Routing Protocols and the IP Layer

CS244A Review Session 2/01/08
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Functions of a router

- Forwarding
  - Determine the correct egress port for an incoming packet based on a forwarding table
- Routing
  - Choosing the best path to take from source to destination
  - Routing algorithms build up forwarding tables in each router
  - Two main algorithms: Bellman-Ford and Dijkstra's Algorithm

Bellman Ford Equation

- Let *G = (V, E)* and *Cost(e) = cost of edge e*
- Suppose we want to find the lowest cost path to vertex *t* from all other vertices in *V*
- Let *Shortest-Path(i, u)* be the shortest path from *u* to *t* using at most *i* edges. Then:

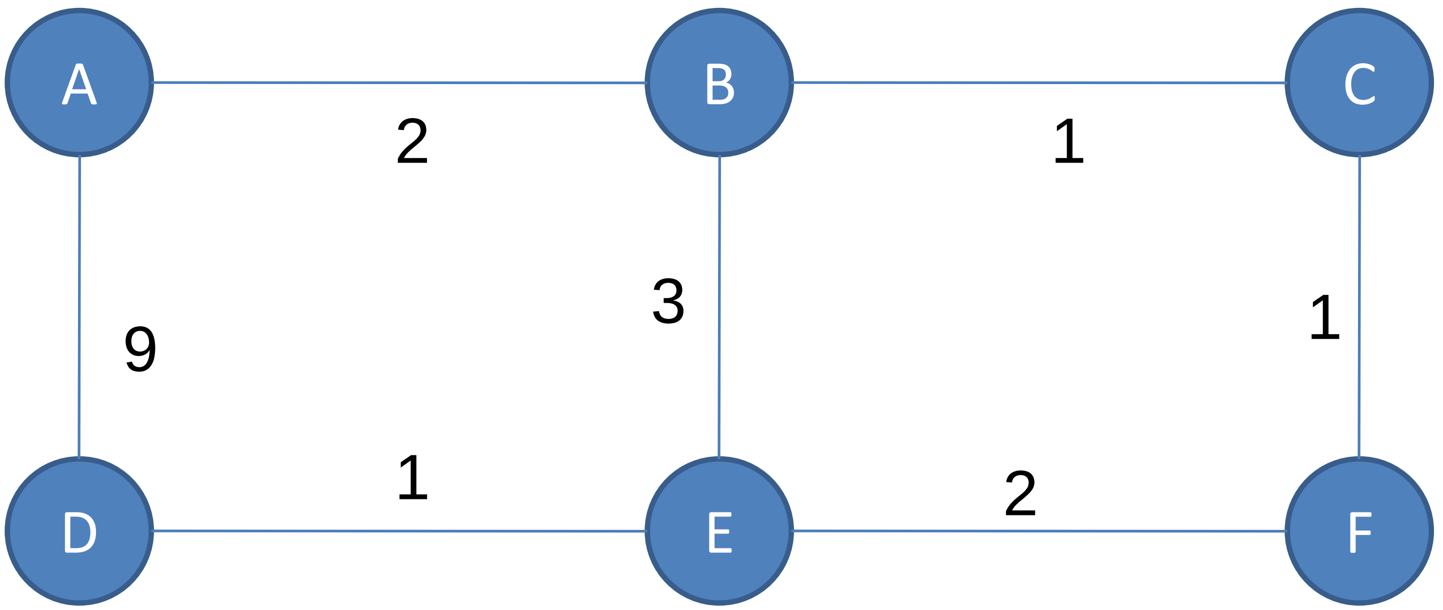
$$ShortestPath(i,u) = \min_{v \in V} \begin{cases} ShortestPath(i-1,u) \\ Cost(u,v) + ShortestPath(i-1,v) \end{cases}$$

- If there are no negative edge costs, then any shortest path has at most *|V|-1* edges. Therefore, algorithm terminates after *|V|-1* iterations.

