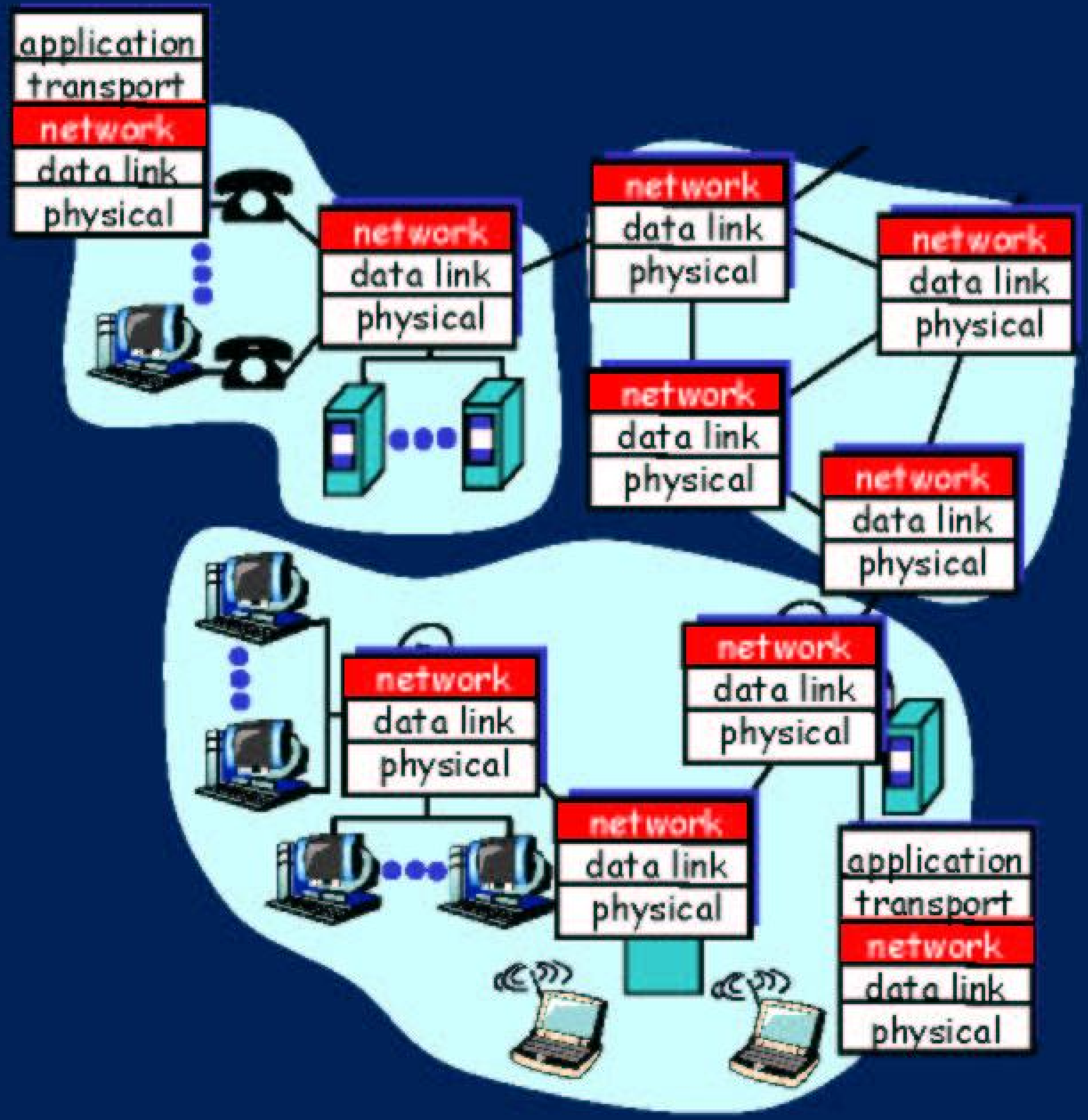
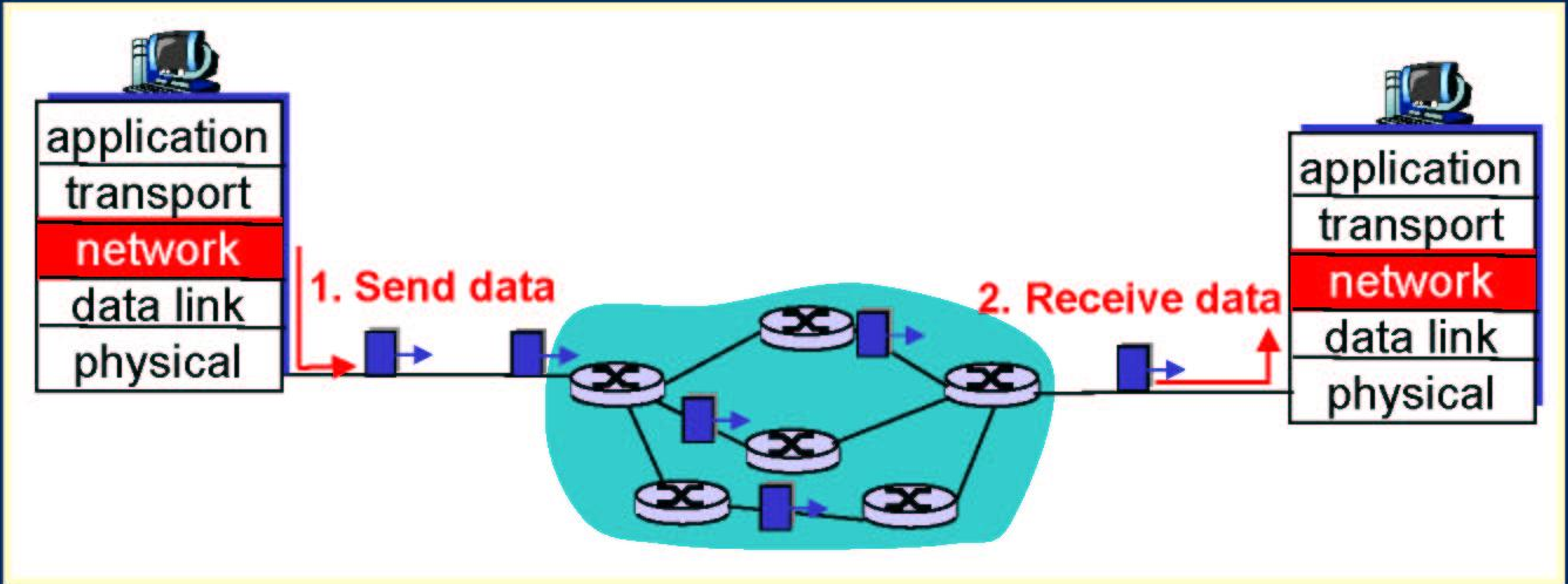
Network layer functions - 1

