COSC264
Introduction to Computer Networks and the Internet

Introduction to Routing – Distance Vector Algorithm

Dr Barry Wu
Wireless Research Centre
University of Canterbury
barry.wu@canterbury.ac.nz

Outline – today

- Network layer overview
- Routing overview
- Link-state routing (Dijkstra’s algorithm)
- Distance-vector routing (Bellman-Ford)
- Summary

Distance Vector Algorithm

- Dynamic
- Decentralised (Distributed)
- Load-sensitive/load-insensitive
- Asynchronous

Routing Algorithms and Routing Protocols

Intra-AS Routing

Routing Protocols	Routing Algorithms
RIP	Bellman-Ford (Distance-vector) Algorithm
OSFP	Dijkstra's Algorithm
BGP	Bellman-Ford (Distance-vector) Algorithm

Inter-AS Routing

Bellman-Ford Equation

Define

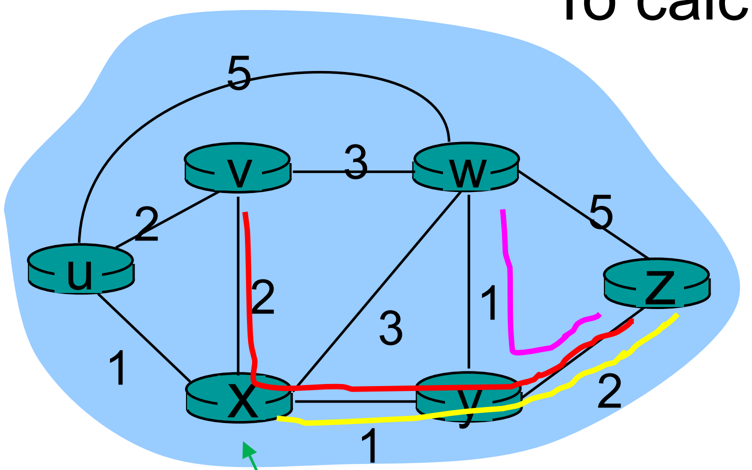
$d_x(y)$:= cost of least-cost path from x to y

Then

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

where min is taken over all neighbours of x

Bellman-Ford example



To calculate $d_u(z)$, according to B-F equation:

$$d_u(z) = \min \{ c(u,v) + d_v(z), \mathbf{c(u,x) + d_x(z)}, c(u,w) + d_w(z) \}$$

Node that achieves minimum is next hop in shortest path.

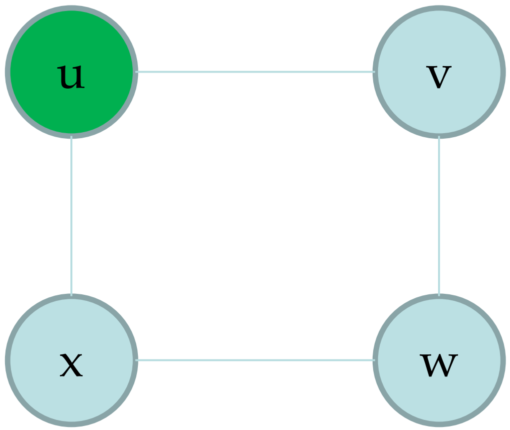
Clearly, $d_v(z) = 5$, $d_x(z) = 3$, $d_w(z) = 3$

$$= \min \{2 + 5, \mathbf{1 + 3}, 5 + 3\} = 4$$

Distance Vector Algorithm

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

An illustration



Distance vectors at node u

D_u

D_v

D_x

Distance vector algorithm

Basic idea:

- Each node periodically sends its own distance vector estimate to neighbours
- When a node x receives new DV estimate from neighbor, it updates its own DV using B-F equation:

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

- Amazingly, as long as all the nodes continue to exchange their distance vectors in an asynchronous fashion, the estimate $D_x(y)$ *converges 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 neighbour

Distributed:

- each node notifies neighbours *only* when its DV changes
  - neighbours then notify their neighbours if necessary
  - The algorithm doesn't know the entire path – only knows the next hop

Each node:

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

recompute estimates

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

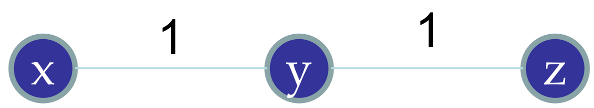
Distance Vector Algorithm

At each node, x:

Initialization:
for all destinations y in N:
$D_x(y) = c(x,y)$ /* $c(x,y) = \infty$ *if y is not a neighbour**/
for each neighbour w
$D_w(y) = \infty$ for all destinations y in N
for each neighbor w
send distance vector $D_x = [D_x(y)$: y in N] to w
loop
wait (until I see a link cost change to some neighbour w
or until I receive a distance vector from some neighbour w)
for each y in N:
$D_x(y) = min_v\{c(x,v) + D_v(y)\}$ /*v is adjacent to x*/
if $D_x(y)$ changed for any destination y
send distance vector $D_x = [D_x(y)$: y in N] to all neighbours
forever

A hidden assumption – N (all destinations)

- *Q: if all nodes exchange distance vectors with their neighbours only, can each of them know all the destination nodes (N, in the pseudocode)?*



- Initially, x knows it has a path to y with cost 1; *but it does not know the existence of z*;
- y knows it has a path to x (and z) with cost 1;
- z knows it has a path to y with cost 1; *but it does not know the existence of x*;
- Then, y and x exchange distance vectors;
- x learned that there is *a new destination z* and it can reach z via y with cost 2;
- y and z exchange distance vectors;
- z learned that there is *a new destination x* and it can reach x via y with cost 2;

- Now both x and z know their destination nodes!

RIP allows at most 25 destination nodes.

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

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

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

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

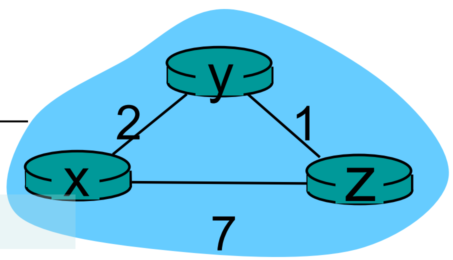
from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0

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

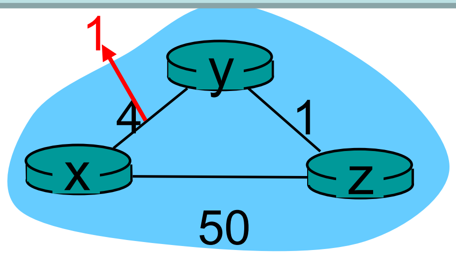
from \ cost to	x	y	z
x	0	2	3
y	2	0	1
z	3	1	0



time

Distance Vector: link cost changes

$D_y(x) = \min\{c(y,x) + D_x(x),\ c(y,z) + D_z(x)\} = \min\{1+0,\ 1+5\} = 1;$



Link cost changes:

- node detects local link cost change
- updates routing info, recalculates distance vector
- if DV changes, notify neighbors
- We consider y and z's DVs only here.

"good news travels fast"

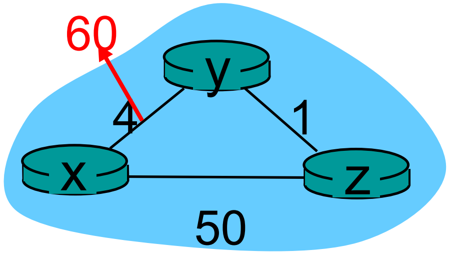
At time t_0, *y* detects the link-cost change (4 → 1), updates its DV, and informs its neighbors.

At time t_1, *z* receives the update from *y* and updates its table. It computes a new least cost to *x* (5 →2) and sends its neighbors its DV.

At time t_2, *y* receives *z*'s update and updates its distance table. *y*'s least costs do not change and hence *y* does *not* send any message to *z*.

Distance Vector: link cost changes

Link cost changes:



- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$ (only y, z's DV to dest. x)
- At time t0, y detects the link-cost

change and re-compute its dv

  - $D_y(x) = \min\{c(y,x)+ D_x(x), c(y,z)+ D_z(x)\} = \min\{60+0, 1+5\} = 6$;
  - The assumption is that y stores its own DV and its neighbours' (and its link costs to its neighbours).

y's DV table	y	x	z
y	0	4 → 6 (via z)	1
x	4	0	5
z	1	5 (via y)	0

False

y's forwarding table

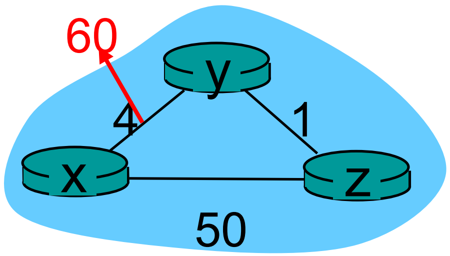
Dest.	Next-hop
x	z
z	z

z's forwarding table

Dest.	Next-hop
x	y
y	y

Distance Vector: link cost changes

Link cost changes:



- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$ (again y, z's DV)
- At time t0, y detects the link-cost change and re-compute its dv
  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+5\} = 6$;
  - At time t1, y sends its new dv to z; after z receives y's new dv; z can update
    $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+6, 50+0\} = 7$;

z's DV table	y	x	z
y	0	6 (via z)	1
x	51	0	50
z	1	5 → 7 (via y)	0

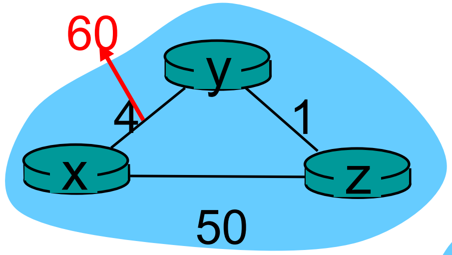
y's forwarding table

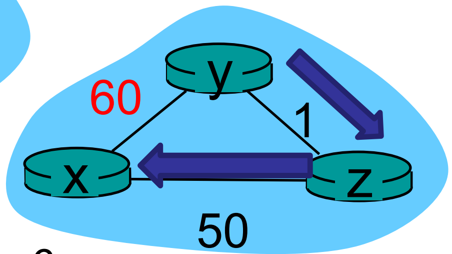
Dest.	Next-hop
x	z
z	z

z's forwarding table

Dest.	Next-hop
x	y
y	y

Distance Vector: link cost changes





Link cost changes:

- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$ (again y, z's DV)
- At time t0, y detects the link-cost change and re-compute its dv
  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+5\} = 6$;
  - At time t1, y sends its new dv to z; after z receives y's new dv; z can update $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+6, 50+0\} = 7$;
  - At time t2, z sends its new dv to y; similarly y can update $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+7\} = 8$;
  - Then $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+8, 50+0\} = 9$;
  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+9\} = 10$;
  - …
  - $D_y(x) = \ldots = 50$;
  - $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+50, 50+0\} = \mathbf{50}$;
  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+50\} = 51$;
  - $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+51, 50+0\} = \mathbf{50}$;

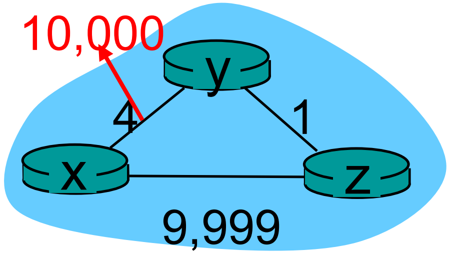
Next-hop changes!

Converged!

The bad news about the increase in link cost has travelled slowly!
Count-to-infinity problem!

Distance Vector: link cost changes

Link cost changes:



- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$
- At time t0, y detects the link-cost

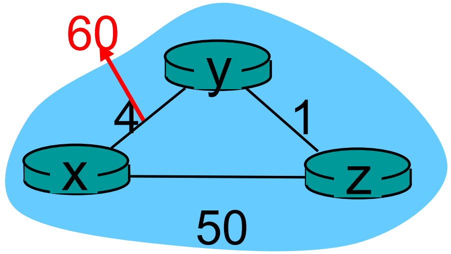
Change and re-compute its dv

- $D_y(x)$: 4 → 6 → 8 → 10, …, → 9998;
- $D_z(x)$: 5 → 7 → 9 → 11, …, → 9999; (causing a routing loop!)
- $D_z(x) = \min\{c(z,y) + D_y(x),\ c(z,x) + D_x(x)\} = \min\{1+9998,\ 9999+0\} = \mathbf{9999}$;
- $D_y(x) = \min\{c(y,x) + D_x(x),\ c(y,z) + D_z(x)\} = \min\{10000+0,\ 1+9999\} = 10000$;
- $D_z(x) = \min\{c(z,y) + D_y(x),\ c(z,x) + D_x(x)\} = \min\{1+10000,\ 9999+0\} = \mathbf{9999}$;

Neighbours exchange distance vectors only!
Distance vectors provide limited information!
z tells y: "I have a path to x with a cost of 7."
It does NOT tell y that this path goes through y!

