CSE 473 – *Introduction to Computer Networks* | *Roch Guérin*

Final Exam Review Solution

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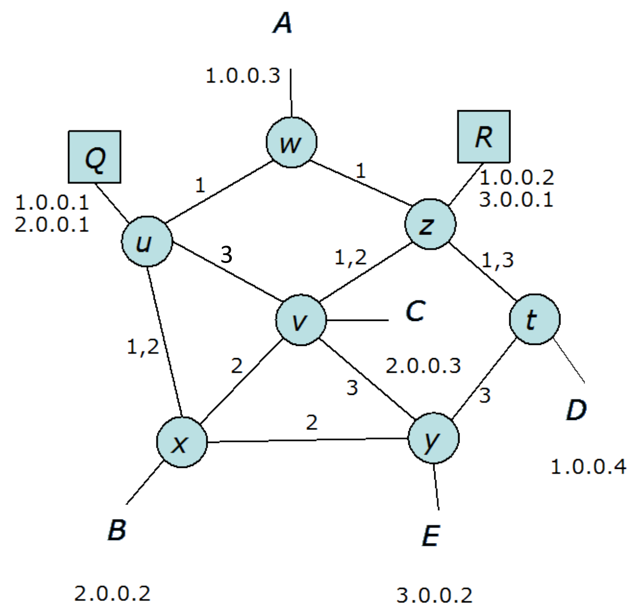
1) The diagram at right shows a switched Ethernet LAN with two routers (labeled *Q* and *R*), seven switches and five hosts. The switches are configured with three VLANs and the labels next to each link show the VLANs active on the link (note, some links are active in multiple VLANs).

Each VLAN is assigned an IP subnet. Specifically, VLAN 1 is assigned subnet 1.0.0.0/8, VLAN 2 subnet 2.0.0.0/8 and VLAN 3 subnet 3.0.0.0/8. The two routers each belong to two subnets and can send/receive packets using two VLAN ids. Both routers are on subnet 1.0.0.0/8, but router R is the default gateway for the subnet. Hosts are configured with the VLAN corresponding to their IP subnet.



a) If host *B* sends a packet to host *C*, what switches and routers does the packet pass through? Explain why and list them in order, repeating any switch the packet traverses more than once. Note that each VLAN forms a spanning tree to start with.

B and C are in the same subnet, so they communicate directly and packets simply go through switches x and v.

b) If host *A* sends a packet to host *B*, what switches and routers does it pass through?

A and B are in different subnets. Their path therefore includes at least one router. A is on subnet 1.0.0.0/8 and, therefore, forwards its packets to router R, that then delivers them to router Q that is connected to subnet 2.0.0.0/8 to which B belongs. Hence the path is w,z,R,z,w,u,Q,u,x.

c) If *B* sends a packet to *E*, what switches and routers does it pass through?

B and E are again on different subnets, so routers must be involved. Using a similar reasoning as in the previous question, the path is x u,Q,u,w,z,R,z,t,y.

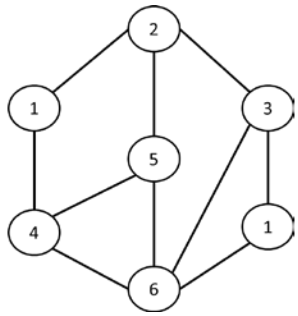
d) If *C* transfers a large file to *E* while *B* transfers a large file to *D*, what maximum data rate could each approximately get, assuming that the links are all 1 Gb/s duplex links?

The two paths are v,x,u,Q,u,w,z,R,z,t,y and x,u,Q,u,w,z,t (note that the return path from D to B is slightly different, i.e., t,z,R,z,w,u,Q,u,x). They have links x,u; u,Q; Q,u; u,w; w,z; and z,t in common, so each gets at most approximately half those links bandwidth or 500 Mb/s.

e) What maximum bandwidth could they each get if *E* was in subnet 2.0.0.0/8 instead?

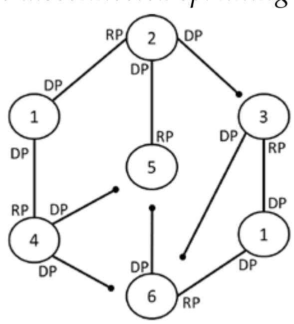
In that case, they could each get up to 1 Gb/s since the paths are now link disjoint.

