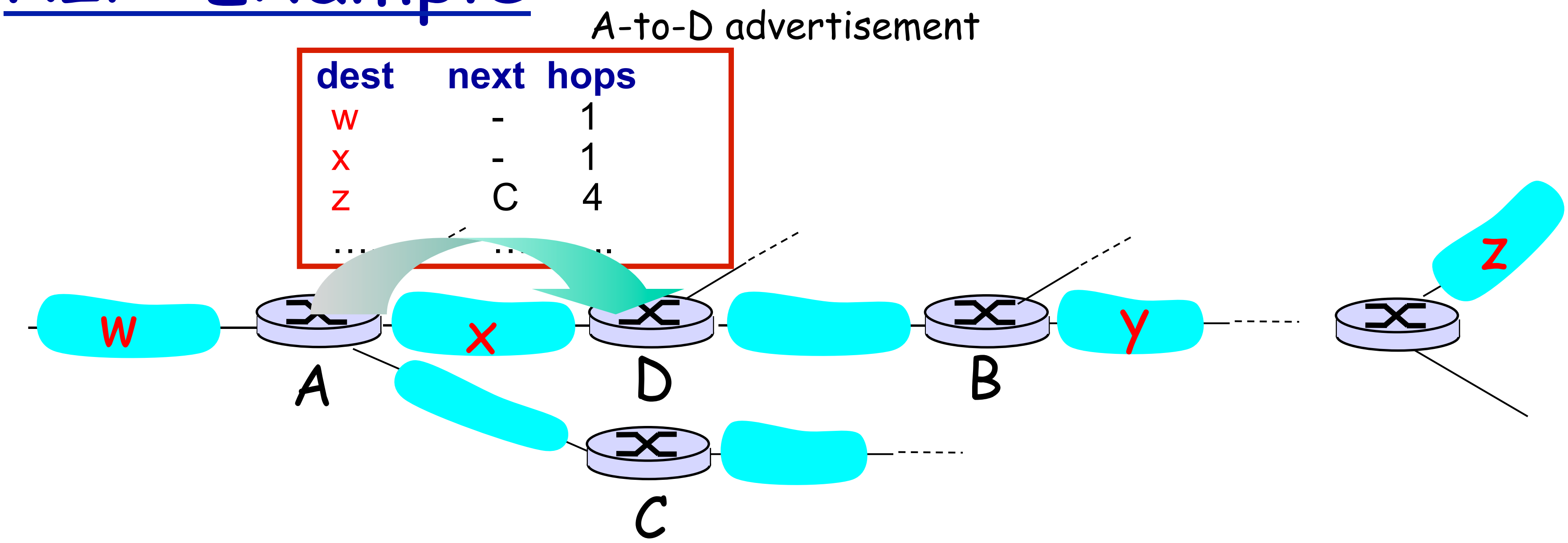
RIP: Example



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
….	….	….

