CSEE 4119 Fall 2019
Homework 5

Assigned: 2019-11-22. **Due: 11pm, 2019-12-09.** The assignment is **optional**, but no late assignments will be accepted, and no slip days may be used. If you choose to submit, your grade on this assignment will replace your grade on the earlier homework of your choice. See below for details.

Corrections: -

You are welcome to discuss your homework with other students, but each student is expected to write his or her final answer independently and in his or her own words. Students are expected to consult whatever resources are necessary to answer homework questions, including things like class papers, textbooks, other papers or RFCs, and the web. However, as above, all answers are expected to be formulated independently in your own words. If you find you must use materials from other sources, standard academic policies apply---you need to cite what material you use and clearly indicate (such as by quotes) what material was yours and what is theirs. You are welcome to use calculators to solve equations, but for full credit, your answer must include the equation you entered in the calculator.

You will submit the homework as a PDF file to the class CourseWorks under Assignments. The homework can be either typeset and converted to pdf, or it can be handwritten and scanned to pdf. For scanned or photographed handwritten homeworks, you need to make sure the images are clear enough to read and that the file is small (the final pdf shouldn't take up more than 5MB). You may find helpful tools online to compress or binarize the original images. Simple text should be sufficient for most questions and is recommended as it is generally easier to mark up and give feedback about. Please identify yourself at the top of the first page. Write your full name and your UNI. This will make it easier for the TAs to grade the homeworks and ensure that everything gets recorded properly.

Homeworks are due on the specified due date and time. Any submission past the deadline (even 1 minute late) will be subject to the late policy described in the syllabus. To avoid last-minute problems (with a scanner, network, etc), please submit your homework well in advance.

Please refer to the course information in the syllabus for further information and policies regarding late homeworks and collaboration, and the academic honesty policies. Make sure that you observe these policies.

Please make sure you label the parts of your answer 1, 2, 3a, 3b, etc. Answers that don't clearly identify what part of the question they are answering, or that are overly long, may not get full credit. If you choose to handwrite your answers, please make sure your writing is clear. Make sure any mathematical notation is clearly explained. Further, unless we derived a formula in class, for full credit you must derive it in your homework in order to use it, including explaining what each term represents and WHY your equations correctly capture the problem. For example, in class, we used an equation to get the probability of collisions under packet switching, but we only briefly discussed the derivation. If you use this equation in your homework answers, you must derive it to get full credit.

Unless otherwise specified, we use 10^3 for "K", 10^6 for "M", and so on to simplify calculations. Please do the same in your answers.

Question 0 [0 points, but required for credit]

If you wish to submit this homework for credit, the process is as follows:

- You will pick the previous homework (1, 2, 3, or 4, where 4 includes both parts) that you wish to replace with this one. For example, say you wish to replace your homework 1 score. HW1 was out of 61 points.
- We will take the % of points you get on this HW and give you that % on the homework you are choosing to replace. For example, if you receive a 90% on this homework and choose to replace HW3, then your HW3 grade would be counted as 90%*61=55.
- We will replace your previous homework score **even if you do worse on HW5 than on the one you are replacing.** So you should only submit HW5 for credit if you are confident it will increase your score.
- Remember that points within one category ARE on the same scale, so HW3 (121 points) is worth more than HW2 (107 points), which is worth more than HW1 (61 points), which is worth more than HW4 (40+9=49 points).

For question 0, please answer which homework you are replacing: HW1, HW2, HW3, or HW4 (including HW4 question 3).