2) Consider the bridged Ethernet network shown below, where circles represent Ethernet bridges, and lines Ethernet LAN segments connecting them. All LAN segments operate at the same speed of 1 Gbps (10^9 bits/sec). The number inside each circle indicates the priority level of the bridge, with lower values corresponding to higher priority. Because of an error made by the network administrator who decided to over-ride the default configuration in a bridge, two bridges have been assigned the highest priority value of 1.

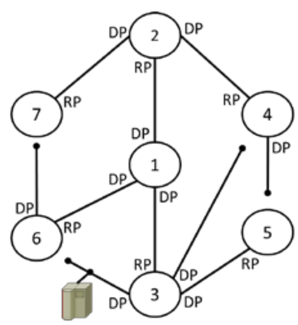


a) Describe the final spanning tree configuration for this network, and identify the state of every single port in the network, i.e., RP, DP or blocking. Justify your results and explain any problem created by the fact that two bridges were assigned priority 1.

The spanning tree construction starts irrespective of the fact that two bridges have been assigned the same highest priority value. All bridges eventually select "the" bridge with the priority value of 1 as the root bridge, but because there are two choices they end-up choosing the one closest to them. Specifically, bridges 3 and 6 select as root the priority 1 bridge to which they are directly attached (this has the lowest cost). Conversely, bridges 2 and 4 select as root the priority 1 bridge to which they are directly attached (this has again the lowest cost). Bridge 5 learns of three different paths to a root bridge with priority 1; all with the same cost of 2. It selects the path through bridge 2 that has the highest priority. This results in two disconnected spanning trees as shown below.



b) Assume next that our network administrator reconfigured the network so that the spanning tree that was finally formed is as shown in the figure below.

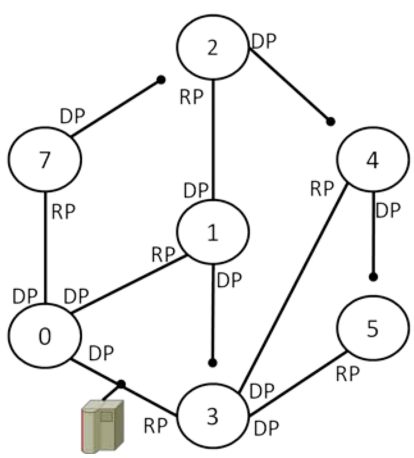


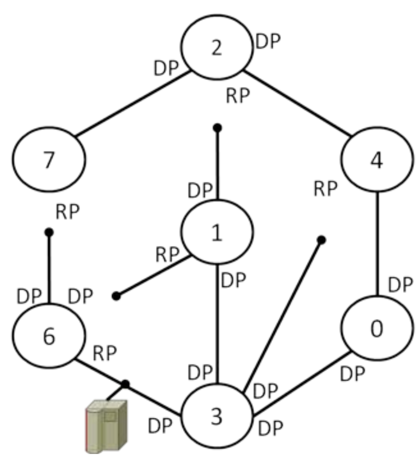
(i) Under the spanning tree configuration shown in the figure, is any bridge not forwarding data packets? If no, identify for each bridge the LAN segments to and from which it forwards data packets. If yes, explain why some bridges may not be forwarding data packets.

Because bridges 5 and 7 have no DP, they will not be forwarding any data packets. They may receive packets on their RP, but since they have no LAN segments attached to them for which they are the DP, they won't be forwarding those packets anywhere. Similarly, because they don't have any DP port, they won't be receiving any packet that should be forwarded on their RP.

