Network Layer

1 Routing Algorithms

Routing is the process of discovering network paths

- Decide what to optimize (e.g., fairness vs efficiency)
- Model the network as a graph of nodes and links
- Update routes for changes in topology (e.g. failures)

2 Optimality Principle

Identify the optimal path from source to destination

Sink tree: optimal routes from all sources to a given destination

Distance metric: the number of hops, or time delay

3 Shortest Path Algorithm

Dijkstra's algorithm computes a sink tree on the graph

- Each nose is labelled with its distance from the source node to the best known path
- Initially no paths are known
- Each link is assigned a non-negative weight/distance
- Shortest path is the one with the lowest total weight

Algorithm

- Start with sink, set distance at other nodes to infinity
- Relax distance to other nodes
- Pick the lowest distance node, add it to sink tree
- Repeat until all nodes are in the sink tree

4 Distance vector routing

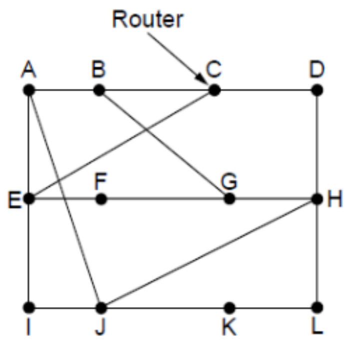
There are two dynamic routing algorithms

4.1 Distance vector

- Each node maintains a table (vector of best known destination)
- Tables are updated by exchanging information between nodes
- Tables have 2 entries: outline line and estimate distance (# hops or propagation delay)

Algorithm:

- Each node knows distance of links to its neighbours
- Each node advertises a vector of the lowest known distances to all neighbours
- Each node uses received vectors to update its own
- Repeat periodically



Network

Compute the route from J to G.

J → A in 8 msec

A → G 18 msec

J → 8 + 18 = 26 msec.

To	A	I	H	K	New estimated delay from J	Line
A	0	24	20	21	8	A
B	12	36	31	28	20	A
C	25	18	19	36	28	I
D	40	27	8	24	20	H
E	14	7	30	22	17	I
F	23	20	19	40	30	I
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	–
K	24	22	22	0	6	K
L	29	33	9	9	15	K
	JA delay is 8	JI delay is 10	JH delay is 12	JK delay is 6		

Vectors received at J from Neighbours A, I, H and K

New vector for J

4.1.1 The Count-to-Infinity Problem

Failures can cause DV to "count to infinity" while seeking a path to an unreachable node

A	B	C	D	E	
	•	•	•	•	Initially
	1	•	•	•	After 1 exchange
	1	2	•	•	After 2 exchanges
	1	2	3	•	After 3 exchanges
	1	2	3	4	After 4 exchanges

Good news of a path to *A* spreads quickly

A	X	B	C	D	E	
		1	2	3	4	Initially
		3	2	3	4	After 1 exchange
		3	4	3	4	After 2 exchanges
		5	4	5	4	After 3 exchanges
		5	6	5	6	After 4 exchanges
		7	6	7	6	After 5 exchanges
		7	8	7	8	After 6 exchanges
			⋮			
		•	•	•	•	

Bad news of no path to *A* is learned slowly

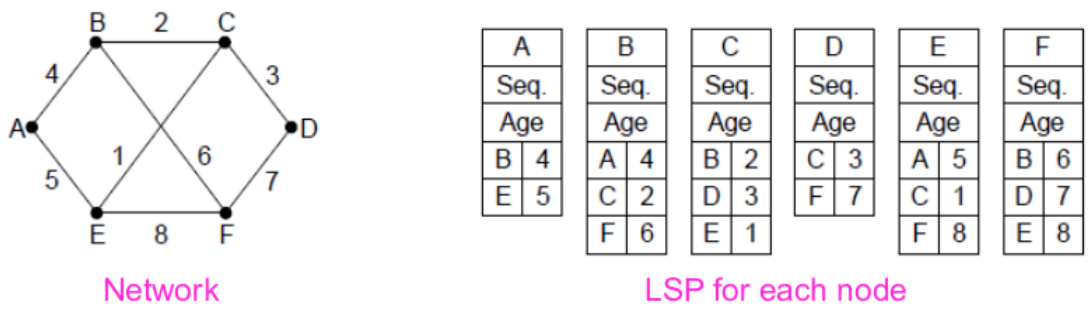
4.2 Link State Routing

Link state is an alternative to distance vector algorithm. There are 5 steps:

1. Learn the network address of the neighb ouring routers
2. Set the distance to each neighbour
3. Construct a (HELLO) packet telling all neighbours what it has just learned
4. Send the packet to neighbours and receive packet from neighbours
5. Compute the shortest path by using Dijkstra's algorithm

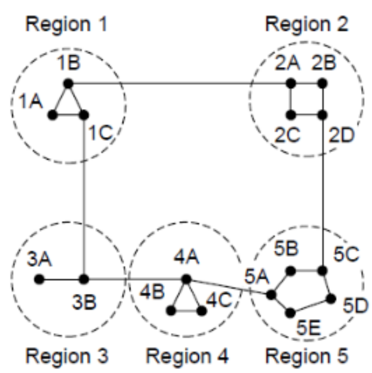
Definition: LSP (Link State Packet)

A list of the node's neighbours and weights of links to reach them



5 Hierarchical Routing

Hierarchical routing reduces the work of route computation but may result in slightly longer paths than flat routing



a

What router should we use from 2A to 4B?

Full table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2A	1B	2
2B	1B	3
2C	1B	3
2D	1B	4
3A	1C	3
3B	1C	2
4A	1C	3
4B	1C	4
4C	1C	4
5A	1C	4
5B	1C	5
5C	1B	5
5D	1C	6
5E	1C	5

b

Hierarchical table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2	1B	2
3	1C	2
4	1C	3
5	1C	4

Best choice to reach nodes in 5 except for 5C

c

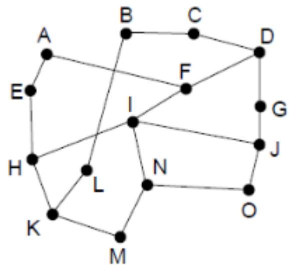
6 Flooding (i.e. broadcasting)

- A simple method to send a packet to all network nodes
- Each node floods a new packet received on an incoming link by sending it out of the other links
- Nodes need to keep track of flooded packets to stop the flood

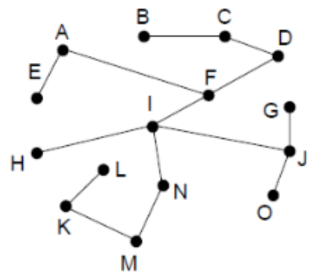
6.1 Broadcast sends a packet to all nodes

Broadcast sends a packet to all nodes:

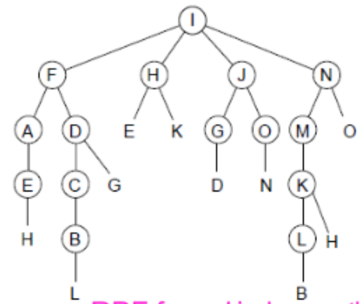
- RPF (Reverse Path Forwarding): Arrived packets are checked to see if they arrived from a preferred link, which is the link that is normally used for sending packets towards the source of the broadcast
- 1st hop: I sends packets to F, H J and N. Packets arrive on the same link that is used to send to I
- 2nd hop: 8 packets are generated, two by each router. 5 of them arrive on the preferred link



Network



Sink tree for *I* is efficient broadcast



RPF from *I* is larger than sink tree