- transport packet from sending to receiving hosts
- network layer protocols in *every* host, router



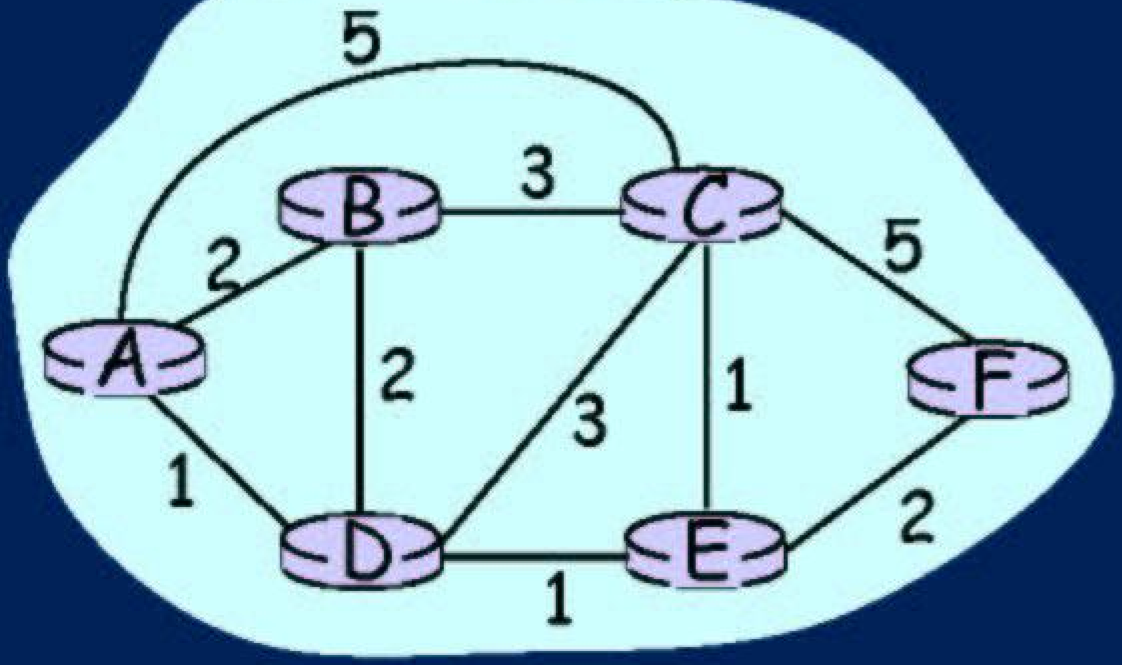
Datagram networks: the Internet model - 2