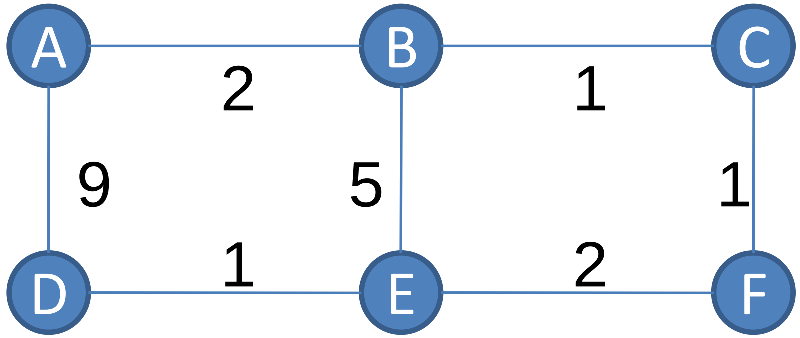
Bellman Ford Algorithm

```
function BellmanFord(list vertices, list edges, vertex dest)
  // Step 1: Initialize shortest paths of w/ at most 0 edges
  for each vertex v in vertices:
    v.next := null
    if v is dest: v.distance := 0
    else:         v.distance := infinity

  // Step 2: Calculate shortest paths with at most i edges from
  // shortest paths with at most i-1 edges
  for i from 1 to size(vertices) - 1:
    for each edge (u,v) in edges:
      if u.distance > Cost(u,v) + v.distance:
        u.distance = Cost(u,v) + v.distance
        u.next = v
```

An Example

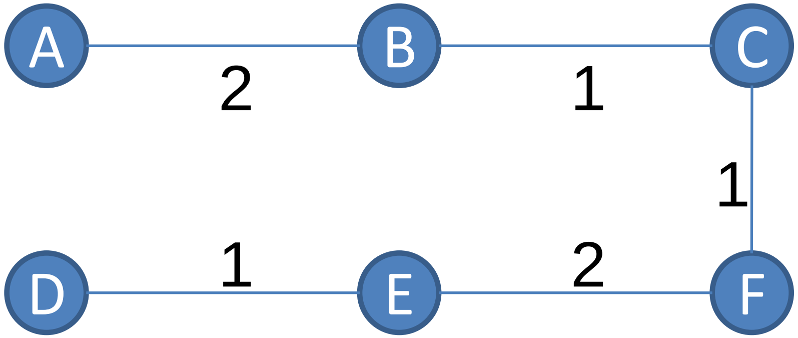


Example



A	0, -					
B	∞, -					
C	∞, -					
D	∞, -					
E	∞, -					
F	∞, -					

Solution

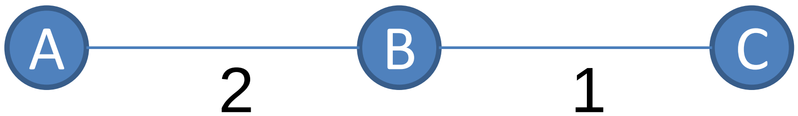


A	0, -	0, -	0, -	0, -	0, -	0, -
B	∞, -	2, A	2, A	2, A	2, A	2, A
C	∞, -	∞, -	3, B	3, B	3, B	3, B
D	∞, -	9, A	9, A	8, E	8, E	7, E
E	∞, -	∞, -	7, B	7, B	6, F	6, F
F	∞, -	∞, -	∞, -	4, C	4, C	4, C

Bellman-Ford and Distance Vector

- We've just run a centralized version of Bellman-Ford
- Can be distributed as well, as described in lecture and text
- In distributed version:
  - Maintain a *distance vector* that maintains cost to all other nodes
  - Maintain cost to each directly attached neighbor
  - If we get a new distance vector or cost to a neighbor, re-calculate distance vector, and broadcast new distance vector to neighbors if it has changed
- For any given router, who does it have to talk to?
- What does runtime depend on?

Problems with Distance Vector



- Increase in link cost is propagated slowly
- Can "count to infinity"
  - What happens if we delete (B, C)?
  - B now tries to get to C through A, and increase its cost to C
  - A will see that B's cost of getting to C increased, and will increase its cost
  - Shortest path to C from B and A will keep increasing to infinity
- Partial solutions
  - Set infinity
  - Split horizon
  - Split horizon with poison reverse

