Networks and Distributed Systems

Lecture 10 – Routing

Outline

- Switching and Bridging
- Basic Internetworking (IP)
- Routing

Routing

Forwarding versus Routing

- Forwarding:
  - to select an output port based on destination address and routing table
- Routing:
  - process by which routing table is built

Routing

- Forwarding table VS Routing table
  - Forwarding table
    - Used when a packet is being forwarded and so must contain enough information to accomplish the forwarding function
    - A row in the forwarding table contains the mapping from a network number to an outgoing interface and some MAC information, such as Ethernet Address of the next hop
  - Routing table
    - Built by the routing algorithm as a precursor to build the forwarding table
    - Generally contains mapping from network numbers to next hops

Routing

(a)

Prefix/Length	Next Hop
18/8	171.69.245.10

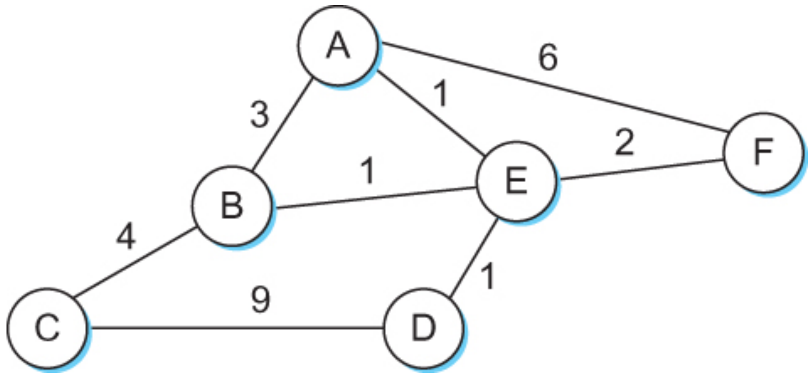
(b)

Prefix/Length	Interface	MAC Address
18/8	if0	8:0:2b:e4:b:1:2

Example rows from (a) routing and (b) forwarding tables

Routing

- Network as a Graph



- The basic problem of routing is to find the lowest-cost path between any two nodes
  - Where the cost of a path equals the sum of the costs of all the edges that make up the path

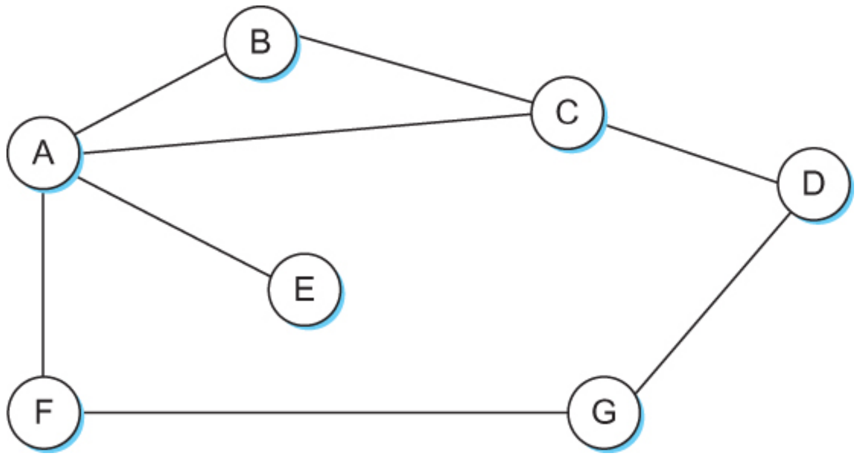
Routing

- For a simple network, we can calculate all shortest paths and load them into some nonvolatile storage on each node.
- Such a static approach has several shortcomings
  - It does not deal with node or link failures
  - It does not consider the addition of new nodes or links
  - It implies that edge costs cannot change

