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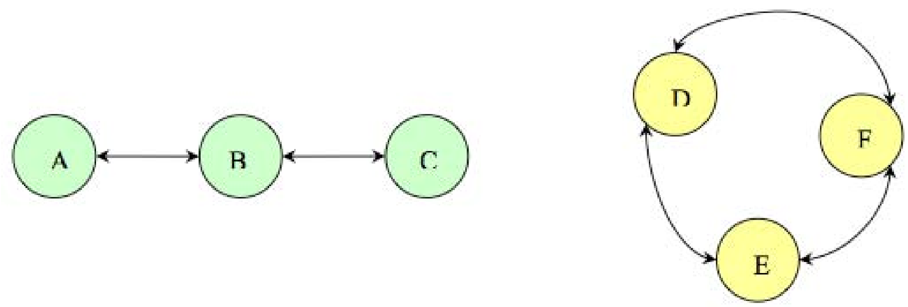
6.02 Practice Problems: Routing

IMPORTANT: IN ADDITION TO THESE PROBLEMS, PLEASE SOLVE THE PROBLEMS AT THE END OF CHAPTERS 17 AND 18.

Problem 1. Consider the following networks: network I (containing nodes A, B, C) and network II (containing nodes D, E, F).



A. The Distance Vector Protocol described in class is used in both networks. Assume advertisements are sent every 5 time steps, all links are fully functional and there is no delay in the links. Nodes take zero time to process advertisements once they receive them. The HELLO protocol runs in the background every time step in a way that any changes in link connectivity are reflected in the next DV advertisement. We count time steps from t=0 time steps.

Please fill in the following table:

Event	Number of time steps
A's routing table has an entry for B	
A's routing table has an entry for C	
D's routing table has an entry for E	
F's routing table has an entry for D	

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B. Now assume the link B-C fails at t = 51 and link D-E fails at t = 71 time steps. Please fill in this table:

Event	Number of time steps
B's *advertisements* reflect that C is unreachable	
A's routing table reflects C is unreachable	
D's routing table reflects a new route for E	

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Problem 2. Alyssa P. Hacker manages MIT's internal network that runs link-state routing. She wants to experiment with a few possible routing strategies. Of all possible paths available to a particular destination at a node, a routing strategy specifies the path that must be picked to create a routing table entry. Below is the name Alyssa has for each strategy and a brief description of how it works.

MinCost: Every node picks the path that has the smallest sum of link costs along the path. (This is the minimum cost routing you implemented in the lab).

MinHop: Every node picks the path with the smallest number of hops (irrespective of what the cost on the links is).

SecondMinCost: Every node picks the path with the second lowest sum of link costs. That is, every node picks the second best path with respect to path costs.

MinCostSquared: Every node picks the path that has the smallest sum of squares of link costs along the path.

Assume that sufficient information (e.g., costs, delays, bandwidths, and loss probabilities of the various links) is exchanged in the link state advertisements, so that every node has complete information about the entire network and can correctly implement the strategies above. You can also assume that a link's properties don't change, e.g., it doesn't fail.

A. Help Alyssa figure out which of these strategies will work correctly, and which will result in routing with loops. In case of strategies that do result in routing loops, come up with an example network topology with a routing loop to convince Alyssa.

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B. How would you implement MinCostSquared in a distance-vector protocol?

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Problem 3. Which of the following tasks does a router R in a packet-switched network perform when it gets a packet with destination address D? Indicate True or False for each choice.

A. R looks up D in its routing table to determine the outgoing link.

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B. R sends out a HELLO packet or a routing protocol advertisement to its neighbors.

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C. R calculates the minimum-cost route to destination D.

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D. R may discard the packet.

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Problem 4. Alice and Bob are responsible for implementing Dijkstra's algorithm at the nodes in a network running a link-state protocol. On her nodes, Alice implements a minimum-cost algorithm. On his nodes, Bob implements a "shortest number of hops" algorithm. Give an example of a network topology with 4 or more nodes in which a routing loop occurs with Alice and Bob's implementations running simultaneously in the same network. Assume that there are no failures.

