

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

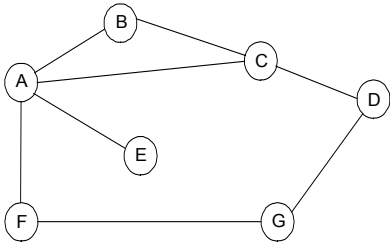
- Overall topic: Routing
- Distance-vector: loops
 - Preventing loops
- Link-state algorithms
 - Link-state forwarding
 - Route computation from link-state data

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 to 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 reach 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
$$\text{Delay} = (\text{DT} - \text{AT}) + \text{Transmit} + \text{Latency}$$
 - 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