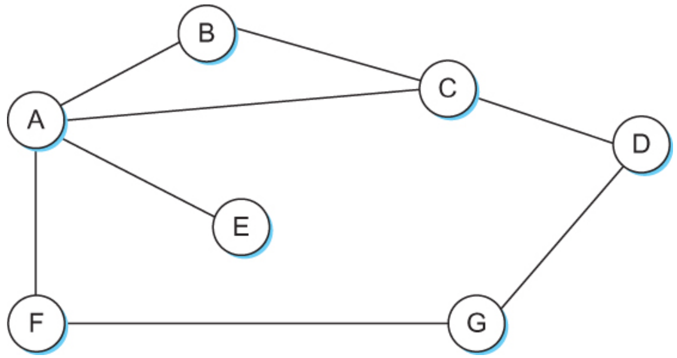
- What is the solution?
  - Need a distributed and dynamic protocol
  - Two main classes of protocols
    - Distance Vector
    - Link State

Distance Vector

- Each node constructs a one dimensional array (a vector) containing the “distances” (costs) to all other nodes and distributes that vector to its immediate neighbors
- Starting assumption is that each node knows the cost of the link to each of its directly connected neighbors



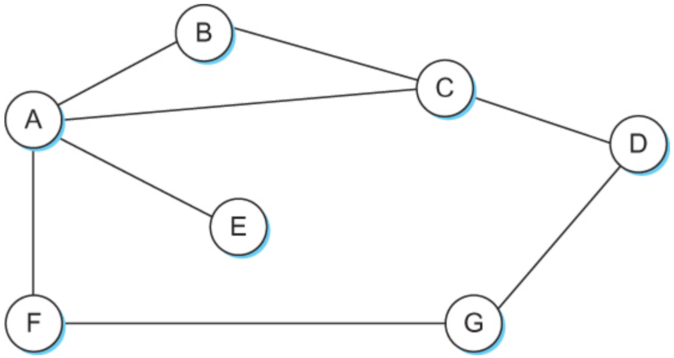
Distance Vector



Information Stored at Node	Distance to Reach Node						
	A	B	C	D	E	F	G
A	0	1	1	∞	1	1	∞
B	1	0	1	∞	∞	∞	∞
C	1	1	0	1	∞	∞	∞
D	∞	∞	1	0	∞	∞	1
E	1	∞	∞	∞	0	∞	∞
F	1	∞	∞	∞	∞	0	1
G	∞	∞	∞	1	∞	1	0

Initial distances stored at each node (global view)

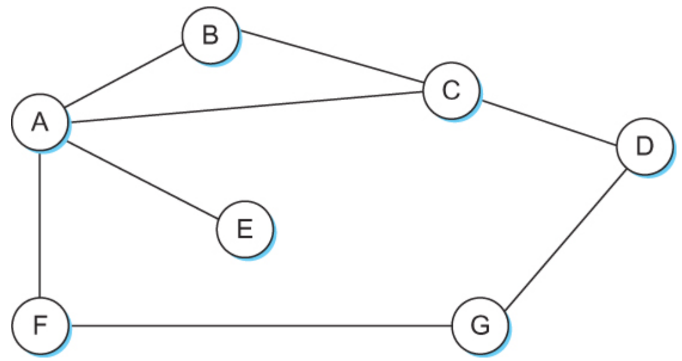
Distance Vector



Destination	Cost	NextHop
B	1	B
C	1	C
D	∞	—
E	1	E
F	1	F
G	∞	—

Initial routing table at node A

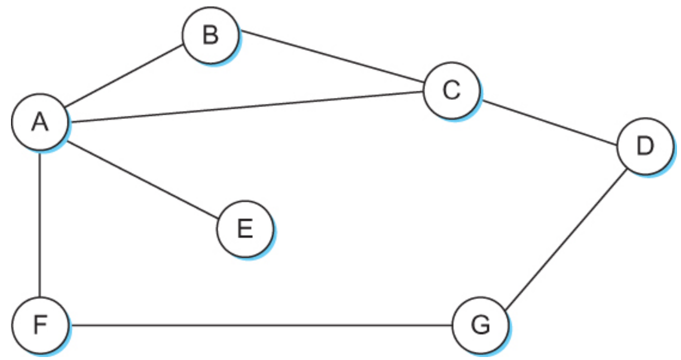
Distance Vector



Destination	Cost	NextHop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	2	F