(Note: A routing loop occurs when a group of k ≥ 1 distinct nodes, n_0 , n_1 , n_2 , …, n_(k-1) have routes such that n_i's next-hop (route) to a destination is n_(i+1 mod k).

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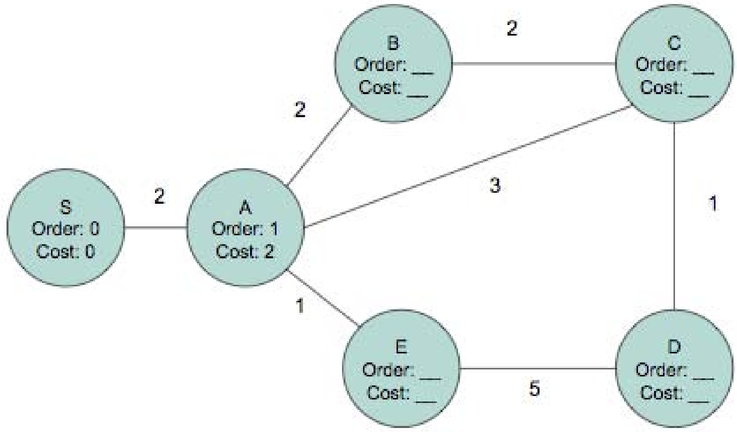
Problem 5. Consider the network shown below. The number near each link is its cost.



We're interested in finding the shortest paths (taking costs into account) from S to every other node in the network. What is the result of running Dijkstra's shortest path algorithm on this network? To answer this question, near each node, list a pair of numbers: The first element of the pair should be the order, or the iteration of the algorithm in which the node is picked. The second element of each pair should be the shortest path cost from S to that node.

To help you get started, we've labeled the first couple of nodes: S has a label (Order: 0, Cost: 0) and A has the label (Order: 1, Cost: 2).

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Problem 6. Consider any two graphs(networks) G and G' that are identical except for the costs of the links. Please answer these questions.

A. The cost of link l in graph G is c_l > 0, and the cost of the same link l in Graph G' is `k*c_l`, where k > 0 is a constant and the same scaling relationship holds for all the links. Are the shortest paths between any two nodes in the two graphs identical? Justify your answer.

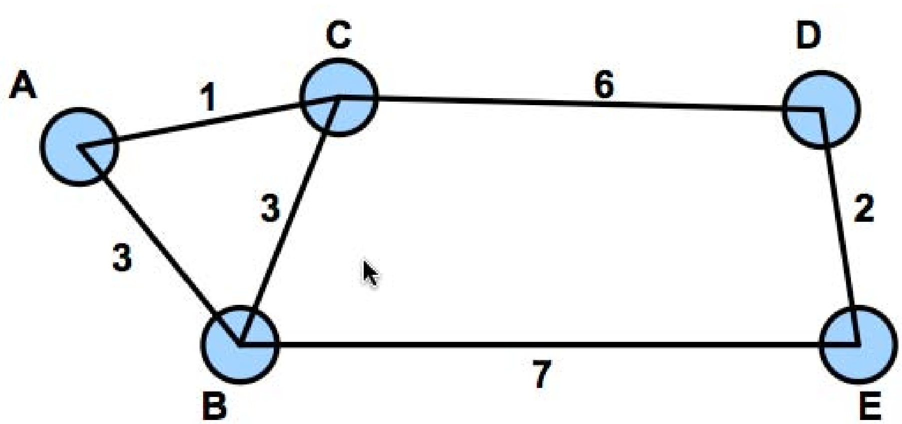
   Show Answer

B. Now suppose that the cost of a link l in G' is `k*c_l + h`, where k > 0 and h > 0 are constants. Are the shortest paths between any two nodes in the two graphs identical? Justify your answer.