1. Routing algorithms [27 points]

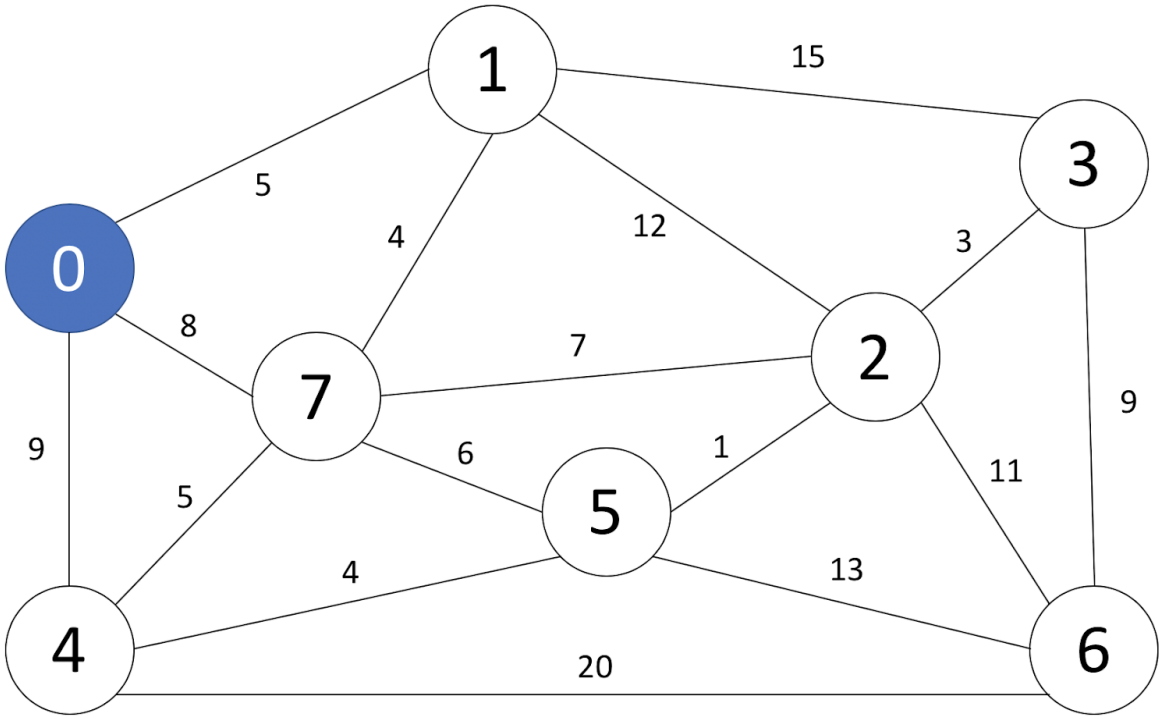

Figure 1. Network for 1.a - 1.c

a. [12 points] Find the shortest paths from source node 0 to all other nodes in the network shown in Figure 1 by applying the link-state (LS) routing algorithm. The LS algorithm we use here is the well-known Dijkstra's algorithm. The number near each edge is its cost. Complete the table below.

step	N'	D(1), p(1)	D(2), p(2)	D(3), p(3)	D(4), p(4)	D(5), p(5)	D(6), p(6)	D(7), p(7)
0	0	5, 0	∞	∞	9, 0	∞	∞	8, 0
1								
2								
3								
4								
5								

6								
7								

D(i): cost of the least-cost path from the source node to destination i as of this iteration of the algorithm.
p(i): previous node (neighbor of i) along the current least-cost path from the source to i.
N′: subset of nodes; i is in N′ if the least-cost path from the source to i is definitively known.

Answer:

step	N'	D(1), p(1)	D(2), p(2)	D(3), p(3)	D(4), p(4)	D(5), p(5)	D(6), p(6)	D(7), p(7)
0	0	5, 0	∞	∞	9, 0	∞	∞	8, 0
1	0, 1		17, 1	20, 1	9, 0	∞	∞	8, 0
2	0, 1, 7		15, 7	20, 1	9, 0	14, 7	∞	
3	0, 1, 7, 4		15, 7	20, 1		13, 4	29, 4	
4	0,1,7,4,5		14, 5	20, 1			26, 5	
5	0,1,7,4,5 ,2			17, 2			25, 2	
6	0,1,7,4,5 ,2, 3						25, 2	
7	0,1,7,4,5 ,2, 3, 6							

+0.2 for each correct box (total 7 * 8 boxes * 0.2 = 11.2 pts)
+0.8 if student got all boxes right
+0.1 for each wrong box due to error in a previous box but tried to follow Dijkstra's algorithm

b. [2 points] What is the shortest path from node 0 to node 6 according to your table in a?
Answer:
p(6) = 2, p(2) = 5, p(5) = 4, p(4) = 0.
So the path is 0 -> 4 -> 5 -> 2 -> 6.