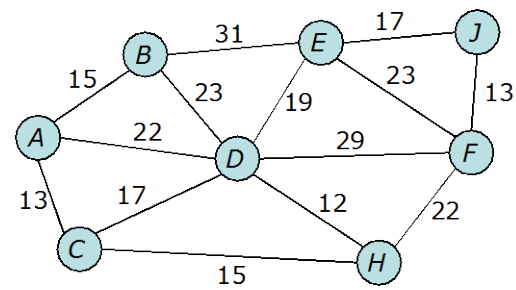
(ii) As shown in the figure, a major server is located on the LAN for which bridge 3 is the DB. This LAN runs at 10 Gbps, but all other LANs are 1 Gbps LANs. At any given time, there are on average 10 users in each LAN that are downloading material from the server. Given the current spanning tree configuration, the LAN between bridges 1 and 3 is, therefore, the most heavily loaded. Suggest a new configuration that involves lowering down to, say, 0, the priority of a single bridge and that results in the largest reduction in the load of the most loaded LAN. Justify your choice and explicitly identify the ratio by which the load of the most loaded LAN is reduced, *i.e.,* compare the load of the LAN between bridges 1 and 3 in the current configuration to the load of the most loaded LAN in your configuration.

Assuming each LAN generates a unit load to the server, the LAN between bridges 1 and 3 carries a load of 7 units in the current configuration. In order to reduce the maximum load as much as possible, we would like to use as many LANs as possible to reach the server. This can be realized by making either bridge 5 or bridge 6 as the root bridge. As shown in the figures below, both distribute the incoming server traffic on four distinct LAN segments, with the most loaded segment carrying traffic originating from 4 outer LAN segments instead of 7. Hence the load of the most loaded LAN is reduced by a factor 4/7.





3) In the diagram at right, nodes are IP routers and the numbers on the links are OSPF link weights.



a) If the network uses PIM with reverse-path forwarding, are any links never used for forwarding multicast packets coming **from** a host connected to router *J*?

The shortest path tree rooted at J includes the links EJ, FJ, BE, DE, CH, AD and FH. So the links that would never be used for multicast packets coming from a host at J are: EF, DF, DH, BD, AB, AC, CD.

Recall that under reverse-path forwarding, a router forwards multicast packets only if they are received on the link corresponding to the shortest to *the sender.*

b) Suppose that router *C* is the PIM DR for some layer 2 subnet, and that a host *X* in that subnet sends an IGMP report for address 229.1.2.3. Assume that *J* is the RP for 229.1.2.3 and that no other routers are currently participating in 229.1.2.3. What does router *C* do at this point? Which routers eventually add forwarding state for 229.1.2.3 as a result of *C*'s action?

C would send a PIM Join packet on the shortest path towards the RP, namely to router H. Eventually, routers C, H, F and J would add forwarding state for 229.1.2.3.

c) If a host connected to router *B* sent a packet to 229.1.2.3, which routers would the packet pass through in order to reach the host connected to the subnet at *C*? List them in the order in which the packet passes through them.

The packet would be encapsulated in a unicast packet address to J, and would therefore pass through routers B and E before arriving at J, which would then decapsulate it before forwarding it as a multicast packet to router F. Router F would forward it to H, which would then forward it to C that would eventually deliver it on its local subnet. Hence, the packet would pass through routers B, E, J, F, H and C.

d) How would the previous answer change if router *C* issued a source-specific join on 229.1.2.3 for the host at router *B*.

The multicast tree would now bypass the RP and be directly rooted at B. Hence packets would now be directly forwarded from B, to A and then C.

e) If the host connected to the subnet at *C* sends a packet to 229.1.2.3, which routers receive a copy? Assume that there has been no other activity on this multicast address, except for what has been described in questions a), b), and c).

Routers C, H, F and J would all receive copies. J would simply discard its copy since it is arriving on the interface it would use to forward a packet to the only subscribed recipient for this multicast address.

4) Consider a corporate network connected to the Internet at two separate locations.

a) The network has been allocated the following blocks of addresses by its Regional Internet Registry (RIR): 149.16.23.0/22; 149.16.24.0/22; and 149.16.30.0/22. What is the smallest number of additional address blocks it would need to request, and what would those blocks be, if it wanted to be able to advertise a single route to the rest of the Internet? And what would that route be?