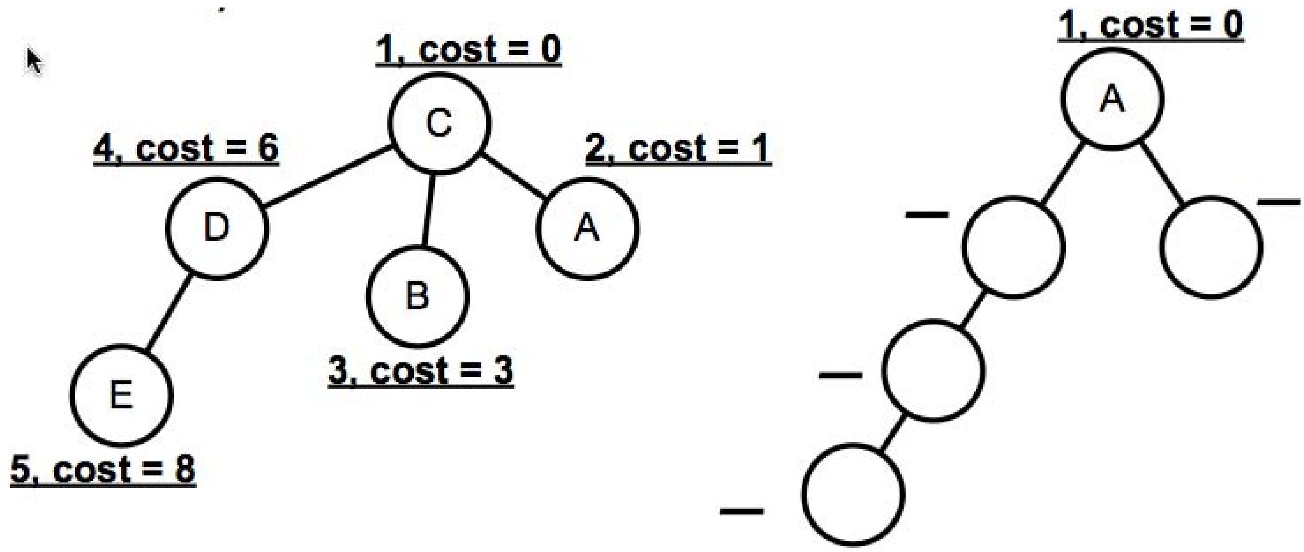
   Show Answer

Problem 7. Dijkstra's algorithm

A. For the following network



an empty routing tree generated by Dijkstra's algorithm for node A (to every other node) is shown below. Fill in the missing nodes and indicate the order that each node was added and its associated cost. For reference, node C's completed routing tree is shown as well.



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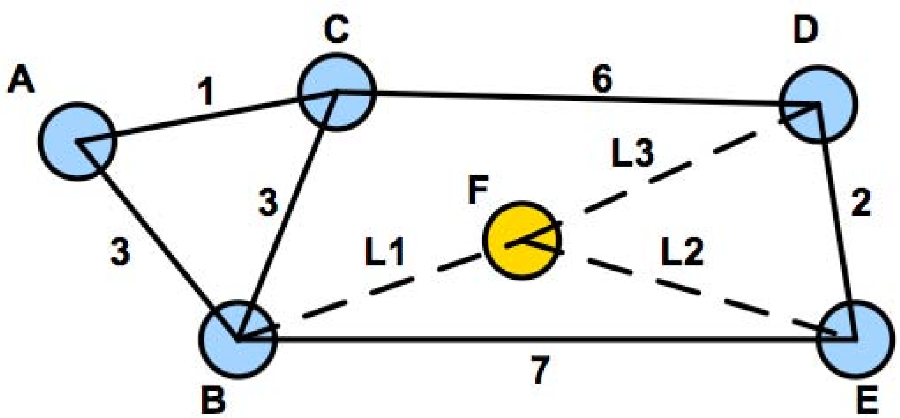
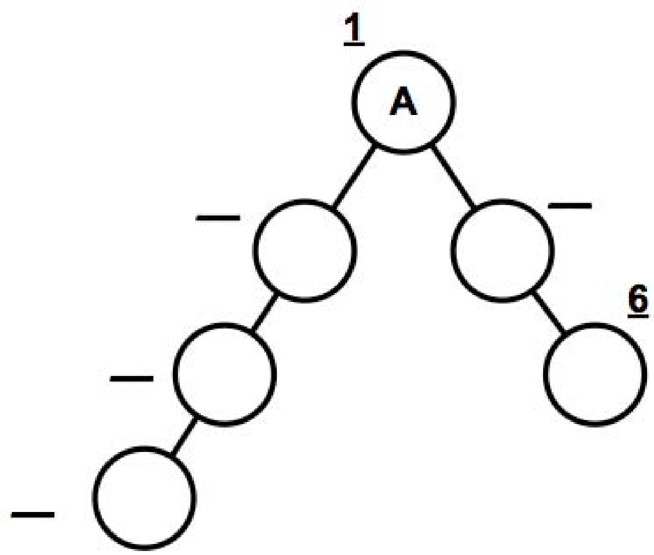
B. Now assume that node F has been added to the network along with links L1, L2 and L3.