Routing

Routing protocol

Goal: determine "good" path (sequence of routers) thru network from source to dest.



- Graph abstraction for routing algorithms:
- graph **nodes** are routers
- graph **edges** are physical links
  - link cost: delay, $ cost, or congestion level

"**good**" path:

typically means minimum cost path

other def's possible

Routing Algorithm classification - 1

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 partial info with neighbors
- "**distance vector**" algorithms

Routing Algorithm classification - 2

<u>Static or dynamic?</u>

Static:

- routes change slowly over time

Dynamic:

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

A Link-State Routing Algorithm - 1

Dijkstra’s algorithm

- net topology, link costs known to all nodes
  - accomplished via “link state broadcast”
  - all nodes have same info
- computes least cost paths from one node (‘source”) to all other nodes
  - gives routing table for that node
  - iterative: after k iterations, know least cost path to k dest.’s

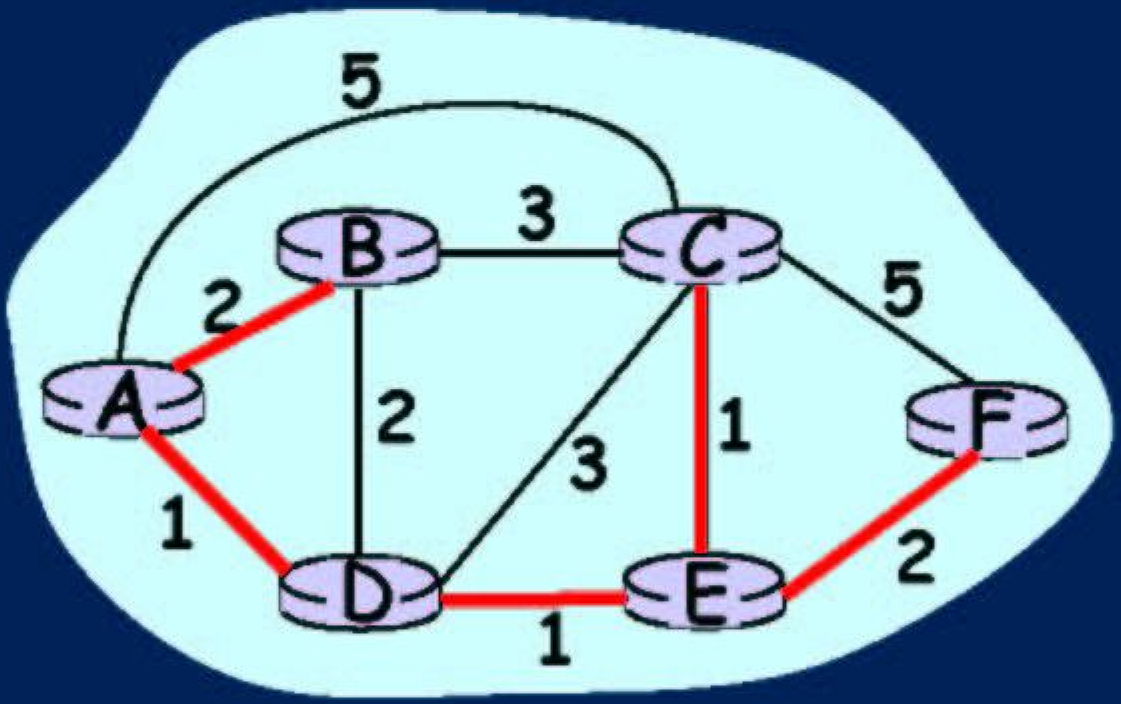
A Link-State Routing Algorithm - 2

Notation:

- **c(i,j):** link cost from node i to j. cost infinite if not direct neighbors
- **D(v):** current value of cost of path from source to dest. V
- **p(v):** predecessor node (neighbor of v) along path from source to v
- **N:** set of nodes whose least cost path definitively known

Dijkstra's algorithm: example

Step	start N	D(B),p(B)	D(C),p(C)	D(D),p(D)	D(E),p(E)	D(F),p(F)
0	A	2,A	5,A	1,A	infinity	infinity
1	AD	2,A	4,D		2,D	infinity
2	ADE	2,A	3,E			4,E
3	ADEB		3,E			4,E
4	ADEBC					4,E
5	ADEBCF					



Dijsktra's Algorithm

```
Initialization:
  $N = \{A\}$
  for all nodes v
    if v adjacent to A
      then $D(v) = c(A,v)$
      else $D(v) = \text{infty}$

Loop
  find w not in N such that D(w) is a minimum
  add w to N
  update D(v) for all v adjacent to w and not in N:
     $D(v) = \min( D(v), D(w) + c(w,v) )$
  /* new cost to v is either old cost to v or known
   shortest path cost to w plus cost from w to v */
until all nodes in N
```

Distance Vector Routing Algorithm - 2

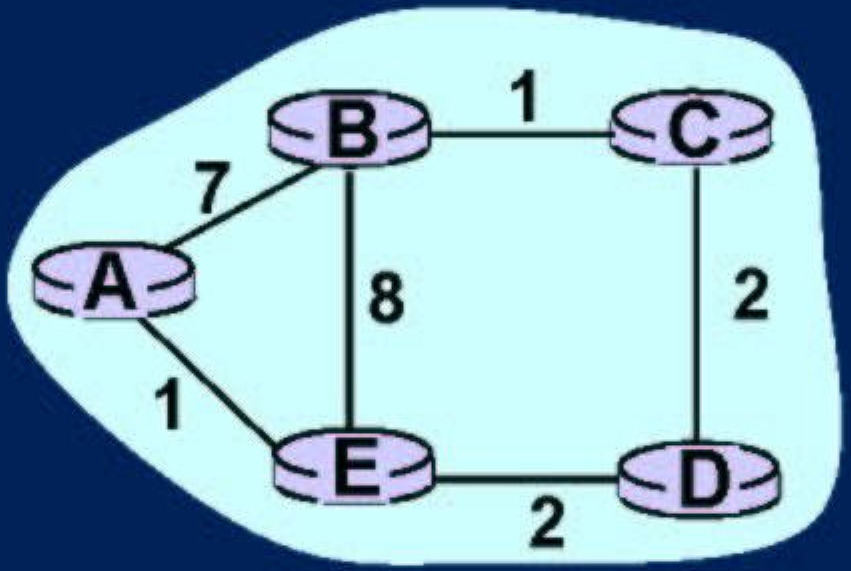
Distance Table data structure

- each node has its own
- row for each possible destination
- column for each directly-attached neighbor to node
- example: in node X, for dest. Y via neighbor Z:

$D^X(Y,Z)$ = distance *from* X *to* Y, *via* Z as next hop

$$= c(X,Z) + \min_w \{D^Z(Y,w)\}$$

Distance table: example



$$D^E(C,D) = c(E,D) + \min_w \{D^D(C,w)\}$$
$$= 2+2 = 4$$

$$D^E(A,D) = c(E,D) + \min_w \{D^D(A,w)\}$$
$$= 2+3 = 5$$ loop!

$$D^E(A,B) = c(E,B) + \min_w \{D^B(A,w)\}$$
$$= 8+6 = 14$$ loop!

		cost to destination via		
	$D^E()$	A	B	D
destination	A	1	14	5
	B	7	8	5
	C	6	9	4
	D	4	11	2