The binary representations of the third bytes of the above three routes are as follows:

*23 = **000101** 11*
*24 = **000110** 00*
*30 = **000111** 10*

*where the bit values in bold-face are the only ones significant given the /22 mask size of the three routes. If the network administrator requests one additional /22 address block, namely, 149.16.16.0/22 (third byte has value '**000100** 00'), then the network administrator could configure its network to advertise to the Internet the single route 149.16.16.0/20.*

b) Assume that there are 12 routers in the network and that the three address blocks of the previous question are sub-divided to allocate one subnet of the same size to each router. What is the mask size of the subnet allocated to each router?

Each /22 address block can be split into four /24 subnets, for a total of twelve such subnets; one for each routers. As a result, each router is allocated one /24 subnet.

c) Two of the twelve routers in the network are connected to the Internet, and are therefore the "exit" points from the network for reaching remote destinations. Those two routers learn of remote routes through the BGP protocol (up to 300,000 routes), but advertising all those routes into the corporate network is not feasible. Suggest a solution that would work independent of the internal routing protocol used in the network and that would allow those two routers to advertise that they can offer connectivity to the Internet.

The easiest option is for both routers to advertise a default route (0.0.0.0/0). This will ensure that any destination address that is not a match for one of the local subnets is a match of a route advertised by both of those routers.

5) Consider a residential network that connects to the internet via a 4 Mb/s DSL link. Assume that three UDP flows share the link, each sending at rates of 1 Mb/s, 2 Mb/s and 3 Mb/s. Assume that the ISP router has a link buffer that can hold 300 packets (assume all packets have the same length). For each flow, what fraction of the packets it sends is discarded?

Assuming a single shared queue, each flow gets a fraction of the 4 Mb/s bandwidth that is proportional to its transmission rate compared to the aggregate input rate. In other words, the 1 Mb/s flow gets a bandwidth of about 2/3 Mb/s, the 2 Mb/s flow gets a bandwidth of about 4/3 Mb/s and the 3 Mb/s flow gets a bandwidth of about 2 Mb/s. Hence, each flow loses about 33% of the packets they send.

a) How many packets does each flow approximately have in the queue?

The number of packets that each flow has in the queue is proportional to the fraction of the output bandwidth it gets. Hence, the first flow has about 50 packets in the queue, the second flow has about 100 packets, and the third flow has about 150 packets.

b) Now, suppose the queue at the ISP router is replaced by three queues that can each hold 100 packets and that the queues are scheduled using weighted-fair queueing, where the weights are all 0.33. In this case, what fraction of packets are discarded from each flow?

In this case, the first flow loses 0% of its packets (the first flow consumes a share of the bandwidth equal to min*(1Mb/s, 4/3 Mb/s)=1Mb/s). The second and third flows equally share the remaining 3 Mb/s of bandwidth, and therefore each get 1.5 Mb/s. Hence, the second flow loses 25% of its packets, and the third flow loses 50% of its packets.*

c) In this configuration, how many packets does each flow have in its queue?

The first flow's queue is empty or close to empty. The other two flows each have about the maximum number of 100 packets in their queues.

d) Now, suppose the weights are 0.2 for the first flow, 0.6 for the second and 0.2 for the third. In this case, what fraction of packets is discarded from each flow?

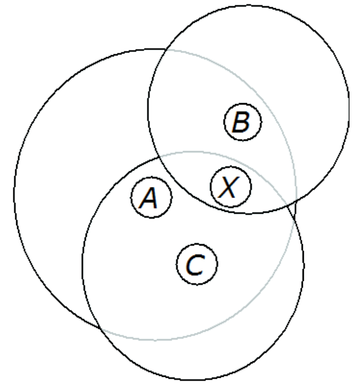
In this configuration, the second flow consumes a bandwidth share of min*(2Mb/s, 0.6*4 Mb/s)=2Mb/s, and the first and third flows equally share the remaining 2 Mb/s ,i.e., each get 1 Mb/s. As a result, and assuming a 100 packets queue, the first flow should lose close to 0%, though this depends on how packets arrive, and it could even experience some losses. The third flow loses approximately 67% of its packets.*

e) How many packets does each flow approximately have in its queue?

The second flow's queue is empty or close to empty. The third flow's queue is about full with about 100 packets.