+1 if student tried to trace back using p(i), but got wrong path
+2 for the correct path

c. [Not graded] Write a program to implement Dijkstra's algorithm and verify your answer for question a and b·.
Answer:
One approach:

First build a class to represent the graph of the network, then write a method that implements Dijkstra's algorithm.
There are many good resources online, e.g.
https://www.geeksforgeeks.org/dijkstras-shortest-path-algorithm-greedy-algo-7/

This question is not graded

d. [13 points] Consider the network shown in Figure 2, now we use Distance-Vector algorithm to figure out the path. At the beginning, the distance of vector of node z is [5, 12, 0, ∞ , ∞](the order is [$d_z(x)$, $d_z(y)$, $d_z(z)$, $d_z(u)$, $d_z(v)$]). Please show how d_z , the distance vector of node z changes in each iteration. Please show your work.
You should write down the final answer in the form of [$d_z(x)$, $d_z(y)$, $d_z(z)$, $d_z(u)$, $d_z(v)$].
For example [5, 12, 0, ∞ , ∞] -> [?, ?, ?, ?,], and also show your work by form. For example:

	x	y	z	u	v
z	5	12	0	∞	∞
x					
y					

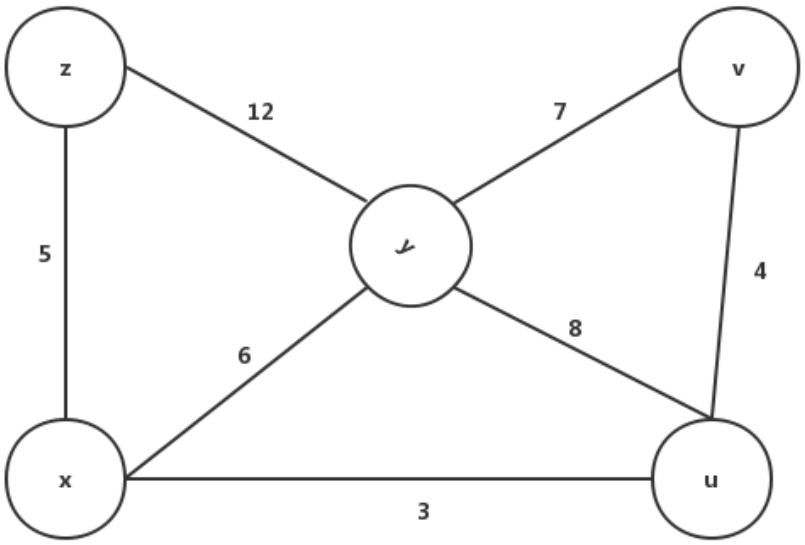

Figure 2. Network for 1.d

At the beginning:

	x	y	z	u	v
z	5	12	0	∞	∞
x	∞	∞	∞	∞	∞
y	∞	∞	∞	∞	∞

x, y tell z their distance vectors

	x	y	z	u	v
z	5	11(update)	0	8(update)	19(update)
x	0	6	5	3	∞
y	6	0	12	8	7

y, z also updates, and tell x their new distance vectors

	x	y	z	u	v
z	5	11	0	8	12(update)
x	0	6	5	3	7
y	6	0	11	8	7

Final answer: [5, 12, 0, ∞, ∞] -> [5, 11, 0, 8, 19] -> [5, 11, 0, 8, 12]

+0.1 for each correct form entry (total 3*15*0.1=4.5) (+0.05 if current calculation is correct but based on previous wrong form entry),
+0.5 to round to whole number
+4 points if [5, 11, 0, 8, 19] is correct
+4 points if [5, 11, 0, 8, 12] is correct