Final routing table at node A

Distance Vector



Information Stored at Node	Distance to Reach Node						
	A	B	C	D	E	F	G
A	0	1	1	2	1	1	2
B	1	0	1	2	2	2	3
C	1	1	0	1	2	2	2
D	2	2	1	0	3	2	1
E	1	2	2	3	0	2	3
F	1	2	2	2	2	0	1
G	2	3	2	1	3	1	0

Final distances stored at each node (global view)

Distance Vector

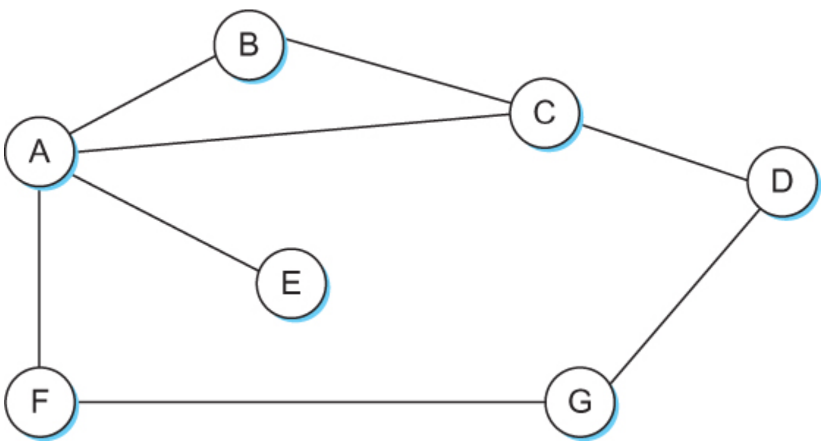
- The distance vector routing algorithm is sometimes called as Bellman-Ford algorithm

- Every T seconds each router sends its table to its neighbor, each router then updates its table based on the new information

- Problems include fast response to good news and slow response to bad news. Also too many messages to update

Distance Vector

- When a node detects a link failure
  - 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



Distance Vector

- Slightly different circumstances can prevent the network from stabilizing
  - Suppose the link from A to E goes down
  - In the next round of updates, A advertises a distance of infinity to E, but B and C advertise a distance of 2 to E
  - Depending on the exact timing of events, the following might happen
    - Node B, upon hearing that E can be reached in 2 hops from C, concludes that it can reach E in 3 hops and advertises this to A
    - Node A concludes that it can reach E in 4 hops and advertises this to C
    - Node C concludes that it can reach E in 5 hops; and so on.
    - This cycle stops only when the distances reach some number that is large enough to be considered infinite
      - **Count-to-infinity problem**

Count-to-infinity Problem

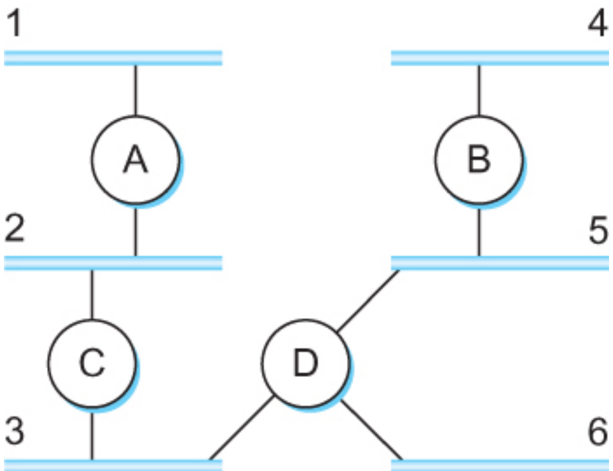
- Use some relatively small number as an approximation of infinity
- For example, the maximum number of hops to get across a certain network is never going to be more than 16

- One technique to improve the time to stabilize routing is called *split horizon*
  - When a node sends a routing update to its neighbors, it does not send those routes it learned from each neighbor back to that neighbor
  - For example, if B has the route (E, 2, A) in its table, then it knows it must have learned this route from A, and so whenever B sends a routing update to A, it does not include the route (E, 2) in that update