As alluded to above, because the first flow is allocated a fraction of the link bandwidth that exactly matches its data rate, the queue load is 1. If packets arrive regularly, the queue will remain mostly empty, but if arrivals are highly bursty, significant queueing and losses could occur. For a single flow however, it's more likely that the queue will never accumulate a large backlog.

6) (10 points) The diagram at right shows a WIFI network with an access point, *X* and three hosts, *A*, *B* and *C*. The large circles indicate the *coverage areas* of the three hosts. The coverage area for *X* is not shown, but you may assume that it includes all three hosts. Assume RTS/CTS are not used.



Suppose *X* is transmitting a packet at time 0 and finishes sending it at time 100µs. Also,

- *A* gets a packet to send at time 50 that takes 100µs to send and is assigned a backoff timer of 100µs.
- *B* gets a packet at time 70µs that takes 200µs and is assigned a backoff timer of 50µs.
- *C* gets a packet at time 90µs that takes 150µs and is assigned a backoff timer of 150µs.

a) For each of the three hosts, what time do they start sending their packets? You may ignore the inter-frame spacing and the time required for acks.

A starts sending at time 200µs (it does not hear B) and finishes at 300µs.
B starts sending at 150µs and finishes at 350µs (or 200µs if it hears A's transmission)
C only decrements its timer before A starts transmitting and once it is finished. Hence, it starts sending at 350µs and finishes at 500µs

b) Of the three packets sent, which are successfully delivered on the first attempt?

Only the one from C is successfully delivered.

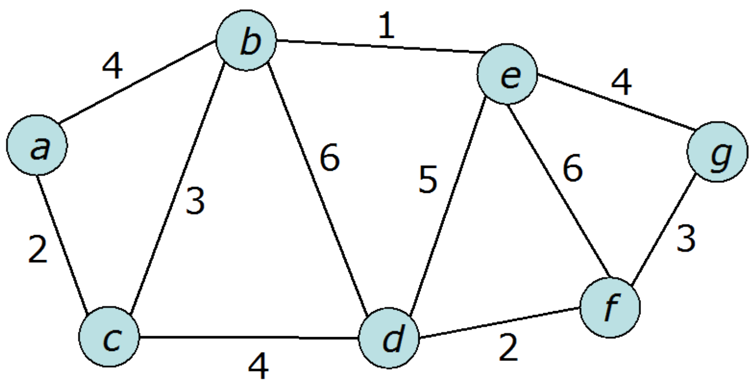
c) For each packet that is not successfully delivered on the first attempt, approximately when does the sending host learn that the packet was lost and must be sent again?

Hosts learn of lost packets from the absence of ACKs. Here, A would expect an ACK at approximately 300µs and so would learn of the lost packet when the ACK fails to arrive at that time. Similarly, B would learn of its lost packet at time 350µs.

d) Now, suppose RTS/CTS is enabled. In this case, approximately when does each host send its data packet? You may assume that the time needed to send RTS, CTS and ACK packets is negligible.

B sends it RTS at 150µs and gets granted permission to send until 350µs by X.
A sends its RTS at 400µs and gets granted permission to send until 500µs by X.
C sends its RTS at 550µs and gets granted permission to send until 590µs by X.

7) The diagram below represents a network with the numbers on the edges representing link costs, and the circles representing routers. The network uses OSPF as its routing protocol.



a) Are any network links never used when sending packets **to** a host Z connected to router *g*? Simply mark these links with an **X** on the diagram, but explain your reasoning. Assume that the topology is stable, that the link costs do not change and that *g* advertises a route to Z.

The shortest path tree rooted at g basically consists of the branches: (a,c)-b-e-g and d-f-g. Hence, none of the transversal links a-c, b-d, d-e, and e-f will be used, and neither will the link c-d.

b) Assume that router *a* sends a new copy of its router LSA. Suppose a copy of this LSA reaches router *e* after passing through *k* other routers. What is the smallest possible value for *k*? What is the largest possible value for *k*? Justify your answers by identifying the paths the LSA would traverse.