2. OSPF and BGP [12 points]

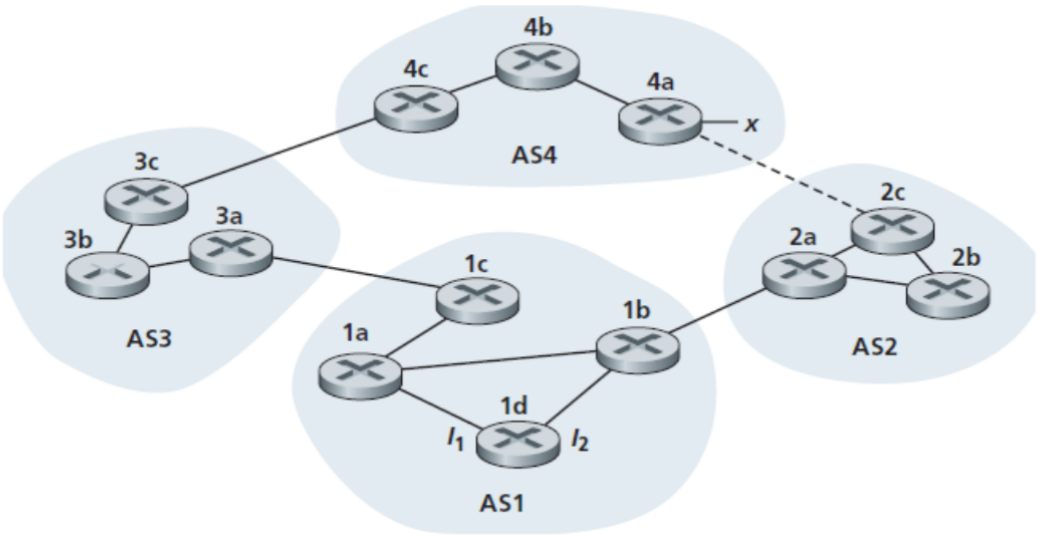

Figure 3. Network for 2

Consider the network in Figure 3. Suppose all AS's are running OSPF for their intra-AS routing, and eBGP and iBGP are used for inter-AS routing. Initially suppose there is no physical link between AS2 and AS4. Once router 1d learns about x it will put an entry (x,I) in its forwarding table. Assume that each link has the same weight.

a. [2 points] Router 1d learns about x from which routing protocol?
   iBGP
b. [2 points] Will *I* be equal to I_1 or I_2 for this entry? Why?
   I_1
   I equals to I1 because there is no link between AS2 and AS4 so that data should be forwarded from 1d to 1c and the least cost path is the path via 1a.
c. [2 points] Now assume there is a physical link between AS2 and AS4 as shown by the dotted line. Router 1d learns that x is accessible both via AS3 and AS2. Will *I* be equal to I_1 or I_2 for this entry if AS1 assigns a higher local preference to routes learned from AS3 than to routes learned from AS2? Why?
   I_1
   Local preference has the highest priority when determining path and because of that in this case the path through AS3 will be prefered.
d. [2 points] Would the answer for the previous question change if the local preference for AS2 and AS3 were the same?
   Yes, in this case I will be set to I_2 because the AS-PATH length is equal and it should consider the the closest NEXT-HOP router which is 1b.

e. [2 points] Now assume there is another AS, called AS5, which lies between AS2 and AS4. Will *I* be equal to I_1 or I_2 for this entry? Why?

I_1

I will be set to I_1 as this path has a shorter AS-PATH length

f. [2 points] We refer to a protocol like OSPF, which is used to exchange routing information for destinations within a single AS, as an Interior Gateway Protocol (IGP). What is one reason an AS commonly needs to use iBGP over an IGP, instead of using iBGP as an IGP?

+2 for mentioning ANY one of the following reasons,

- iBGP can't solve IP/router-level **loops** whereas IGPs like OSPF can.
- iBGP doesn't support **metrics** but IGPs like OSPF can.
- iBGP can't tell you how to get to **next hop** but IGPs like OSPF can. iBGP assumes the route already can reach the nexthop, whereas OSPF builds up that state.

