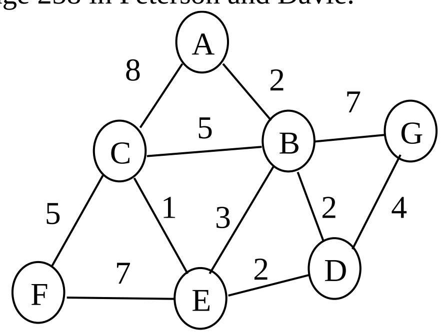
ECE 4380/6380: Computer Communications **Spring 2017**
Problem Set 9 **Due: in class, Friday, April 14**

Assigned reading:

- Peterson and Davie, Chapter 3. Section 3.4 is not required.
- Peterson and Davie, Chapter 4. Only Sections 4.1(Global Internet) and 4.4 (Routing Among Mobile Devices).

1. **Link-state routing.** Show how the link-state algorithm builds the routing table for node *A* in the following network. Assume that the link weights are the same in both directions on a link. Use the same format as Table 3.14, page 258 in Peterson and Davie.



2. **Link-state routing.** As discussed in class, the link-state routing algorithm does not have the looping problems found with distance-vector routing. However, link-state routing does depend on all nodes having an up-to-date database of link-state packets (LSP's). If there is inconsistent information at different nodes then routing errors may occur. Consider a network that has nodes A, B, C, D, E, F, and G. Each node generates a LSP that contains the following information:
   - The ID of the node that created the LSP
   - A list of directly connected neighbors of that node, with the cost of the link to each one
   - Additional information such as sequence number and time to live

We will ignore the sequence number and time to live information and just focus on the ID and list of neighbors. Assume that each node generates its own LSP as shown below and that each node has an up-to-date copy of all LSP's

Source A	
Nbr	Cost
D	6
F	1

Source B	
Nbr	Cost
D	4
E	3
F	3

Source C	
Nbr	Cost
E	1
F	5
G	1

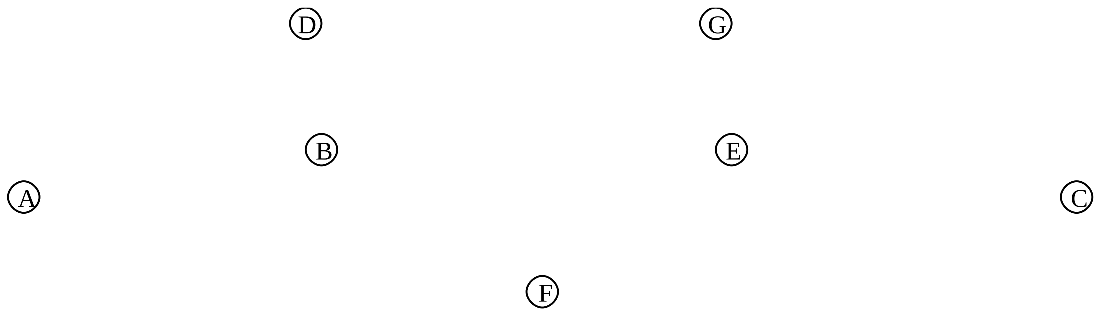
Source D	
Nbr	Cost
A	1
B	5
G	1

Source E	
Nbr	Cost
B	4
C	1
G	1

Source F	
Nbr	Cost
A	2
B	1
C	5

Source G	
Nbr	Cost
C	1
D	6
E	1

(a) Draw a diagram of the network that is consistent with these tables, showing the cost of all links.

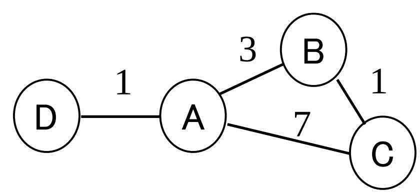


(b) For a packet that is generated at node A with node G as its destination, give the path that the packet follows.

(c) Assume that node B updates the cost of its link to D with a new value of 1. Node B runs Dijkstra's algorithm and updates its forwarding table, but it does not notify any of the other nodes in the network of the change (say for example, due to an error). Does this change the path that a packet from A to G follows? If so, give the new path.