What are the constraints on L1, L2 and L3 such that node A's routing tree must match the topology shown below (regardless of how ties are broken in the algorithm), and it is known that node F is not the last node added when using Dijkstra's algorithm? All costs are positive integers.



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Problem 8. Under some conditions, a distance vector protocol finding minimum cost paths suffers from the "count-to-infinity" problem. Indicate True or False for each choice.

A. The count-to-infinity problem may arise in a distance vector protocol when the network gets disconnected.

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B. The count-to-infinity problem may arise in a distance vector protocol even when the network never gets disconnected.

Show Answer

C. The "path vector" enhancement to a distance vector protocol always enables the protocol to converge without counting to infinity.

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Problem 9. Ben Bitdiddle has set up a multi-hop wireless network in which he would like to find paths with high probability of packet delivery between any two nodes. His network runs a distance vector protocol similar to what you developed in the pset. In Ben's distance vector (BDV) protocol, each node maintains a metric to every destination that it knows about in the network. The metric is the nodeâ€™s estimate of the packet success probability along the path between the node and the destination.

The packet success proba bility along a link or path is defined as 1 minus the packet loss probability along the corresponding link or path. Each node uses the periodic HELLO messages sent by each of its neighbors to estimate the packet loss probability of the link from each neighbor. You may assume that the link loss probabilities are symmetric; i.e., the loss probability of the link from node A to node B is the same as from B to A. Each link L maintains its loss probability in the variable `L.lossprob` and `0 < L.lossprob < 1`.

A. The key pieces of the Python code for each node's `integrate()` function in BDV is given below. It has three missing blanks. Please fill them in so that the protocol will eventually converge without routing loops to the correct metric at each node. The variables are the same as in the pset: `self.routes` is the dictionary of routing entries (mapping destinations to links), `self.getlink(fromnode)` returns the link connecting the node self to the node fromnode, and the `integrate` procedure runs whenever the node receives an advertisement (`adv`) from node fromnode. As in the pset, adv is a list of (destination, metric) tuples. In the code below, `self.metric` is a dictionary storing the nodeâ€™s current estimate of the routing metric (i.e., the packet success probability) for each known destination. Please fill in the missing code.

```
# Process an advertisement from a neighboring node in BDV
```

```
def integrate(self, fromnode, adv):
  L = self.getlink(fromnode)
  for (dest, metric) in adv:
    my_metric = __________________________________
    if (dest not in self.routes
        or self.metric[dest] _____ my_metric
        or ___________________________________________):
      self.routes[dest] = L
      self.metric[dest] = my_metric

  # rest of integrate() not shown
```

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Ben wants to try out a link-state protocol now. During the flooding step, each node sends out a link-state advertisement comprising its address, an incrementing sequence number, and a list of tuples of the form `(neighbor, lossprob)`, where the lossprob is the estimated loss probability to the `neighbor`.