Distance table gives routing table

cost to destination via

destination

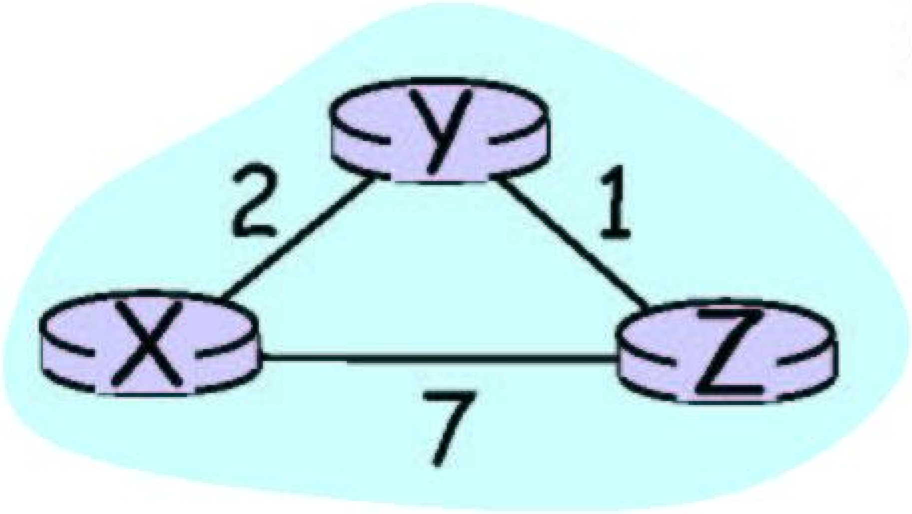
$D^E()$	A	B	D
A	1	14	5
B	7	8	5
C	6	9	4
D	4	11	2

destination

	Outgoing link to use, cost
A	A,1
B	D,5
C	D,4
D	D,4

Distance table → Routing table

Distance Vector Algorithm: example - 1



	D^X	cost via	
		Y	Z
dest	Y	2	∞
	Z	∞	7

	D^Y	cost via	
		X	Z
dest	X	2	∞
	Z	∞	1

	D^Z	cost via	
		X	Y
dest	X	7	∞
	Y	∞	1

	D^X	cost via	
		Y	Z
dest	Y	2	8
	Z	3	7

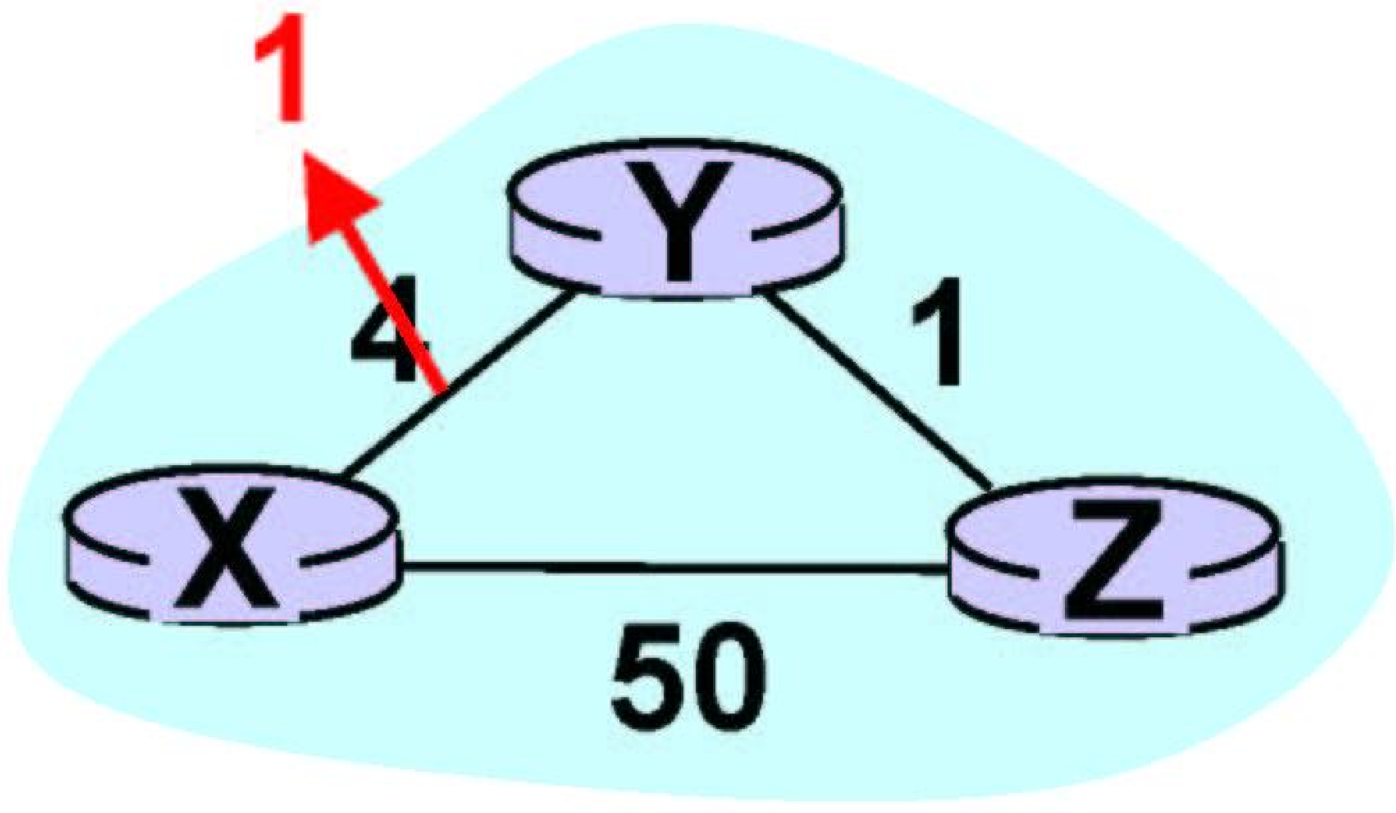
$$D^X(Y,Z) = c(X,Z) + \min_w\{D^Z(Y,w)\}$$
$$= 7+1 = 8$$

