Routing Algorithm Classification

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

Static or dynamic?

Static:
- Routes change slowly over time

Dynamic:
- Routes change more quickly
  - Periodic update
  - In response to link cost changes
A Distance Vector Routing Algorithm

Decentralized algorithm:
- Router knows its neighbors and link costs to neighbors
- Iterative computation, exchange of info with neighbors

Bellman-Ford Equation (dynamic programming)
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 neighbors $v$ of $x$
Bellman-Ford Example

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

Bellman-Ford equation says:

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

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

Node that yields minimum is next hop in shortest path → forwarding table
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 Distance Vector changes
  - Neighbors then notify their neighbors if necessary

Each node:
- wait for (change in local link cost of msg from neighbor)
- recompute estimates
  if Distance Vector to any dest has changed, notify neighbors
\[ D_x(y) = \min \{ c(x,y) + D_y(y), c(x,z) + D_z(y) \} \]
\[ = \min \{ 2+0, 7+1 \} = 2 \]

\[ D_z(z) = \min \{ c(x,y) + D_y(y), c(x,z) + D_z(z) \} \]
\[ = \min \{ 2+1, 7+0 \} = 3 \]
Distance Vector (DV): 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"

- At time $t_0$, $y$ detects link-cost change, updates its DV, and informs its neighbors.
- At time $t_1$, $z$ receives update from $y$ and updates its table, computes a new least cost to $x$ and sends its neighbors its DV
- At time $t_2$, $y$ receives $z$'s update and updates its distance table. As $y$'s least costs do not change $y$ does not send updates to $z$. 
### node y table

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### node z table

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</table>
Distance Vector: Link Cost Changes

Link cost changes:
- Good news travels fast
- Bad news travels slow
\[ D_y(x) = \min \{c(y,x) + D_x(x), \ c(y,z) + D_z(x)\} \]
\[ = \min \{60 + 0, 1 + 5\} = 6 \]

\[ D_y(x) = \min \{c(y,x) + D_x(x), \ c(y,z) + D_z(x)\} \]
\[ = \min \{60 + 0, 1 + 7\} = 8 \]
Distance Vector: Link Cost Changes

Link cost changes:
- Good news travels fast
- Bad news travels slow – “count to infinity” problem!
- E.g., 44 iterations before algorithm stabilizes

Poissoned reverse:
- If Z routes through Y to get to X:
  - Z tells Y its (Zs) distance to X is infinite (so Y won’t route to X via Z)
- Will this completely solve count to infinity problem?
A Link-State Routing 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

- Example:
  Dijkstra’s algorithm
  - Iterative: after k iterations, know least cost path to k dst.’s
## Dijkstra’s Algorithm: Example

<table>
<thead>
<tr>
<th>Step</th>
<th>start N</th>
<th>$D(B),p(B)$</th>
<th>$D(C),p(C)$</th>
<th>$D(D),p(D)$</th>
<th>$D(E),p(E)$</th>
<th>$D(F),p(F)$</th>
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</thead>
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<td>5,A</td>
<td>1,A</td>
<td>infinity</td>
<td>infinity</td>
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<tr>
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<td>AD</td>
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<td>4,D</td>
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</tbody>
</table>

![Network diagram](attachment:image.png)
Dijkstra’s Algorithm: Example (2)

Resulting shortest-path tree from A:

![Graph Diagram]

Resulting forwarding table at A:

<table>
<thead>
<tr>
<th>destination</th>
<th>link</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>(A,B)</td>
</tr>
<tr>
<td>D</td>
<td>(A,D)</td>
</tr>
<tr>
<td>E</td>
<td>(A,D)</td>
</tr>
<tr>
<td>C</td>
<td>(A,D)</td>
</tr>
<tr>
<td>F</td>
<td>(A,D)</td>
</tr>
</tbody>
</table>
Dijkstra’s Algorithm: Discussion

Oscillations possible:
- E.g., link cost = amount of carried traffic

![Initial routing diagram](image1)
![Routing recomputation diagram 1](image2)
![Routing recomputation diagram 2](image3)
![Routing recomputation diagram 3](image4)
Comparison of LS and DV Algorithms

Speed of Convergence
- **LS:** $O(n \log n)$ 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