3. BGP routing policy [24 points]

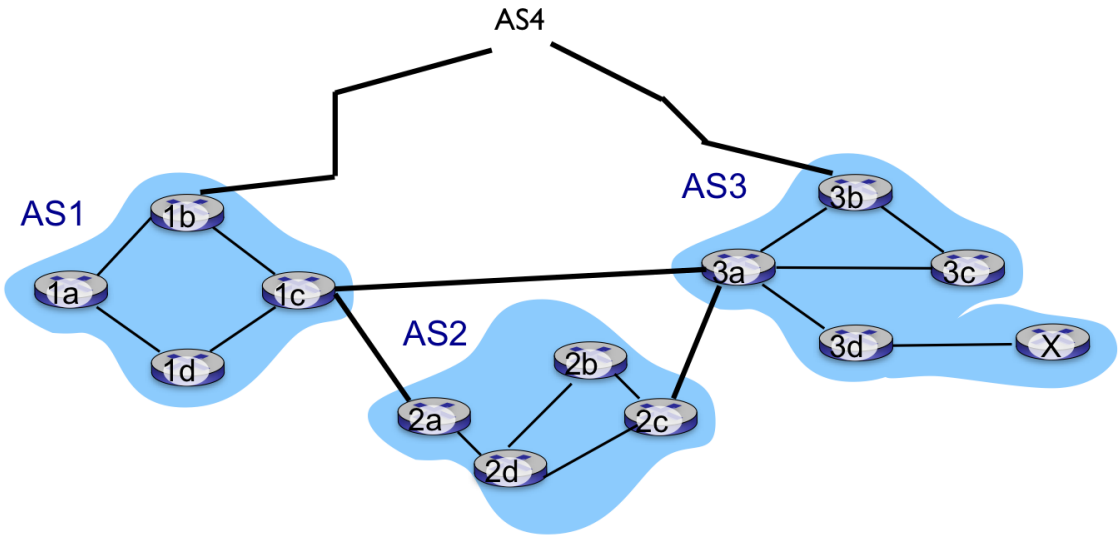

Figure 4. Network topology for 3

Consider the network topology shown in Figure 4. AS2 is a customer AS and it pays two providers, AS1 and AS3, to provide it connectivity to the Internet. AS4 is a provider to both AS1 and AS3, and AS1 and AS3 are peers (meaning neither pays the other for connectivity, and they will only exchange traffic and routes if both make money on it from some other AS). AS2 learns two routes to AS4, one from AS1 (via router 1c) and one from AS3 (from router 3a).

a. [2 points] Will AS4 be willing to carry traffic from AS1 destined to AS3? Why or why not?

Yes--both will pay it.

+1 Yes.

+1 both will pay it or other reasonable explanations.

b. [2 points] Will AS1 be willing to carry traffic from AS3 destined to AS4? Why or why not?

No--neither will pay it.

+1 No.

+1 neither will pay it or other reasonable explanations.

c. [2 points] Will AS2 be willing to carry traffic from AS1 destined to AS3? Why or why not?

No--neither will pay it.

+1 No.

+1 neither will pay it or other reasonable explanations.

d. [2 points] Will AS1 be willing to carry traffic from AS2 destined to AS3? Why or why not?

Yes--AS2 will pay it.

+1 Yes.

+1 AS2 will pay it or other reasonable explanation.

e. [4 points] Suppose AS2 prefers to route all traffic destined to AS4 via AS1 if a route via AS1 exists, and only use AS3 as a backup. What BGP configuration is needed to achieve this goal? Be specific about how BGP should be configured in each relevant router, referring to the routers by name as needed.

AS2 should configure its routers to assign higher local pref to routes from AS1 than routes from AS3.

+2 mention assign local pref

+2 mention AS1's local pref is higher than AS4

f. [4 points] Suppose AS2 does not want to use AS3 to reach AS4 under any circumstances. What BGP configuration is needed to achieve this goal? Be specific about how BGP should be configured in each relevant router, referring to the routers by name as needed.

AS2 should configure 2c to drop the route on import.

+2 mention drop the route

+1 mention 2c

+1 mention import

g. [4 points] Suppose AS2 wants its traffic to AS4 to exit its network as quickly as possible (for example, router 2b is closer to 2c than it is to 2a, so traffic from 2b should use AS3). What BGP configuration is needed to achieve this goal? Be specific about how BGP should be configured in each relevant router, referring to the routers by name as needed.