(d) Next, assume that node D updates the cost of its link to G with a new value of 8. Node D updates its forwarding table and forwards its LSP packet to nodes A, F, and G, but because of another error, the LSP packet does not reach nodes B, C, or E. In addition, the change that node B made in part (c) still has not reached any of the other nodes in the network. Does this change the path that a packet from A to G follows? If so, give the new path.

3. Distance-Vector Routing



Consider a network with nodes A, B, C, and D and each node executes a distributed distance-vector protocol that includes triggered updates. That is, if a node calculates a new route to a destination or updates a new cost for an existing route to a destination, then it generates a triggered update. A node stores the most recent distance vector (DV) it has received from each of its neighbors. Assume that neither split horizon nor poison reverse has been implemented. The initial link costs are shown in the figure. Consider an example in which the link cost for the link between A and B decreases from 3 to 1. Below is the sequence of events that occur in response to this change *with respect to routes to node D only*. (We will ignore all other routes for this problem.)

Event number	Action	Response by neighbor
1.	link cost decreases from 3 to 1	Node B had these DVs for destination D *before* change Via A (dest=D, cost = 1) Via C (dest=D, cost = 5) *After* decrease in link cost: Node B's best route to D: next=A, cost =2 (cost reduced from 4 to 2)

2.	Node B generates triggered update with DV (dest=D, cost=2)	Node C had these DVs for D *before* receiving triggered update Via A (dest=D, cost = 1) Via B (dest=D, cost = 4) *After* change to C's DV table: Via B (dest=D, cost = 2) Node C's best route to D: next=B, cost=3 (cost reduced from 5 to 3)
3	Node C generates triggered update with DV (dest=D, cost=3)	Node B had these DVs for D *before* receiving triggered update Via A (dest=D, cost = 1) Via C (dest=D, cost = 5) *After* change to B's DV table: Via C (dest=D, cost = 3). Node B does not change route to D so no triggered update and sequence done

Note that we can ignore any actions at node A and D for this problem. Only the actions taken by nodes B and C are important, and only the triggered updates exchanged between nodes B and C need to be considered.

Next assume that the cost increases on the link between A and B from 1 to 10. Here are the first few steps. Continue filling out the table starting with the response in event 4 and continue until there are no more changes.

Event number	Action	Response by neighbor
1.	link cost increase from 1 to 10	Node B had these DVs for destination D *before* change Via A (dest=D, cost = 1) Via C (dest=D, cost = 3) *After* increase in link cost: Node B's best route to D: next=C, cost =4 (cost increases from 2 to 4)
2.	Node B generates triggered update with DV (dest=D, cost=4)	Node C had these DVs for D *before* receiving triggered update Via A (dest=D, cost = 1) Via B (dest=D, cost = 2) *After* change to C's DV table: Via B (dest=D, cost = 4) Node C's best route to D: next=B, cost=5 (cost increase from 3 to 5)
3	Node C generates triggered update with DV (dest=D, cost=5)	Node B had these DVs for D *before* receiving triggered update Via A (dest=D, cost = 1) Via C (dest=D, cost = 3) *After* change to B's DV table: Via C (dest=D, cost = 5). Node B's best route to D: next=C, cost =6 (cost increase from 4 to 6)
4	Node B generates triggered update with DV (dest=D, cost=6)	Node C had these DVs for D *before* receiving triggered update Via A (dest=D, cost = 1) Via B (dest=D, cost = 4)

Split horizon with poisoned reverse. The routing protocol is updated at all nodes to use the split horizon with poisoned reverse improvement. The same scenario starts from the beginning but now with the new routing protocol. That is, the link between A and B is initially 3 and it decreases to 1. After the change in link cost the network stabilizes with the new DV tables. Next, assume that the cost increases on the link between A and B from 1 to 10. Show the sequence of events that occur.

