NETWORK LAYER PART 4

ROUTING ALGORITHMS – DISTANCE VECTOR ROUTING

DISTANCE VECTOR ALGORITHM

Bellman-Ford equation (dynamic programming)

let

$d_x(y)$:= cost of least-cost path from x to y

then

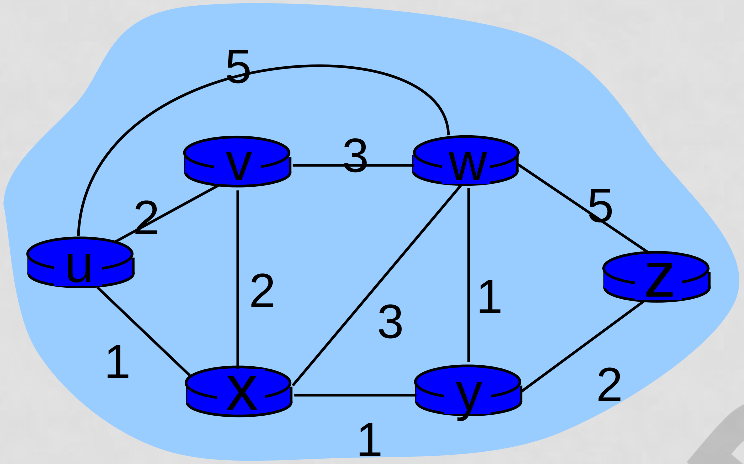
$$d_x(y) = min_v \{c(x,v) + d_v(y)\}$$

cost from neighbor v to destination y

cost to neighbor v

min taken over all neighbors v of x

BELLMAN-FORD EXAMPLE



clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

B-F equation says:

$$
\begin{aligned}
d_u(z) &= \min \{ c(u,v) + d_v(z), \\
&\qquad c(u,x) + d_x(z), \\
&\qquad c(u,w) + d_w(z) \} \\
&= \min \{2 + 5, \\
&\qquad 1 + 3, \\
&\qquad 5 + 3\} = 4
\end{aligned}
$$

node achieving minimum is next
hop in shortest path, used in forwarding table

DISTANCE VECTOR ALGORITHM

- $D_x(y)$ = estimate of least cost from x to y
  - x maintains distance vector $\mathbf{D}_x = [D_x(y): y \in N]$
- node x:
  - knows cost to each neighbor v: $c(x,v)$
  - Node x's distance vector D_x
  - maintains its neighbors' distance vectors. For each neighbor v, x maintains $\mathbf{D}_v = [D_v(y): y \in N]$

DISTANCE VECTOR ALGORITHM

key idea:

- from time-to-time, each node sends its own distance vector estimate to neighbors
- when x receives new DV estimate from neighbor, it updates its own DV using B-F equation:

$$D_x(y) \leftarrow \min_v\{c(x,v) + D_v(y)\} \quad \text{for each node } y \in N$$

- under minor, natural conditions, the estimate $D_x(y)$ *converge to the actual least cost* $d_x(y)$

DISTANCE VECTOR ALGORITHM

iterative, asynchronous: each local iteration caused by:

- local link cost change
- DV update message from neighbor

distributed:

- each node notifies neighbors *only* when its DV changes
  - neighbors then notify their neighbors if necessary

each node:

wait for (change in local link cost or msg from neighbor)

↓

recompute estimates

↓

if DV to any dest has changed, *notify* neighbors

DISTANCE VECTOR ALGORITHM

Initialization

for all destinations y in N:

$D_x(y)=C(x,y)$ /* if y is not a neighbor $c(x,y)=\infty$

for each neighbor w

$D_w(y)=\infty$ for all destinations y in N

for each neighbor w

send distance vector $D_x=[D_x(y):y \text{ in } N]$ to w

loop

wait (until link cost change to some neighbor w or until distance vector from neighbor w received)

for each y in N:

$D_x(y)=\min_v\{c(x,v)+D_v(y)\}$

if $D_x(y)$ changed for any destination y

Send distance vector $D_x=[D_x(y): y \text{ in } N]$ to all neighbors

forever

$$D_x(y) = \min\{c(x,y) + D_y(y),\ c(x,z) + D_z(y)\} = \min\{2+0\ ,\ 7+1\} = 2$$

$$D_x(z) = \min\{c(x,y) + D_y(z),\ c(x,z) + D_z(z)\} = \min\{2+1\ ,\ 7+0\} = 3$$

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

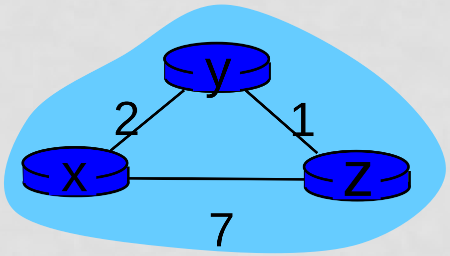
node y table

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

node z table

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

time



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$= \min\{2+0\ ,\ 7+1\} = 2$

$D_x(z) = \min\{c(x,y) + D_y(z),\ c(x,z) + D_z(z)\}$
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node y table

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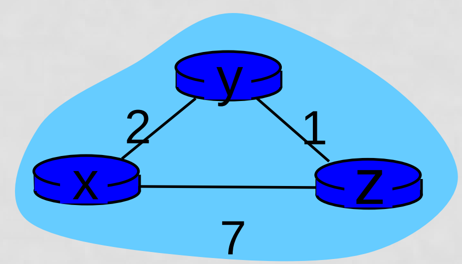
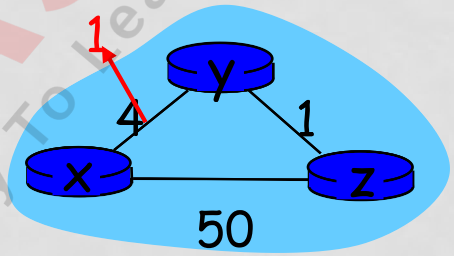


time

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.

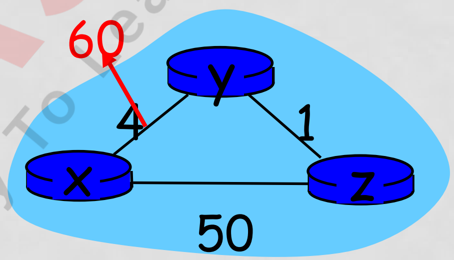
t_1 : *z* receives update from *y*, updates its table, computes new least cost to *x* , sends its neighbors its DV.

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 CHANGES

link cost changes:

- node detects local link cost change
- *bad news travels slow* - "count to infinity" problem!
- 44 iterations before algorithm stabilizes: see text



poisoned reverse:

- If Z routes through Y to get to X :
  - Z tells Y its (Z's) distance to X is infinite (so Y won't route to X via Z)
- will this completely solve count to infinity problem?

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