Distance Vector: link cost changes

Link cost changes:



- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$ (only y, z's DV)
- At time t0, y detects the link-cost

change and re-compute its dv

  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+5\} = 6$;
  - The assumption is that y stores its own DV and its neighbours' (and its link costs to its neighbours).

y's DV table	y	x	z
y	0	4 → 6 (via z)	1
x	4	0	5
z	1	5 (via y)	0

False

y's forwarding table

Dest.	Next-hop
x	z
z	z

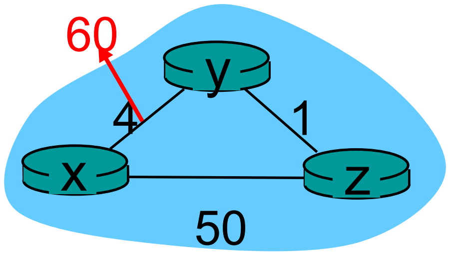
z's forwarding table

Dest.	Next-hop
x	y
y	y

Distance Vector: link cost changes

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)

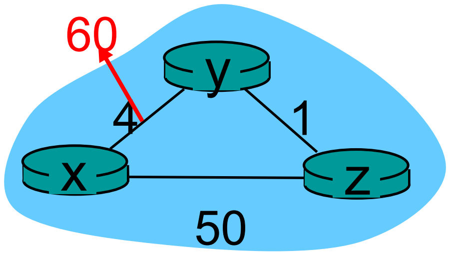


- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$, but z will lie to y saying "**$D_z(x) = \infty$**" *(poisoned reverse)*

y's DV table	**y**	**x**	**z**
y	0	4	1
x	4	0	∞
z	1	∞	0

Distance Vector: link cost changes

Poisoned reverse:



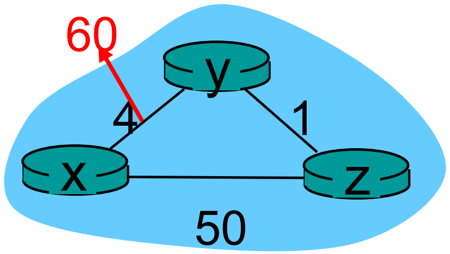
- If z routes through y to get to x :
  - z tells y its (z's) distance to x is infinite (so y won't route to x via z)
- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$, but z will lie to y saying "**$D_z(x) = \infty$**" *(poisoned reverse)*
- At time t0, y detects the link-cost

change and re-compute its dv
  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+\infty\} = 60;$

y's DV table	**y**	**x**	**z**
y	0	4 → 60 (via x)	1
x	4	0	∞
z	1	∞	0

Distance Vector: link cost changes

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)
- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$, but z will lie to y saying "**$D_z(x) = \infty$**" *(poisoned reverse)*
- At time t0, y detects the link-cost

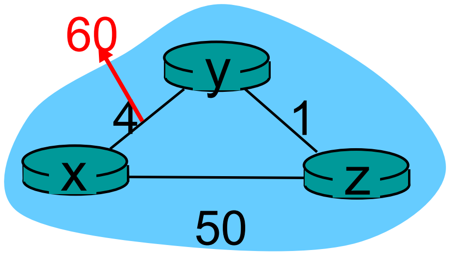
change and re-compute its dv
  - $D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+\infty\} = 60$;
  - Now y sends data directly to x;
  - At time t1, y sends its new dv to z; after z receives y's new dv; z can update

    $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+60, 50+0\} = 50$;

z's DV table	**y**	**x**	**z**
y	0	60	∞
x	∞	0	∞
z	1	***50 (via x)***	0

Distance Vector: link cost changes

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)
- Before the link cost changes
  - rse)
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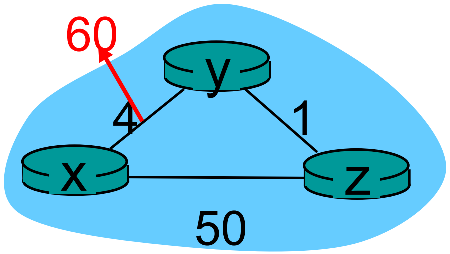
y's DV table	**y**	**x**	**z**
y	0	51 (via z)	1
x	51	0	50
z	1	50 (via x)	0