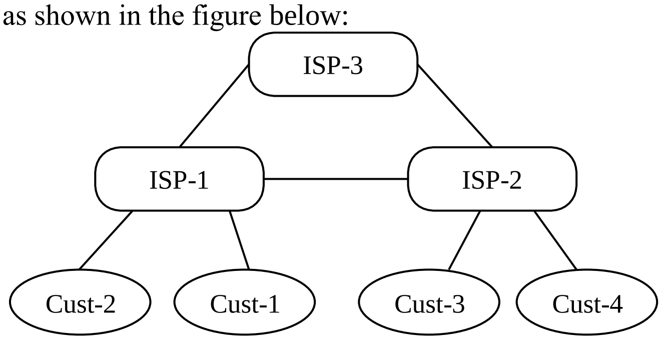
Event number	Action	Response by neighbor
1.	link cost increase from 1 to 10	Node B had these DVs for destination D *before* change Via A (dest=D, cost = 1) Via C (dest=D, cost = ←*Hint: what goes here?* *After* increase in link cost: Node B's best route to D: next= , cost =

4. **Forwarding** tables with CIDR (variation on Chapter 4 numbers 5 and 6)
Suppose ISP-1, ISP-2, and ISP-3 are network service providers, with respective CIDR address allocations D1.0.0.0/8, D2.0.0.0/8, and D3.0.0.0/8. Each provider's customers initially receive address allocations that are a subset of the provider's. Address bytes are in hexadecimal. The ISP's have the following customers (and assume that there are no other providers or customers):

ISP-1	
Customer	address allocation
Cust1.isp1	D1.A3.0.0/16
Cust2.isp1	D1.B0.0.0/12

ISP-2	
Customer	address allocation
Cust3.isp2	D2.0A.10.0/20
Cust4.isp2	D2.0B.0.0/16

The ISP's are connected as shown in the figure below:



(a) Give the forwarding tables for ISP-1, ISP-2 and ISP-3. Use the format for the forwarding table as shown below.

ISP-1	
Address	Next hop

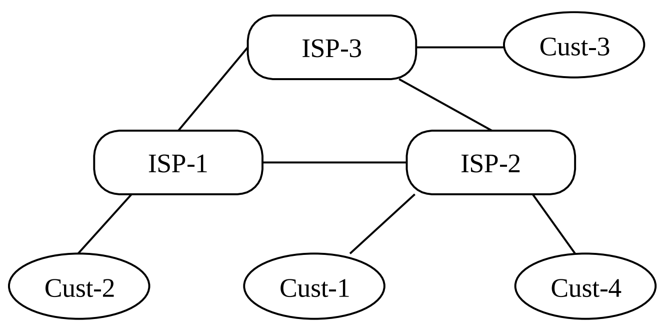
ISP-2	
Address	Next hop

ISP-3	
Address	Next hop

D2.0.0.0/8	ISP-2
D3.0.0.0/8	ISP-3
D1.A3.0.0/16	Cust1
D1.B0.0.0/12	Cust2

(b) Suppose customer 1 (cust1.isp1) acquires a direct link to ISP-2, and customer 3 (cust3.isp2) acquires a direct link to ISP-1, in addition to existing links. Give the new forwarding tables.

(c) Suppose customer 1 (cust1.isp1) switches to provider ISP-2, and customer 3 (cust3.isp2) switches to provider ISP-3. The CIDR longest-match rule allows these customers to switch without having to renumber their original addresses. Give the routing tables for all three providers that allow this switch to occur.



5. **Mobile IP**. Consider the same network as used for the previous homework set, problem 7. Assume R2 is upgraded to serve as an 802.11 access point. The access point assigns IP addresses for the mobile hosts that associate with it from LAN B's allocation. Also, Mobile IP is enabled and router R2 serves as the home agent.
   - **(a)** Suppose an IP packet arrives at R1 from the Internet with a destination address corresponding to a mobile host associated with this access point. Describe the frames that are transmitted on LAN B in delivering this packet to the mobile host. In particular, R1 is an old router and does not know about Mobile IP or 802.11
   - **(b)** Suppose a mobile associated with R2 moves to another 802.11 network that is not local but can be reached through the internet connection. Describe how a packet for this mobile host is forwarded from the home agent to the foreign agent given that none of the routers between these agents have been changed.

