Housekeeping

- Midterm exam Friday 10/12 – covering Chapters 1-4
- Homework for chapters 3&4 assigned 10/3 due 10/17

Quick Essay

- Do NOT put your name on your paper
- List the 3 most important things to learn from Project 1
- What is still most unclear about Project 1?
- I'll report results by email tomorrow or in class Wednesday

Today

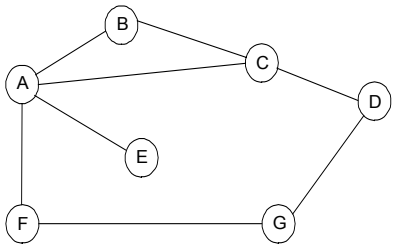
- Overall topic: Routing
- Distance-vector: loops
  - Preventing loops
- Link-state algorithms
  - Link-state forwarding
  - Route computation from link-state data

Distance Vector also known as Bellman-Ford

- Each node maintains a set of triples
  - `(Destination, Cost, NextHop)`
- Exchange updates directly connected neighbors
  - periodically (on the order of several seconds)
  - whenever table changes (called *triggered* update)
- Each update is a list of pairs:
  - `(Destination, Cost)`
- Update local table if receive a "better" route
  - smaller cost
  - came from next-hop
  - Refresh existing routes; delete if they time out

Example

Routing Table for node B



Destination	Cost	NextHop
A	1	A
C	1	C
D	2	C
E	2	A
F	2	A
G	3	A

Routing Loops

- Example 1
  - F detects that link to G has failed
  - F sets distance to G to infinity and sends update t o A
  - A sets distance to G to infinity since it uses F to reach G
  - A receives periodic update from C with 2-hop path to G
  - A sets distance to G to 3 and sends update to F
  - F decides it can reach G in 4 hops via A
- Example 2
  - link from A to E fails
  - A advertises distance of infinity to E
  - B and C advertise a distance of 2 to E
  - B decides it can reach E in 3 hops; advertises this to A
  - A decides it can read E in 4 hops; advertises this to C
  - C decides that it can reach E in 5 hops…

Loop-Breaking Heuristics

- Set infinity to 16 – ok for small networks
- Split horizon
  - Don't send routes back to the peers they were learned from
  - If B has (E,2,A) in its routing table, it doesn't send (E,2) as an update to A
- Split horizon with poison reverse
  - B sends (E,infinity) to A (and ONLY A)
- Still haven't handled loops of >2 routers

Internet RIP

- Goal is to reach networks, not routers, so route table contains network identity, not router identity
  - route print
- Update every 30 seconds + triggered updates

Link State

- Strategy
  - send to all nodes (not just neighbors) information about directly connected links (not entire routing table)
- Link State Packet (LSP)
  - id of the node that created the LSP
  - cost of link to each directly connected neighbor
  - sequence number (SEQNO)
  - time-to-live (TTL) for this packet

Link State (cont)

- Reliable flooding
  - store most recent LSP from each node
  - forward LSP to all nodes but one that sent it
  - generate new LSP periodically
    - increment SEQNO
  - start SEQNO at 0 when reboot
  - decrement TTL of each stored LSP
    - discard when TTL=0

Link-state table

- At each node, link weight table and forwarding table:

l(i,j) – "same" everywhere					
	A	B	C	D	E
A	0	2	1		
B	2	0	1		
C	1	1	0	1	3
D			1	0	1
E			3	1	0

Forwarding – node E		
Dest	NH	Cost
A		
B		
C		
D		
E		

Route Calculation

- Dijkstra's shortest path algorithm
- Let
  - N denotes set of nodes in the graph
  - $l(i, j)$ denotes non-negative cost (weight) for edge (i, j)
  - s denotes this node
  - M denotes the set of nodes incorporated so far
  - $C(n)$ denotes cost of the path from s to node n

```
M = {s}
for each n in N - {s}
   C(n) = l(s, n)
while (N != M)
   M = M union {w} such that C(w) is the minimum for
       all w in (N - M)
   for each n in (N - M)
      C(n) = MIN(C(n), C (w) + l(w, n ))
```

Metrics

- Original ARPANET metric
  - measures number of packets enqueued on each link
  - took neither latency or bandwidth into consideration
- New ARPANET metric
  - stamp each incoming packet with its arrival time (**`AT`**)
  - record departure time (**`DT`**)
  - when link-level ACK arrives, compute

    ```
    Delay = (DT - AT) + Transmit + Latency
    ```

  - if timeout, reset **`DT`** to departure time for retransmission
  - link cost = average delay over some time period
- Fine Tuning
  - compressed dynamic range
  - replaced **`Delay`** with link utilization