  - At time t1, y sends its new dv to z; after z receives y's new dv; z can update
    $D_z(x) = \min\{c(z,y)+ D_y(x), c(z,x)+ D_x(x)\} = \min \{1+60, 50+0\} = 50$;
  - At time t2, z sends its new dv to y without lying since it will not route through y; similarly y can update
    $D_y(x) = \min\{c(y,x)+ D_x(x), c(y,z)+ D_z(x)\} = \min \{60+0, 1+50\} = 51$;

Distance Vector: link cost changes

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)
- Before the link cost changes
  - $D_y(x) = 4$, $D_z(x) = 5$, but z will lie to y saying "**$D_z(x) = \infty$**" *(poisoned reverse)*
- At t

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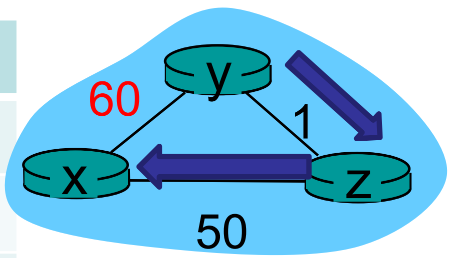
z's DV table	y	x	z
y	0	∞	∞
x	∞	0	∞
z	1	***50 (via x)***	0



n update

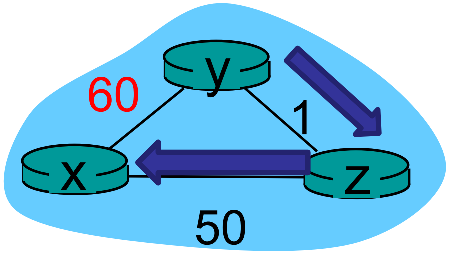
$D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+60, 50+0\} = 50;$

- At time t2, z sends its new dv to y without lying since it will not route through y; similarly y can update

$D_y(x) = \min\{c(y,x) + D_x(x), c(y,z) + D_z(x)\} = \min\{60+0, 1+50\} = 51;$

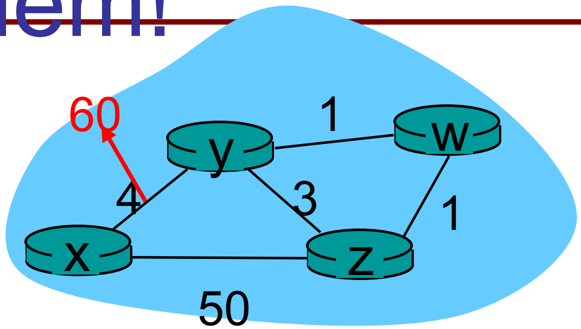
- Then $D_z(x) = \min\{c(z,y) + D_y(x), c(z,x) + D_x(x)\} = \min\{1+\infty, 50+0\} = 50$; *y lies to z this time because it routes through z;*

A little lie helps!



y uses z as its next-hop and will lie to z by saying that "I have a path to x with a cost of *infinity*."
(Do not count on me to route your traffic to x, --poisoned reverse.)

But a little lie helps only a little; it does not *solve* the problem!



Consider y,z,w distance table entries to x only. *Using poisoned reverse*,

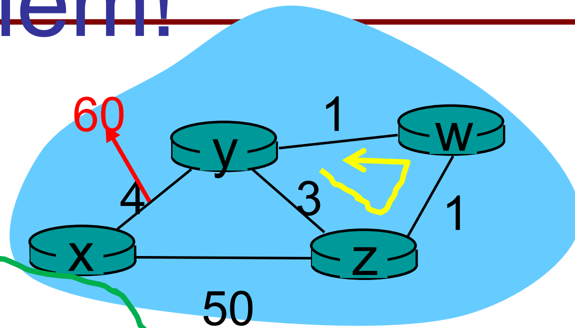
z → w, $D_z(x) = \infty$; z → y $D_z(x) = 6$ (not lying);

w → y, $D_w(x) = \infty$; w → z $D_w(x) = 5$ (not lying);

y → w, $D_y(x) = 4$ (not lying); y → z $D_y(x) = 4$ (not lying);

Then there is link-cost change (4→60);

But a little lie helps only a little; it does not *solve* the problem!



y re-computes:

$D_y(x)=\min\{c(y,z)+D_z(x), c(y,w)+D_w(x)\} = \min\{3+11, 1+\infty\} = 14$ (via z);

y notifies z and w; → z $D_y(x) = \infty$ *(lying);*

→ w $D_y(x) = 14$ (telling truth);