Count-to-infinity Problem

- In a stronger version of split horizon, called *split horizon with poison reverse*
  - B actually sends that back route to A, but it puts negative information in the route to ensure that A will not eventually use B to get to E
  - For example, B sends the route (E, ∞) to A

Routing Information Protocol (RIP)



Example Network running RIP

0	8	16 31
Command	Version	Must be zero
Family of net 1		Route Tags
Address prefix of net 1		
Mask of net 1		
Distance to net 1		
Family of net 2		Route Tags
Address prefix of net 2		
Mask of net 2		
Distance to net 2		

RIPv2 Packet Format

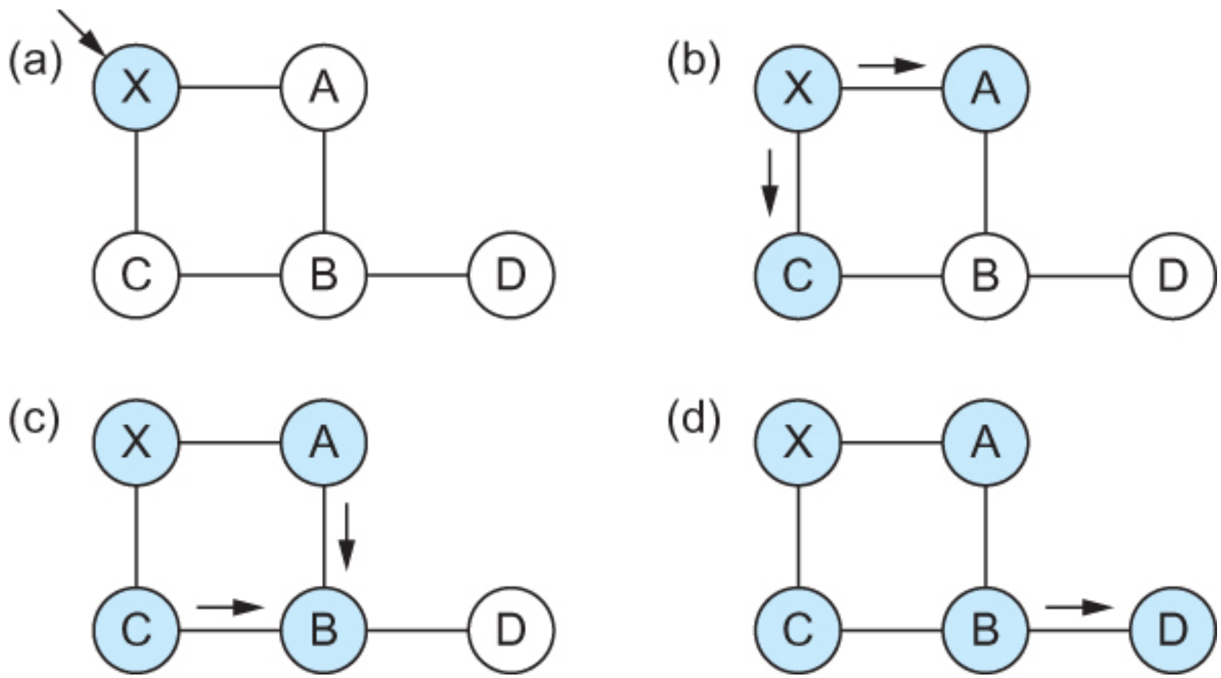
Link State Routing

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
- 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

Reliable Flooding



Flooding of link-state packets. (a) LSP arrives at node X; (b) X floods LSP to A and C; (c) A and C flood LSP to B (but not X); (d) flooding is complete

Shortest Path Routing

- Dijkstra's Algorithm - Assume non-negative link weights
  - N: set of nodes in the graph
  - l((i, j): the non-negative cost associated with the edge between nodes i, j ∈N and l(i, j) = ∝ if no edge connects i and j
  - Let s ∈N be the starting node which executes the algorithm to find shortest paths to all other nodes in N
  - Two variables used by the algorithm
    - M: set of nodes incorporated so far by the algorithm
    - C(n) : the cost of the path from s to each node n
    - The algorithm

```
M = {s}
For each n in N - {s}
    C(n) = l(s, n)
while ( N ≠ M)
  M = M U {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))
```