Because LSAs are flooded, the shortest path is basically the minimum hop path, which in the case of routers a and e would be two hops, i.e., k_{min}*=2. Conversely, the longest possible path that traverses each router no more than once would be a-c-b-d-f-g-e, for a total of* k_{max}*=6. Note that a-b-c-d-f-g-e is another alternative.*

c) Suppose that router *e* receives *n* copies of this LSA, all with the same sequence number. What is the largest possible value for *n*?

The largest possible value for n is the degree of e, i.e., n_{max}*=4.*

8) Recall that an RSA encryption key is a pair of numbers (*n*,*e*) and the corresponding decryption key is another pair (*n*,*d*). Which of the following could be used as RSA key pairs (ignoring the fact that they are too small)? For those that are valid key pairs, show that they meet all the requirements for a key pair, for those that are not, explain why they are not.

- (31,5), (31,11)

31 is itself a prime number so that it cannot be the product of two primes. Hence this is not a valid RSA key pair.

- (301,17), (301,89)

*301 is equal to 43*1, so that p=43 and q=7, which are both primes. Hence (p-1)(q-1)=252= 2*2*3*3*7, and e=17 is relatively prime with 252. This implies that (301,17) is a valid RSA encryption key. Conversely, 89*17=6*252+1, and therefore (301,89) is a valid RSA decryption key.*

- (55,7), (55,41)

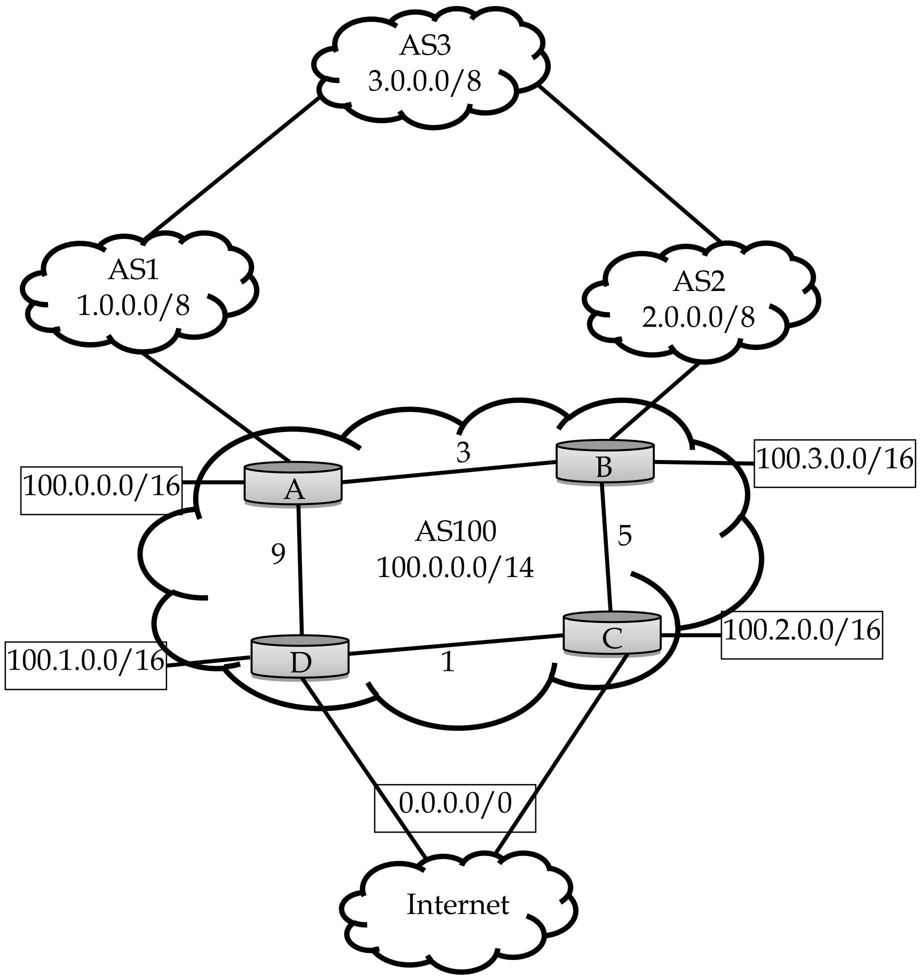
*55 is equal to 11*5, sot that p=11 and q=5, which are both primes. Hence (p-1)(q-1)=40, and e=7 is relatively prime with 40, so that (55,7) is a valid RSA encryption key. However, 41*7=287 cannot be expressed in the form k*40+1 (k=7 gives 211 and k=8 gives 361). Hence, (55,41) is not a valid RSA decryption key.*