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z –

w –

y – ... ot lying);

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At t1, y updates its $D_y(x) = 9$ (via z, z did not lie:);

Now y notifies w and z; y → w, $D_y(x)$ ... 9; y → z $D_y(x) = \infty$;

$D_y(x) = \min\{c(y,z)+D_z(x), c(y,w) + D_w(x), c(y,x) + D_x(x)\} = \min\{3+6,$ ... $\infty, 60+0\} = 9$ (via z)

w re-computes:

$D_w(x)=\min\{c(w,y)+D_y(x), c(w,z)+D_z(x)\} = \min\{1+9, 1+\infty\} = 10$ (via y);

w notifies y and z; → y $D_w(x) = \infty$ *(lying);*

→ z $D_w(x) = 10$ (telling truth);

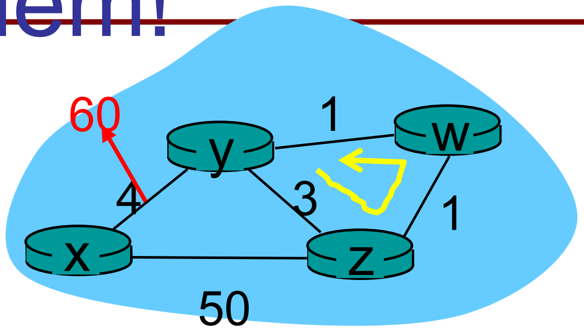
z re-computes:

$D_z(x)=\min\{c(z,w)+D_w(x), c(z,y)+D_y(x)\} = \min\{1+10, 3+\infty\} = 11$ (via w);

z notifies w and y; → w $D_z(x) = \infty$ *(lying);*

→ y $D_z(x) = 11$ (telling truth);

But a little lie helps only a little; it does not *solve* the problem!



Consider y,z,w distance table entries to x only. Using poisoned reverse,

z → w, $D_z(x) = \infty$; z → y $D_z(x) = 6$ (not lying);

w → y, $D_w(x) = \infty$; w → z $D_w(x) = 5$ (not lying);

y → w, $D_y(x) = 4$ (not lying); y → z $D_y(x) = 4$ (not lying);

Then there is link-cost change (4→60);

At t1, y updates its $D_y(x) = 9$ (via z, z did not lie:);

Now y notifies w and z; y → w, $D_y(x) = 9$; y → z $D_y(x) = \infty$;

$D_y(x) = \min\{c(y,z)+D_z(x),\ c(y,w) + D_w(x),\ c(y,x) + D_x(x)\} = \min\{3+6,\ 1+\infty,\ 60+0\} = 9$ (via z)

	t0	t1	t2	t3	t4
z	→ w, $D_z(x) = \infty$; → y, $D_z(x) = 6$;		No change	→ w, $D_z(x) = \infty$; → y, $D_z(x) = 11$;	
w	→ y, $D_w(x) = \infty$; → z $D_w(x) = 5$;		→ y, $D_w(x) = \infty$; → z, $D_w(x) = 10$;		No change
y	→ w, $D_y(x) = 4$; → z, $D_y(x) = 4$;	→ w, $D_y(x) = 9$; → z, $D_y(x) = \infty$;		No change	→ w, $D_y(x) = 14$; → z $D_y(x) = \infty$;

This continues y-w-z-y-w-z-y-w-z; there is a routing loop (y-z, z-w, w-y). [ZL]

Distance Vector Algorithm

Iterative, asynchronous:
each local iteration caused by:

- local link cost change
- DV update message from neighbour

Distributed:

- each node notifies neighbours *only* when its DV changes
  - neighbours then notify their neighbours if necessary
  - The algorithm doesn't know the entire path – only knows the next hop

Each node:

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

↓

recompute estimates

↓

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

DV has the count-to-infinity problem and poisoned reverse does not solve it. *In RIP the maximum cost of a path is limited to 15.*

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 propagates thru network

Neither is an obvious winner over the other; both are used in deed!

Summary

- Network layer overview
- Routing overview
- Link-state routing (Dijkstra’s algorithm)
- Distance-vector routing (Bellman-Ford)
  - B-F algorithm
  - Count-to-infinity problem and poisoned reverse
  - LS vs DV
- Summary

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