Networked Systems
ETH Zürich — seit 2015

Communication Networks

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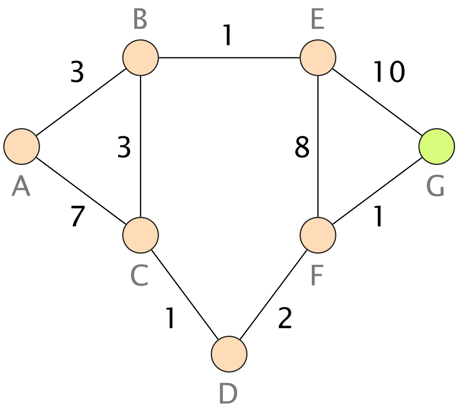
Solution: Exercise 3 – Routing Concepts, Ethernet & Switching

Routing Concepts

3.1 Distance Vector



Weighted graph representing a network topology.

#	A	B	C	D	E	F	G
0	∅	∅	∅	∅	∅	∅	0
1	∅	∅	∅	∅	10	1	0
2	∅	11	∅	3	9	1	0
3	14	10	4	3	9	1	0
4	11	7	4	3	9	1	0
5	10	7	4	3	8	1	0
6							

The figure on the left shows a weighted graph representing a network topology with 7 nodes. The nodes in the network use a distance vector algorithm to compute the shortest-paths in a distributed way. It takes one time step for a distance vector message to be sent from one node to another on a link. A node can send the distance vector message on multiple links at the same time.

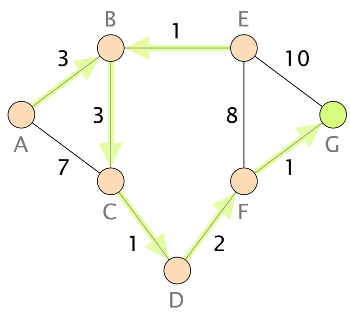
In case paths have the same weight, the node picks the path traversing the smaller number of links. In case there is still a tie, the node picks the path of the neighbor with the lower identifier (alphabetical order).

a) Compute the paths from any node in the network to G. Use the provided table to fill in the state of each node at every time step. Stop when a stable state is reached. The first time step is provided as an example.

Solution: cf. table on the left

b) Highlight the actual paths taken in the graph.

Solution:



c) The network operator realizes that there is a potential bottleneck as all traffic is crossing the following links: C-D, D-F, and F-G. She prefers to balance the traffic across the available links in the network. Therefore, she would like to have all traffic from the nodes A, B, E to go across the link E-G and the traffic of the remaining nodes to go across F-G.

(i) If she can only change the weight of the link E-G, what should she change it to?

Solution: Any value in the range from 1 to 6.

(ii) If she cannot change the weight of the link E-G, what should she change instead? Propose a change that requires to change the weights of as few links as possible.

Solution: She could set the weight of F-G to a value in the range from 5 to 10.

3.2 Reverse Dijkstra (Exam Question 2020)

The network engineer at your company just retired and you have to take over. Unfortunately, it is unclear how the current network looks like. All you know is that it consists of 10 nodes (see below). In addition, you know that there is at most one link between two nodes and that each link has a non-negative weight. However, you neither know which links exist nor the weights configured on these links.

a) To figure out the links and the corresponding weights, you look at an output of Dijkstra's algorithm performed from node **U**. The table below shows the entire output of the algorithm. For each iteration, the table indicates the shortest path found so far towards each other node (starting from node **U**). The algorithm follows the one discussed in the lecture. If after one iteration there are multiple nodes with an equally-shortest path, the algorithm continues with the node which comes first in the alphabet.