AS2 should configure the routes to have the same local pref and configure its IGP costs to correspond to distance, then use hot potato routing.

+2 mention set the same local pref

+2 mention configure IGP costs according to distance or other methods which uses shortest path for routing

h. (4 points) Suppose AS4 prefers to receive traffic via AS1 rather than AS3, in cases in which the sender does not have a strong preference. What BGP configuration is needed to achieve this goal? Be specific about how BGP should be configured in each relevant router, referring to the routers by name as needed.

AS4 should “prepend” its announcements to AS3, setting the AS path to have multiple instances of AS4. This will cause that route to be longer than the one via AS1, and so it will lose out on decisions based on AS path length.
+2 mention setting AS path to have multiple instances of AS4
+2 mention make the route via AS3 longer than the one via AS1

Partial credit: AS4 signals it via communities (1/4 if only mentions AS4, 3/4 if also mentions that AS4 will have to coordinate with other ASes to have them interpret and honor the community). This is similar to the customer/provider communities example from Project 2. However, it would be very unlikely to work Internet-wide: first, many ASes will strip communities on transit, so it is hard to use them to signal ASes beyond your immediate neighbors; second, it would be hard to coordinate to have lots of ASes interpret the community as AS4 intends and act on it.

4. Multiple access [20 points]

a. [5 points] Consider the **slotted** ALOHA protocol with N stations (N is a positive integer). What is the optimal transmission probability p* that maximizes the efficiency in terms of N?

$efficiency = Np(1-p)^{N-1}$

Maximum efficiency is achieved when derivative of efficiency in p is 0.

$\mathrm{d}\, efficiency / \mathrm{d}\, p = N(1-p)^{N-1} - Np(N-1)(1-p)^{N-2}$

$N(1-p^*)^{N-2}[(1-p^*) - p^*(N-1)] = 0$

Apparently $p^* = 1$ is not a reasonable solution.

$(1-p^*) - p^*(N-1) = 0$

$p^* = 1/N$

b. [5 points] Consider the **unslotted** ALOHA protocol with N stations (N is a positive integer). What is the optimal transmission probability p* that maximizes the efficiency in terms of N?

$efficiency = Np(1-p)^{2(N-1)}$

Maximum efficiency is achieved when derivative of efficiency in p is 0.

$\mathrm{d}\, efficiency / \mathrm{d}\, p = N(1-p)^{2N-2} - Np \times 2(N-1)(1-p)^{2N-3}$

$N(1-p^*)^{2N-3}[(1-p^*) - p^*(2N-2)] = 0$

$(1-p^*) - p^*(2N-2) = 0$

$p^* = 1/(2N-1)$

c. [2 points] Explain why slotted ALOHA achieves a higher maximum efficiency than unslotted ALOHA.

In slotted ALOHA a station only conflicts with other stations when they attempt to send at the same time slot (one unit of transmission time), while in unslotted ALOHA, it conflicts with all stations that attempt to send between t0-1 and t0+1.

d. [2 points] Explain why ALOHA (both slotted and unslotted) is not completely distributed.
Clarification posted on Piazza: This question can be rephrased as follows: If we want to achieve the maximum efficiency, what is the problem that arises if Aloha is run without any coordination/configuration, but could be addressed with coordination/configuration?
Each station has to know the total number of stations N in the network.

e. [6 points] Suppose there are three stations that have message(s) to send (i.e. the other N-3 stations generate no traffic). Consider the following questions:
i). If there are only three stations in total (N=3), and the three stations always have something to send at their turn, which protocol among (TDMA, CSMA, Slotted Aloha, Token passing) should be used in order to get no worse utilization than the other three? Why? (consider the maximum utilization a protocol can get)
TDMA/Token passing. [+1] When N=3 and the three stations always have something to send at their turn, the utilization for TDMA can be 1 in this scenario. [+1]
Also, in this case, since the three stations always have something to send, there maybe many collisions, so slotted ALOHA will not get max utilization due to the wasting slots and idle slots, and CSMA will not get max utilization since it doesn't have collision detection.
ii). If the traffic is very heavy in this network, if CSMA is used, how long is the worst case time for a station has to wait before it can send its next message?
Infinite. [+1] There is no maximum length of time for which the channel can be detected to be busy.[+1]
iii). When N is relatively big, and the traffic is heavy, which protocol among (TDMA, CSMA, Slotted Aloha, Token passing)should be used in order to get no worse utilization than the other three? Why? (consider the maximum utilization a protocol can get, and only need to consider the cost of passing the token for token passing)
Token passing.[+1] When N relative big, TDMA's utilization will be lower. The traffic is heavy, since CSMA doesn't have collision detection and Slotted Aloha may have a high possibility of collision, the utilization of them could be relatively low. [+1]