$$D^X(Z,Y) = c(X,Y) + \min_w\{D^Y(Z,w)\}$$
$$= 2+1 = 3$$

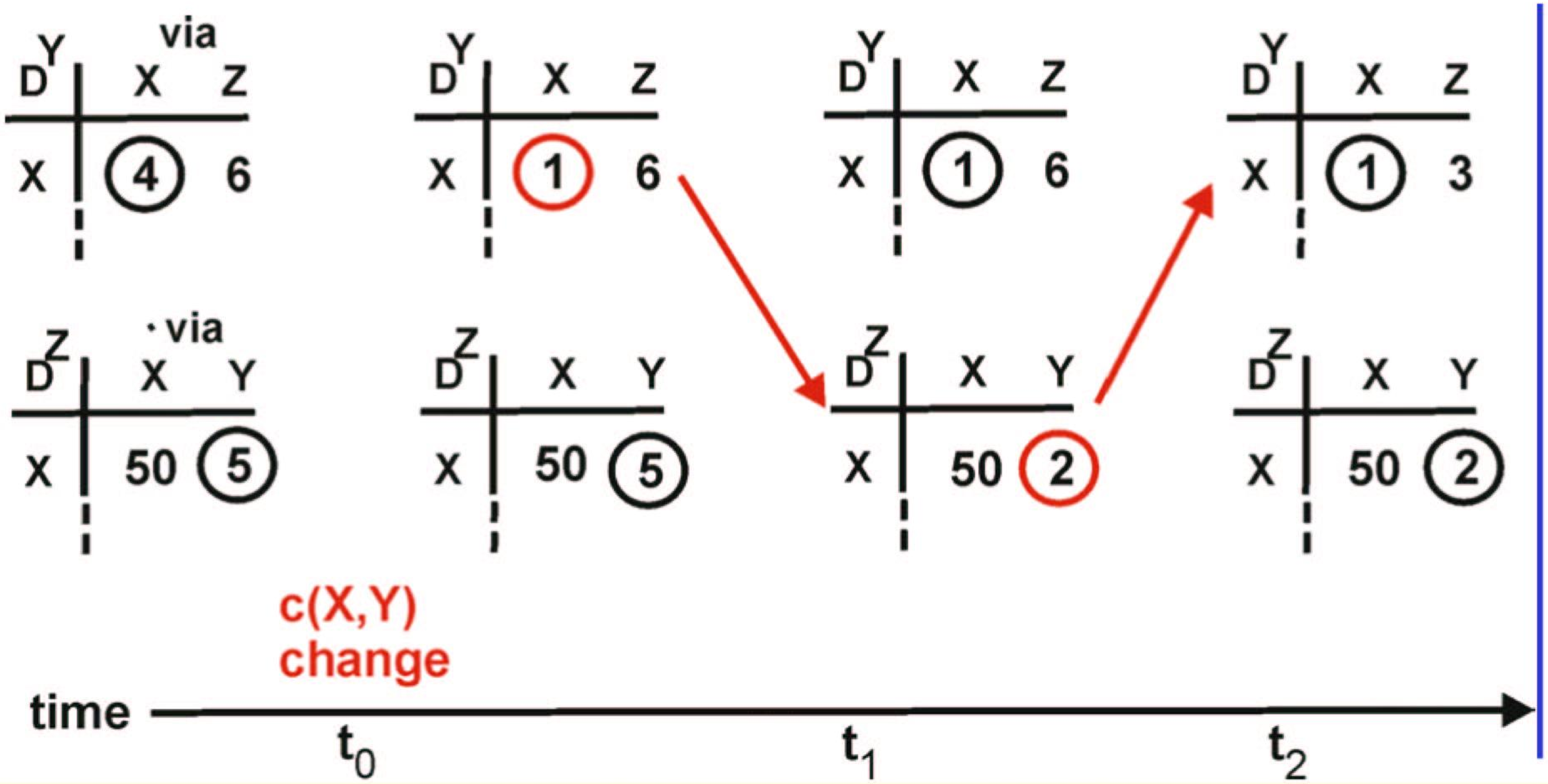
Distance Vector: link cost changes - 1

Link cost changes:

node detects local link cost change
updates distance table (line 15)
if cost change in least cost path, notify neighbors (lines 23,24)



"good news travels fast"



D^Y	X	Z
X	4	6

D^Z	X	Y
X	50	5

D^Y	X	Z
X	1	6

D^Z	X	Y
X	50	5

D^Y	X	Z
X	1	6

D^Z	X	Y
X	50	2

D^Y	X	Z
X	1	3