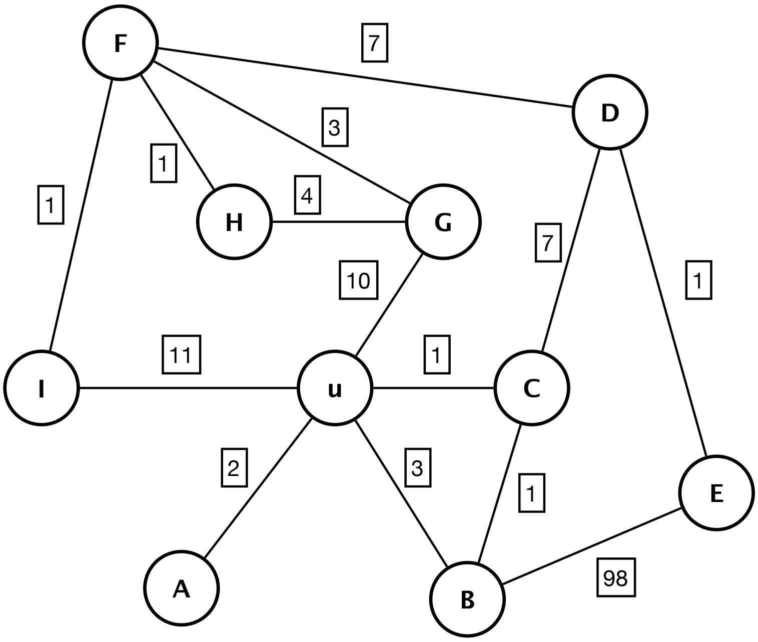
Add all the links with their corresponding weight that you can identify based on the output from Dijkstra's algorithm.

A network consisting of 10 nodes with unknown links and link weights.

#	**U**	A	B	C	D	E	F	G	H	I
1	0	2	3	1	-	-	-	10	-	11
2	0	2	2	1	8	-	-	10	-	11
3	0	2	2	1	8	-	-	10	-	11
4	0	2	2	1	8	100	-	10	-	11
5	0	2	2	1	8	9	15	10	-	11
6	0	2	2	1	8	9	15	10	-	11
7	0	2	2	1	8	9	13	10	14	11
8	0	2	2	1	8	9	12	10	14	11
9	0	2	2	1	8	9	12	10	13	11
10	0	2	2	1	8	9	12	10	13	11

For each iteration (1 to 10) the table shows the shortest path found by Dijkstra's algorithm performed on node **U** towards all other nodes.

Solution: The figure shows the found links and weights.



b) After analyzing the output from Dijkstra's algorithm, you are unsure if you really found all links in the network.

Could there be an additional link starting from node **U** which you could not identify based on the output from Dijkstra? If you think that is possible, give an example (link between node **U** and node ...) and indicate in which range the weight of this link could be. Otherwise, explain why this is not possible.

Solution: Not possible. Given that we perform Dijkstra's algorithm starting from node **U** (and there is only a single link between each pair of nodes) we see all possible links in the first iteration as Dijkstra adds all adjacent nodes during its initialization.

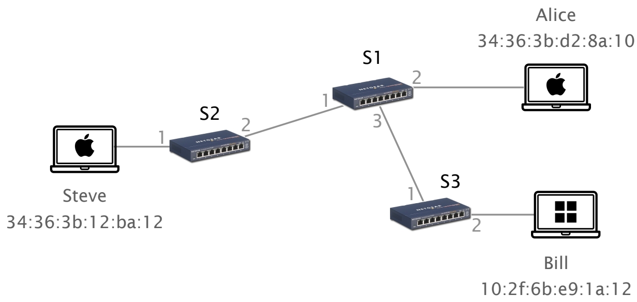
c) Could there be an additional link starting from node C which you could not identify based on the output from Dijkstra? If you think that is possible, give an example (link between node C and node ...) and indicate in which range the weight of this link could be. Otherwise, explain why this is not possible.

Solution: Possible. For example link between C and G with weight greater (or equal) than 9.

Ethernet & Switching

3.3 Apple vs. Microsoft

Consider three hosts Steve, Alice, and Bill connected through the network below composed of 3 Layer 2 (Ethernet) switches. Assume that (i) all hosts know the MAC addresses of each other and (ii) the currently learned forwarding tables of all switches (i.e., S1, S2, and S3) are as listed below.