B. Why does the link-state advertisement include a sequence number?

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Ben would like to reuse, without modification, his implementation of Dijkstra's shortest paths algorithm from the pset, which takes a map in which the links have non-negative costs and produces a path that minimizes the <u>sum of the costs</u> of the links on the path to each destination.

C. Ben has to transform the lossprob information from the LSA to produce link costs so that he can use his Dijkstra implementation without any changes. Which of these transformations will accomplish this goal? Choose the BEST answer.

   a. Use `lossprob` as the link cost.
   b. Use `-1/log(1-lossprob)` as the link cost.
   c. Use `log(1/(1-lossprob))` as the link cost.
   d. Use `log(1 - lossprob)` as the link cost.

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Problem 10. We studied a few principles for designing networks in 6.02.

A. State one significant difference between a circuit-switched and a packet-switched network.

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B. Why does topological addressing enable large networks to be built?

Show Answer

C. Give one difference between what a switch does in a packet-switched network and a circuit-switched network.

Show Answer

Problem 11. Eager B. Eaver implements distance vector routing in his network in which the links all have arbitrary positive costs. In addition, there are at least two paths between any two nodes in the network. One node, u, has an erroneous implementation of the integration step: it takes the advertised costs from each neighbor and picks the route corresponding to the minimum advertised cost to each destination as its route to that destination, *without adding the link cost to the neighbor*. It breaks any ties arbitrarily. All the other nodes are implemented correctly.

Let's use the term "correct route" to mean the route that corresponds to the minimum-cost path. Which of the following statements are true of Eager's network?

a. Only u may have incorrect routes to any other node.
b. Only u and u's neighbors may have incorrect routes to any other node.
c. In some topologies, all nodes may have correct routes.
d. Even if no HELLO or advertisements packets are lost and no link or node failures occur, a routing loop may occur.

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Problem 12. Consider a network running the link-state routing protocol as described in lecture and on the pset. How many copies of any given LSA are received by a given node in the network?

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Problem 13. In implementing Dijkstra's algorithm in the link-state routing protocol at node u, Louis Reasoner first sets the route for each directly connected node v to be the link connecting u to v. Louis then implements the rest of the algorithm correctly, aiming to produce minimum-cost routes, but does not change the routes to the directly connected nodes. In this network, u has at least two directly connected nodes, and there is more than one path between any two nodes. Assume that all link costs are non-negative. Which of the following statements is true of u's routing table?

A. There are topologies and link costs where the *majority* of the routes to other nodes will be *incorrect*.

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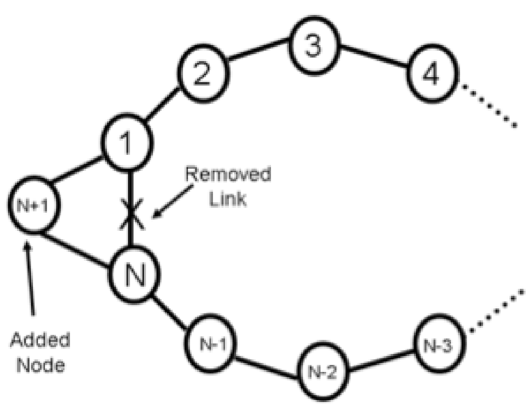
B. There are topologies and link costs where *no* routing table entry (other than from u to itself) will be *correct*.

Show Answer

C. There are topologies and link costs where *all* routing table entry (other than from u to itself) will be *correct*.

Show Answer

Problem 14. A network with N nodes and N bidirectional links is connected in a ring, and N is an even number.



The network runs a distance-vector protocol in which the advertisement step at each node runs when the local time is `T*i` seconds and the integration step runs when the local time is `T*i + T/2` seconds, (i=1,2,...). Each advertisement takes time δ to reach a neighbor. Each node has a separate clock and time is not synchronized between the different nodes.