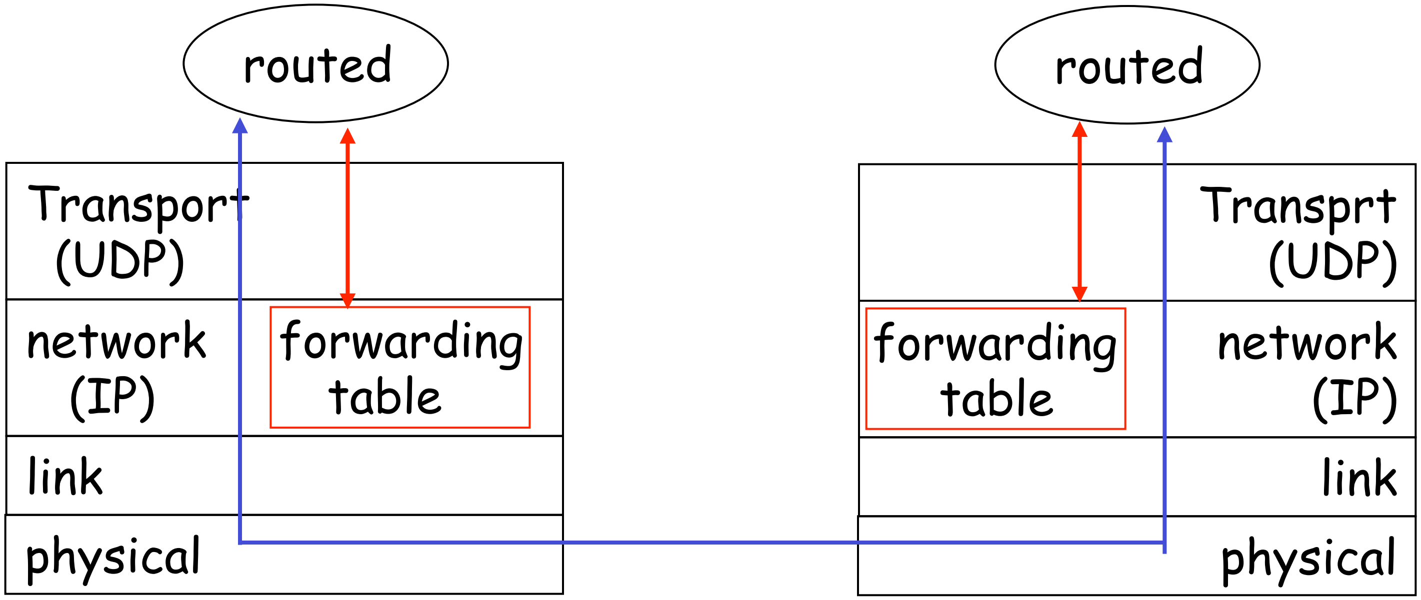
RIP: Link Failure and Recovery

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
- *poison reverse* used to prevent ping-pong loops (infinite distance = 16 hops)

RIP Table processing

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



OSPF (Open Shortest Path First)

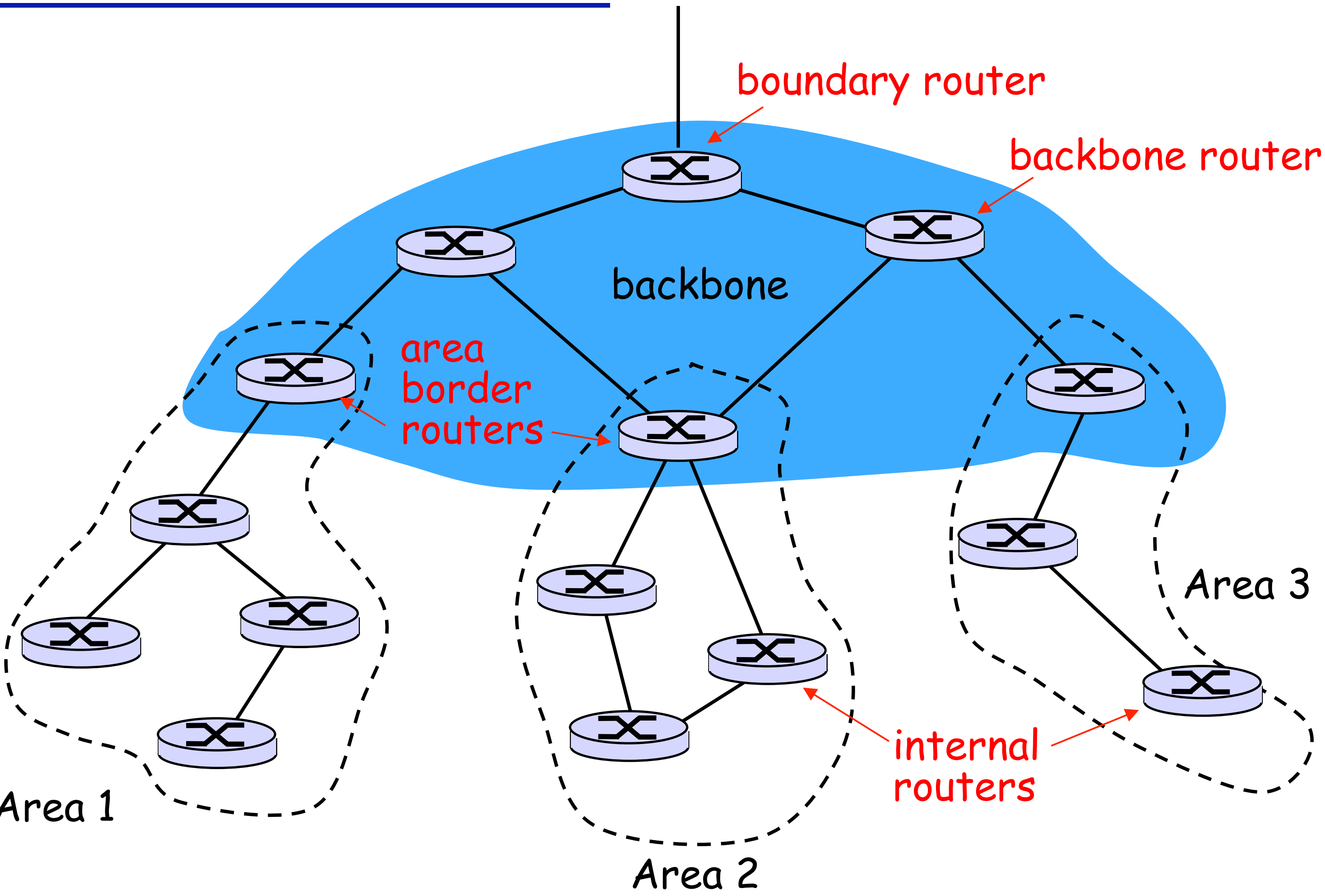
- "open": publicly available
- uses Link State algorithm
  - LS packet dissemination
  - topology map at each node
  - route computation using Dijkstra's algorithm

- OSPF advertisement carries one entry per neighbor router
- advertisements disseminated to entire AS (via flooding)
  - carried in OSPF messages directly over IP (rather than TCP or UDP

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 uni- 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.