Solution:

S1 MAC-Table	
MAC address	port
a) 34:36:3b:12:ba:12	1
b) 10:2f:6b:e9:1a:12	3

S2 MAC-Table	
MAC address	port
34:36:3b:12:ba:12	1
b) 10:2f:6b:e9:1a:12	2

S3 MAC-Table	
MAC address	port
a) 34:36:3b:12:ba:12	1
b) 10:2f:6b:e9:1a:12	2

As Steve works in Apple's customer satisfaction department, he sends an Ethernet frame with the message "Are you satisfied with your Apple device?" to Alice.

a) Complete the MAC-tables with the learned information.

Solution: cf. tables above

b) Which hosts received Steve's frame?

Solution: S1 sends the frame to all ports except the incoming one because there is no entry for Alice in the MAC-table yet. Hence, Alice and Bill receive the frame. S1 would learn Alice's port as soon as she sends a frame.

Conversely, Bill works in Microsoft's sales department. To convice Alice to buy a Microsoft device, he sends her a frame with the message "Use the code BILL to get 20% off all Microsoft devices".

c) Complete the MAC-tables with the learned information.

Solution: cf. tables above

d) Which hosts received Bills's frame?

Solution: S1 *still* does not know which port Alice can be reached on, as she has not yet sent a frame. Hence, S1 sends the frame to all ports except the incoming one, so that Alice and Steve receive the frame.

Steve thinks about asking all Apple device owners on the LAN what Apple can improve.

e) Assuming that Apple holds 1474 MAC address prefixes, how many frames does Steve need to send to reach all Apple devices?

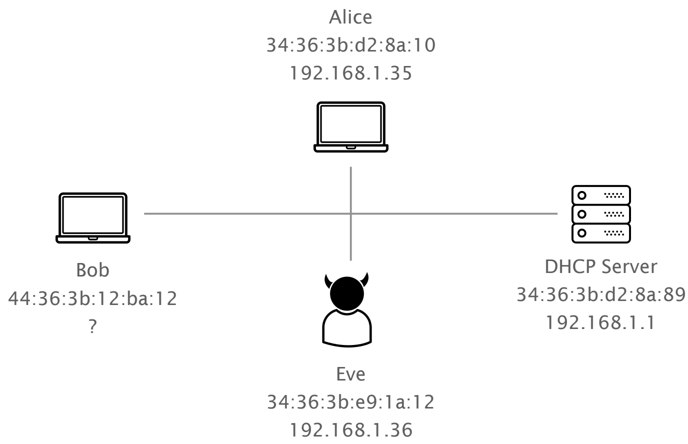
Solution: A MAC address consists of two parts. The first 24 bits (e.g. 001101000011011000111011 or 34:36:3b) are assigned to a vendor by the IEEE, while the last 24 bits (e.g. 000100101011101000010010 or 12:ba:12) are assigned by the vendor. Hence, Steve needs to send $1474 * 2^{24} = 24'729'616'384$ frames.

f) Could Steve specifically target all MacBook Pro's with M2 chips?

Solution: No, the vendor's MAC address prefix does not reveal specific information on a device's type.

3.4 Impostor

The three hosts Bob, Alice and Eve are all connected to the same network, which has a DHCP server.



Bob just connected to the network and wants to send important IP packets to Alice. Bob only knows the IP address of Alice (`192.168.1.35`) and his laptop is not yet configured with an IP address.

a) Explain all the steps that are necessary such that Bob's computer can finally send packets to Alice.

Solution: cf. table below

Please note that the lecture slides introduce a simplified version of the DHCP protocol which only shows the first two steps (discovery and offer). This is enough to solve the question, i.e., afterwards Bob is able to communicate with Alice as he knows which IP to use. However, in reality we also have a request and ack step which are also shown in the table below. This way Bob tells the DHCP server that he accepts the IP address and the server sends an acknowledgement back. It now also knows that the given IP is currently used.

You might wonder why Bob uses the broadcast address as DST MAC in the DHCP request step instead of the MAC address which belongs to the DHCP server (known from the previous DHCP offer step). In larger networks, you often have multiple DHCP servers, e.g., for redundancy. After the discovery message each of the DHCP servers will send an offer to Bob. Afterwards Bob selects one offer and sends the corresponding DHCP request. By broadcasting this message, all DHCP servers in the network will know if their offer was either picked (in this case they will send a DHCP ack back) or not picked, in which case they can use the offered IP address again for the next discovery message they get (they will not send an ack back).