5. ARP and Ethernet [30 points]

1) [6 points] Some warmup T/Fs. For each question, indicate True or False for each index. *Example answer: d) i) True, ii) True, iii) False, iv) False.*
    a) [2 points] ARP requests propagate through:
        i) Switches True
        ii) Links True
        iii) Wireless links True
        iv) Routers False

b) [2 points] For a switch which has N interfaces, an ethernet frame coming through an interface will be forwarded through:
   i) 1 interface False
   ii) N-1 interfaces False
   iii) N interfaces False
   iv) This is a trick question: it all depends on the state of the forwarding table. True

c) [2 points] ARP tables contain the following key,value pairs:
   i) IP address, DNS name False
   ii) IP address, forwarding interface False
   iii) MAC address, forwarding interface False
   iv) MAC address, IP address True

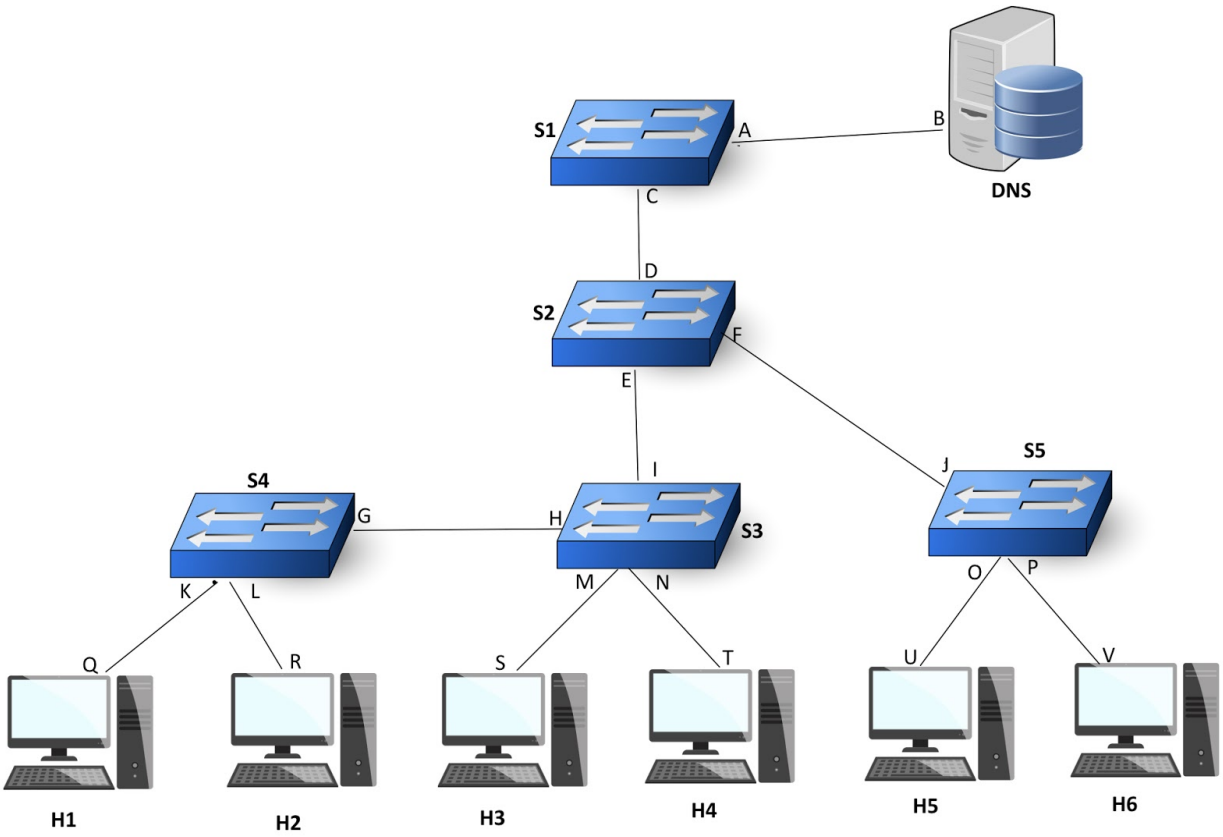

Figure 5. Subnet topology for 4.2

2) [24 points] Consider the subnet topology in Figure 5. All forwarding tables of the switches (S1, S2, S3, S4, S5) start empty. Letters denote interfaces (e.g. switch S4 has interfaces K,L and G). DNS is the local DNS server. Host H3 sends an ethernet frame df1 to host H6. Then, as a response, host H6 sends an ethernet frame df2 to host H3. df1 has source MAC address s and destination MAC address v. df2 has source MAC address v and destination MAC address s.

a) [8 points] Describe all traffic generated in the network between the moment frame df1 is sent by host H3 and the moment it is received by host H6: which device(s) send or receive which frame(s)?

H3 sends df1 to S3.

S3 doesn't have an entry in the forwarding table. Thus, it forwards df1 to H4, S4 and S2. H4 ignores it. S4 doesn't have an entry in the forwarding table. Thus it forwards df1 to H1 and H2, which all ignore it.

S2 doesn't have an entry in the forwarding table. Thus it forwards df1 to S1 and S5. S1 doesn't have an entry in the forwarding table. Thus it forwards it to DNS.

S5 doesn't have an entry in the forwarding table. Thus it forwards df1 to H5 and H6. H5 ignores it. H6 receives df1.