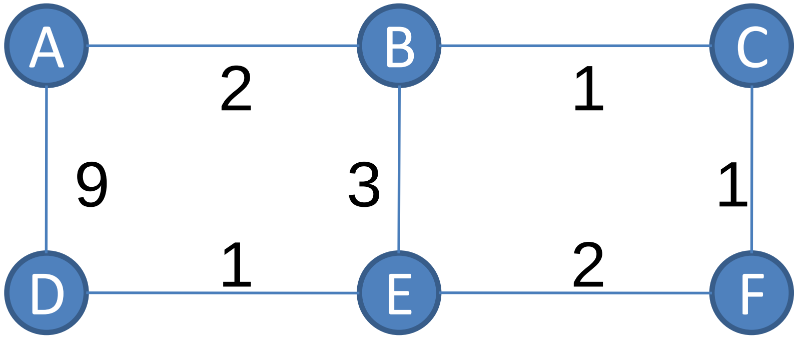
Dijkstra’s Algorithm

- Given a graph G and a starting vertex s, find shortest path from s to any other vertex in G
- Use greedy algorithm:
  - Maintain a set S of nodes for which we know the shortest path
  - On each iteration, grow S by one vertex, choosing shortest path through S to any other node not in S
  - If the cost from S to any other node has decreased, update it

Dijkstra’s Algorithm

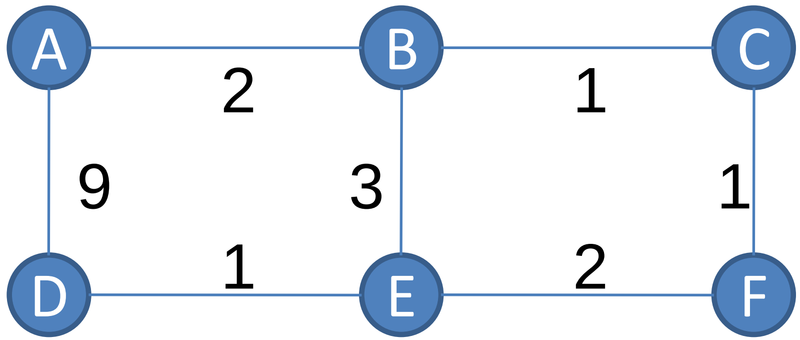
```
function Dijkstra(G, w, s)
    Q = new Q                           // Initialize a priority queue Q
    for each vertex v in V[G]           // Add every vertex to Q with inf. cost
        d[v] := infinity
        previous[v] := undefined
        Insert(Q, v, d[v])
    d[s] := 0                           // Distance from s to s
    ChangeKey(Q, s, d[s])               // Change value of s in priority queue
    S := empty set                      // Set of all visited vertices

    while Q is not an empty set
        // Remove min vertex from priority queue, mark as visited
        u := ExtractMin(Q)
        S := S union {u}

        // Relax (u,v) for each edge
        for each edge (u,v) outgoing from u
            if d[u] + w(u,v) < d[v]
                d[v] := d[u] + w(u,v)
                previous[v] := u
                ChangeKey(Q, v, d[v])
```

Example



Explored Set S	Unexplored Set Q = V - S
A(0, -)	**B(0+2, A)**, C(∞, -), D(0+9, A), E(∞, -), F(∞, -)

Solution



Explored Set S	Unexplored Set Q = V - S
A(0, -)	**B(0+2, A)**, C(∞, -), D(0+9, A), E(∞, -), F(∞, -)
A(0, -), B(2,A)	**C(2+1, B)**, D(9, A), E(2+3, B), F(∞, -)
A(0, -), B(2, A), C(3, B)	D(9, A), E(5, B), **F(3+1, B)**
A(0, -), B(2, A), C(3, B), F(4, B)	D(9, A), **E(5, B)**
A(0, -), B(2, A), C(3, B), F(4, B), E(5, B)	**D(5+1, B)**
A(0, -), B(2, A), C(3, B), F(4, B), E(5, B), D(6, B)	

Link-State (Using Dijkstra's)

- Algorithm must know the cost of every link in the network
  - Each node broadcasts LS packets to all other nodes
  - Contains source node id, costs to all neighbor nodes, TTL, sequence #
  - If a link cost changes, must rebroadcast
- Calculation for entire network is done locally

Comparison between LS and DV

- Messages
  - In link state: Each node broadcasts a link state advertisement to the whole network
  - In distance vector: Each node shares a distance vector (distance to every node in network) to its neighbor
- How long does it take to converge?
  - $O((|E|+|V|) \log |V|) = O(|E| \log |V|)$ for Dijkstra's
  - $O(|E||V|)$ for centralized Bellman-Ford; for distributed, can vary
- Robustness
  - An incorrect distance vector can propagate through the whole network