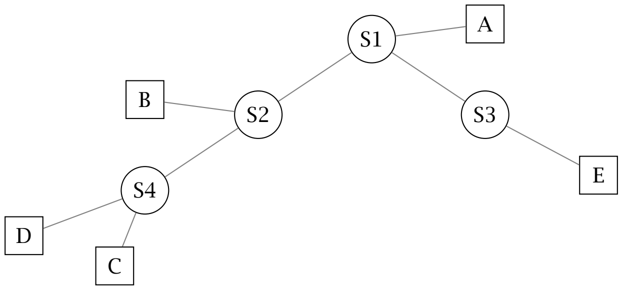
SRC MAC address	DST MAC address	Message type	Message content
44:36:3b:12:ba:12	ff:ff:ff:ff:ff:ff	DHCP discovery	I need an IP address
34:36:3b:d2:8a:89	44:36:3b:12:ba:12	DHCP offer	use 192.168.1.37
44:36:3b:12:ba:12	ff:ff:ff:ff:ff:ff	DHCP request	I want the offered IP
34:36:3b:d2:8a:89	44:36:3b:12:ba:12	DHCP ack	Lease duration & configuration
44:36:3b:12:ba:12	ff:ff:ff:ff:ff:ff	ARP request	Who has 192.168.1.35 Tell 192.168.1.37
34:36:3b:d2:8a:10	44:36:3b:12:ba:12	ARP reply	192.168.1.35 is at 34:36:3b:d2:8a:10

b) Eve is very interested to find out what Bob is sending to Alice. What could she do to intercept Bob's packets?

Solution: When Bob sends the ARP request to learn the MAC address of Alice, Eve also receives it as it is destined to the MAC broadcast address (`ff:ff:ff:ff:ff:ff`). If Eve can send a fake reply to Bob before Alice does so, she can make Bob believe that her MAC address is the one of Alice. This is called ARP spoofing.

3.5 MAC-Learning (Exam question from 2021)

Consider the Local Area Network (LAN) made up of 4 Ethernet switches in the figure below. Several hosts (A, B, C, D, E) are connected to the switches. The MAC tables of all switches are still empty.



a) Host A sends a packet to host B. List below all the hosts that will receive the packet. In addition, fill in the MAC tables of all switches with the learned information.

Hosts receiving the packet:

Solution: All hosts receive the packet since the MAC tables are still empty and all the switches simply flood the packet.

S1 MAC-Table	
dst	next hop
A	connected

S2 MAC-Table	
dst	next hop
A	S1

S3 MAC-Table	
dst	next hop
A	S1

S4 MAC-Table	
dst	next hop
A	S2

b) Host C sends a packet to host A. Again, list all the hosts that receive the packet and update the MAC tables with the learned information. The entries from task a) are still available.

Hosts receiving the packet:

Solution: Only A will receive the packet as all the switches have learned through which port they can reach A.

S1 MAC-Table	
dst	next hop
A	connected
C	S2

S2 MAC-Table	
dst	next hop
A	S1
C	S4

S3 MAC-Table	
dst	next hop
A	S1

S4 MAC-Table	
dst	next hop
A	S2
C	connected

c) After some time, the switches have full MAC-tables (i.e., they have an entry for each host in the network). Host B wants to hijack all the packets destined to host A. By only sending packets, how can host B manipulate the switches in the network to receive all that traffic? How many "manipulation" packets are minimally necessary and to which addresses does host B have to send them? Explain your approach, state the required number of manipulated packets, and list the source and destination addresses of all manipulated packets.

Note: The hosts are not aware of the other hosts and do not know the network's topology.

Solution: B can send a packet destined either to the broadcast address or to almost any address in the network (not any because if the switches already learned the address, not all switches will be reached) with the source address set to the MAC address of A. The switches will update their tables and B will receive the frames for A as long as A does not send a packet. Therefore, B needs to send minimally **1** packet, which is destined either to the broadcast or to a random MAC address that is not present in the network.