b) [8 points] Describe all traffic generated in the network between the moment frame df2 is sent by host H6 and the moment it is received by host H3: which device(s) send or receive which frame(s)?

(The forwarding tables are not empty anymore!)

Host H6 forwards df2 to S5.

S5 has an entry in the forwarding table. Thus it forwards df2 to S2.

S2 has an entry in the forwarding table. Thus it forwards df2 to S3.

S3 has an entry in the forwarding table. Thus it forwards df2 to H3. H3 receives df2.

c) [4 points] Assume that the aforementioned traffic is completed (i.e. df1 is delivered, and so is df2). Now, fill the forwarding tables of the switches given below:

Forwarding table of S2

MAC address	forwarding interface
S	E
V	F

Forwarding table of S4

MAC address	forwarding interface

S	G

A common mistake will be having an entry for V in the forwarding table of S4, i.e. <V,G>. That entry should not appear because S3 won't propagate df2!

d) [4 points] Host H3 now wants to connect to *courseworks2.columbia.edu* to check for his HW5 grade. Say *courseworks2.columbia.edu/H3gradeHW5.png* contains H3's grade. A classmate, H4, wants to play a bad joke on H3 by tricking him into getting a fake version of *H3gradeHW5.png* which contains a bad grade. Give an ARP-related attack that H4 can perform to achieve this.
Assume that all hosts have just been initially configured (i.e. each host has only i) its own IP, ii) the gateway router's IP, iii) the local DNS server's IP). Assume also that all caches are empty.
Answer: To access the URL is to send a DNS request to the DNS server. Given that we are at the initial setup phase, H3 doesn't know the MAC address of the DNS server and therefore has to make an ARP request. H4 can send ARP replies as soon as it sees the ARP request (which, remember, switch S3 broadcasts to S2, S4 and H4), effectively impersonating the DNS server. The rest is history…

Other answers that will get full credits are: 1) assuming that the URL resolves to an IP inside the Local Area Network, H4 can spoof the web host by flooding ARP responses when H3 does an ARP request to resolve the web host's MAC. 2) Similar logic but assuming that the URL resolves to an IP outside the Local Area Network, H4 can spoof the gateway router...