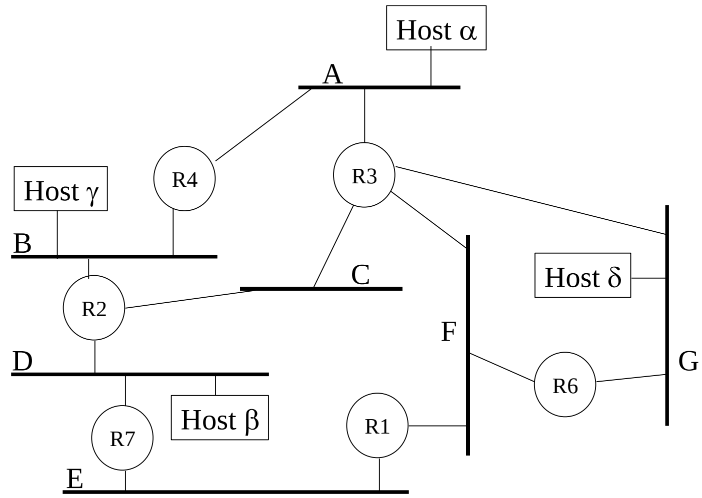
Students enrolled in 638 will be responsible for material in Sections 4.2 and 4.3 and should solve the next two problems.

6. **Multicast**. Chapter 4, number 16 (see also problem 15)
7. **Multicast**. Consider multicast routing over an internet built from local area networks and routers as shown.

A certain multicast group Z has members γ, β, and δ. Suppose that host α wishes to send a packet to Z. To do so suppose α sends a packet to router R4 with a "Z" in the address field of the packet and "α" as the source address. (Router R3 does not read this initial packet.)

(a) For this part, suppose the link state method is used. What local area networks will carry copies of the packet? What header information related to routing is included in the packet from R4 to R2? Explain how router R2 knows which local area network(s) to forward copies of the packet on.

(b) For this part, suppose reverse-path *broadcast* is used to send the packet from R4. Suppose parents have been selected for each local area network (for communication form R4 to Z), so that multiple copies of the packet are not sent on a local area network (not counting the initial transmission from alpha). What local area networks will carry copies of the packet?



(c) For this part, suppose the reverse-path *multicast* is used to send the packet from router R4. Suppose that the multicast group has been used frequently in the recent past so that the maximum amount of helpful information about the multicast group is in the router caches. What local area networks will carry copies of the packet? What header information related to routing is included in the packet from R4 to R2? Explain hour router R2 knows which local area network(s) to forward copies of the packet on.

EXTRA CREDIT. This problem is optional, and is worth 10 points of extra credit for this homework set.

8. **Computer program for minimum distance calculation**. Suppose a network has 100 nodes, numbered 0 through 99. Assume that the cost of the one-way link from node *i* to node *j* is

$$d_{i,j} = |i - j| + (i - j + 3)^2 + 5j$$

Write a computer program (in the language of your choice) to find the least cost path from node 0 to node 99 and the cost of the path. You can use either a distance-vector or link-state algorithm to find the solution. The output of your program should give the cost of the minimum distance route and the nodes in the path. For example, here is the output from my program (using a different link cost function):

```
dijkstra% cc linkstate.c -lm
dijkstra% a.out

link-state algorithm:
min cost 3454.000000
Reverse route 99  74  53  36  22  11  5  1  0

distance-vector algorithm:
min cost 3454.000000
Route   0  1  5  11  22  36  54  75  99
```

(Notice the routes have the same cost, but do not have the same sequence of nodes. There is more than one route with the minimum cost.) I have implemented both a distance-vector and link-state algorithm and you need only do one. Also, note if you implement the link-state algorithm you may find it easier to print the route in the reverse order. Either ordering for the route is fine.

(My former ECE 223 students cannot just turn in the Dijkstra's machine problem from 223. Either implement the Bellman-Ford algorithm (and compare its run time to Dijkstra's), or implement Dijkstra's in a new language.)

Hand in (a) a well-commented copy of your code and (b) a capture of the output of compiling and running your code.