Consider the RSA key pair (91,11), (91,59). Assume the first is the encryption key and the second is the decryption key. What is the encrypted value of the number 8?
Hint: 8^4 mod 91 =1

*Note that 91=7*13, so that (p-1)(q-1)=72=2*2*2*7, which is relatively prime with 11, so that (91,11) is a valid RSA encryption key. Conversely, 59*11=649=9*72+1, so that (91,59) is a valid decryption key.*

The encrypted value of 8 is 8^{11} mod 91 = (8^4 mod 91)(8^4 mod 91)*(8^3 mod 91)=57.*

9) Consider the network shown below. AS100 uses OSPF as its internal routing protocol, and BGP to exchange routes with neighboring ASes. AS100 assigns a LOCAL_PREF value of 100 to all routes learned by routers C and D over their eBGP connection to the "Internet", a LOCAL_PREF value of 50 to routes learned by router B over its eBGP connection with AS2, and a LOCAL_PREF value of 10 to routes learned by router A over its eBGP connection with AS1. The four routers in AS100, A, B, C, and D, are connected by a full iBGP mesh.



a) Specify the routing table at router A, and for each entry identify the next hop(s) in the form of either a local connection, or connections to internal routers, or a neighboring AS.

The routing table at A is of the form

0.0.0.0/0: Next hop of B (lowest internal cost of 8 to the Internet)
100.0.0.0/16: Local
100.1.0.0/16: Next hops of B and D (equal cost of 9)
100.2.0.0/16: Next hop of B
100.3.0.0/16: Next hop of B
1.0.0.0/8: Next hop of B (highest LOCAL_PREF)
2.0.0.0/8: Next hop of B (highest LOCAL_PREF)
3.0.0.0/8: Next hop of B (highest LOCAL_PREF)

b) Assume that AS100 wants to ensure that all traffic coming from the "Internet" enters through router D when destined for subnets 100.0.0.0/16 and 100.1.0.0/16, and conversely through router C and when destined for subnets 100.2.0.0/16 and 100.3.0.0/16. Similarly, it wants that all traffic coming from ASes 1, 2, and 3 to enter through router A when destined for subnets 100.0.0.0/16 and 100.1.0.0/16, and conversely through router B and when destined for subnets 100.2.0.0/16 and 100.3.0.0/16. Identify a mechanism that would **guarantee** that this happens, while ensuring that AS100 maintains bidirectional Internet connectivity even if one of its two connections to the Internet or to ASes 1, 2, and 3 breaks.

The only option that will guarantee the desired outcome is to advertise 100.0.0.0/14 on all eBGP connections, and the more specific subnets 100.0.0.0/16 and 100.1.0.0/16 on the eBGP connections from D to the Internet and from A to AS1, and the more specific subnets 100.2.0.0/16 and 100.3.0.0/16 on the eBGP connections from C to the Internet and from B to AS2

c) Assume that AS100 is willing to allow traffic from AS2 and AS3 to transit through it to reach the Internet. How could AS100 try to realize this, and would it **guarantee** that its actions have the exact desired outcome. Justify your answer.

AS100 would advertise a default route to AS2. This would guarantee that all Internet traffic originating from AS2 knows that it can transit through AS100.

However, this does not ensure that AS3 is also able to do so, and neither does it guarantee that AS1 cannot transit its Internet traffic through AS100. Specifically, enabling AS3 to send its Internet traffic through AS100 depends on a decision that rests with AS2 and that AS100 cannot control, namely, having AS2 advertise Internet connectivity (e.g., in the form of a default route) to AS3. Conversely, if AS2 does advertise a default route to AS3, preventing AS1 from eventually sending its own Internet traffic through AS100 would require that AS3 not advertise Internet connectivity to AS3. This is again under the sole purview of AS1 and is not something that AS100 can control.