Suppose that at some time t after the routing has converged, node N + 1 is inserted into the ring, as shown in the figure above. Assume that there are no other changes in the network topology and no packet losses. Also assume that nodes 1 and N update their routing tables at time t to include node N + 1, and then rely on their next scheduled advertisements to propagate this new information.

A. What is the minimum time before every node in the network has a route to node N + 1?

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B. What is the maximum time before every node in the network has a route to node N + 1?

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Problem 15. Louis Reasoner implements the link-state routing protocol discussed in 6.02 on a best-effort network with a non-zero packet loss rate. In an attempt to save bandwidth, instead of sending link-state advertisements periodically, each node sends an advertisement *only if* one of its links fails or when the cost of one of its links changes. The rest of the protocol remains unchanged. Will Louis' implementation always converge to produce correct routing tables on all the nodes?

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Problem 16. Consider a network implementing minimum-cost routing using the distance-vector protocol. A node, S, has k neighbors, numbered 1 through k, with link cost c_i to neighbor i (all links have symmetric costs). Initially, S has no route for destination D. Then, S hears advertisements for D from each neighbor, with neighbor i advertising a cost of p_i. The node integrates these k advertisements. What is the cost for destination D in S's routing table after the integration?

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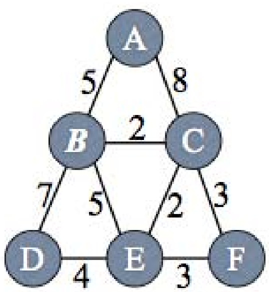
Problem 17. Consider the network shown in the picture below. Each node implements Dijkstra's shortest path algorithm using the link costs shown in the picture.



A. Initially, node B's routing table contains only one entry, for itself. When B runs Dijkstra's algorithm, in what order are nodes added to the routing table? List all possible answers.

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B. Now suppose the link cost for one of the links changes but all costs remain non-negative. For each change in link cost listed below, state whether it is possible for the route at node B (i.e., the link used by B) for any destination to change, and if so, name the destination(s) whose routes may change.

a. The cost of link(A, C) increases.

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b. The cost of link(A, C) decreases.

Show Answer

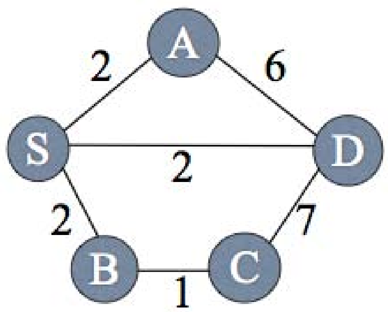
c. The cost of link(B, C) increases.

Show Answer

d. The cost of link(B, C) decreases.

Show Answer

Problem 18. Alyssa P. Hacker implements the 6.02 distance-vector protocol on the network shown below. Each node has its own local clock, which may not be synchronized with any other node's clock. Each node sends its distance-vector advertisement every 100 seconds. When a node receives an advertisement, it immediately integrates it. The time to send a message on a link and to integrate advertisements is negligible. No advertisements are lost. There is no HELLO protocol in this network.



A. At time 0, all the nodes except D are up and running. At time 10 seconds, node D turns on and immediately sends a route advertisement for itself to all its neighbors. What is the minimum time at which each of the other nodes is guaranteed to have a correct routing table entry corresponding to a minimum-cost path to reach D? Justify your answers.

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B. If every node sends packets to destination D, and to no other destination, which link would carry the most traffic?

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Alyssa is unhappy that one of the links in the network carries a large amount of traffic when all the nodes are sending packets to D. She decides to overcome this limitation with Alyssa's Vector Protocol (AVP). In AVP, *S lies*, advertising a "path cost" for destination D that is different from the sum of the link costs along the path used to reach D. All the other nodes implement the standard distance-vector protocol, not AVP.

C. What is the smallest numerical value of the cost that S should advertise for D along each of its links, to *guarantee* that only its own traffic for D uses its direct link to D? Assume that all advertised costs are integers; if two path costs are equal, one can't be sure which path will be taken.

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