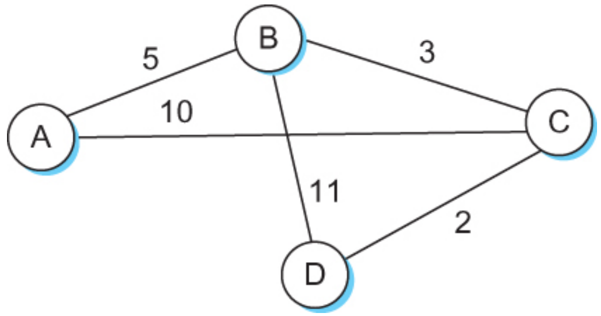
Shortest Path Routing

- In practice, each switch computes its routing table directly from the LSP's it has collected using a realization of Dijkstra's algorithm called the *forward search algorithm*
- Specifically each switch maintains two lists, known as **Tentative** and **Confirmed**
- Each of these lists contains a set of entries of the form (Destination, Cost, NextHop)

Shortest Path Routing

- The algorithm
  - Initialize the **Confirmed** list with an entry for myself; this entry has a cost of 0
  - For the node just added to the **Confirmed** list in the previous step, call it node **Next**, select its LSP
  - For each neighbor (Neighbor) of **Next**, calculate the cost (Cost) to reach this Neighbor as the sum of the cost from myself to Next and from Next to Neighbor
    - If Neighbor is currently on neither the **Confirmed** nor the **Tentative** list, then add (Neighbor, Cost, Nexthop) to the **Tentative** list, where Nexthop is the direction I go to reach Next
    - If Neighbor is currently on the **Tentative** list, and the Cost is less than the currently listed cost for the Neighbor, then replace the current entry with (Neighbor, Cost, Nexthop) where Nexthop is the direction I go to reach Next
  - If the **Tentative** list is empty, stop. Otherwise, pick the entry from the **Tentative** list with the lowest cost, move it to the **Confirmed** list, and return to Step 2.

Shortest Path Routing



Step	Confirmed	Tentative	Comments
1	(D,0,–)		Since D is the only new member of the confirmed list, look at its LSP.
2	(D,0,–)	(B,11,B) (C,2,C)	D's LSP says we can reach B through B at cost 11, which is better than anything else on either list, so put it on Tentative list; same for C.
3	(D,0,–) (C,2,C)	(B,11,B)	Put lowest-cost member of Tentative (C) onto Confirmed list. Next, examine LSP of newly confirmed member (C).
4	(D,0,–) (C,2,C)	(B,5,C) (A,12,C)	Cost to reach B through C is 5, so replace (B,11,B). C's LSP tells us that we can reach A at cost 12.
5	(D,0,–) (C,2,C) (B,5,C)	(A,12,C)	Move lowest-cost member of Tentative (B) to Confirmed, then look at its LSP.
6	(D,0,–) (C,2,C) (B,5,C)	(A,10,C)	Since we can reach A at cost 5 through B, replace the Tentative entry.
7	(D,0,–) (C,2,C) (B,5,C) (A,10,C)		Move lowest-cost member of Tentative (A) to Confirmed, and we are all done.

Open Shortest Path First (OSPF)

0	8	16	31
Version	Type	Message length	
SourceAddr			
AreaId			
Checksum		Authentication type	
Authentication			

OSPF Header Format

LS Age			Options	Type=1
Link-state ID				
Advertising router				
LS sequence number				
LS checksum			Length	
0	Flags	0	Number of links	
Link ID				
Link data				
Link type		Num_TOS	Metric	
Optional TOS information				
More links				

OSPF Link State Advertisement

Summary

- We have looked at some of the issues involved in building scalable and heterogeneous networks by using switches and routers to interconnect links and networks.
- To deal with heterogeneous networks, we have discussed in details the service model of Internetworking Protocol (IP) which forms the basis of today's routers.
- We have discussed in details two major classes of routing algorithms
  - Distance Vector
  - Link State