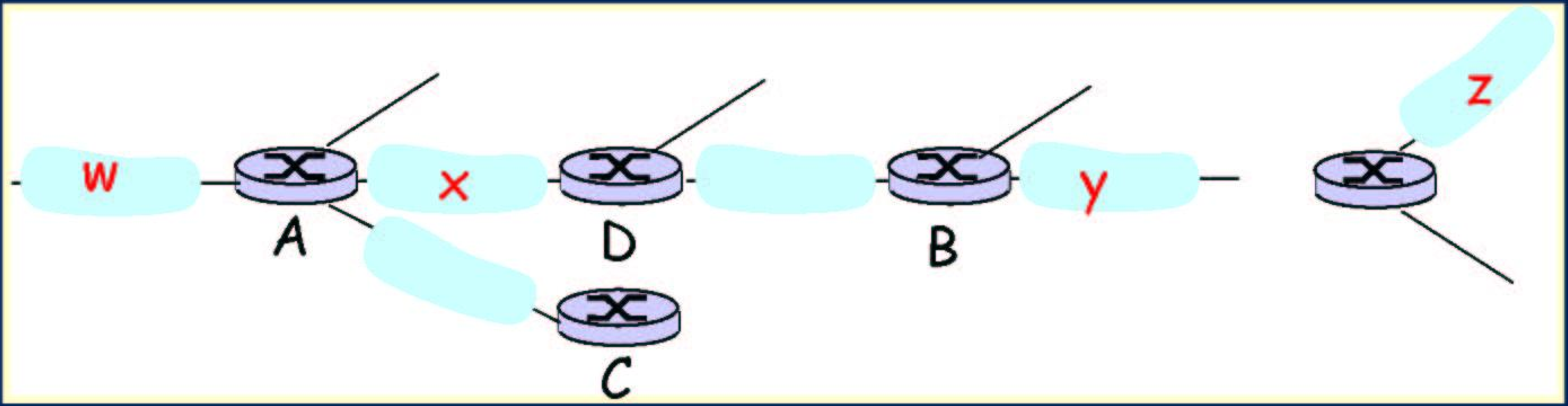
D^Z	X	Y
X	50	2

algorithm terminates

Intra-AS Routing

- Also known as Interior Gateway Protocols (IGP)
- Most common IGPs:
  - RIP: Routing Information Protocol
  - OSPF: Open Shortest Path First
  - IGRP: Interior Gateway Routing Protocol (Cisco propr.)

RIP
(Routing Information Protocol) - 2



Destination Network	Next Router	Num. of hops to dest.
w	A	2
y	B	2
z	B	7
x	--	1
....	....	....

Routing table in D