Homework 3: L2 Forwarding

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Part I.

Intro
1. Symbols

- Repeater - Hub
- Bridge - Switch
- Router
- Host
2. Methodology

The solution to these exercises can be easily obtained through the following steps:

1. Determine the frames transmitted on the network, considering all the links as shared medium (e.g., shared Ethernet)

2. Starting from the first frame generated on the network:
   a) use the MAC source address to populate/update the filtering database of the first switch encountered by the frame on its journey toward the destination
   b) use the MAC destination address as a lookup key for the filtering database; if the MAC address is present, forward the frame only on the interface contained in that entry; otherwise, forward the frame on all the ports of the switch, except the port on which the frame has been received
   c) move to the next switch (or switches, e.g., in case the frame has been flooded by the previous switch) that received the current frame and repeat the process from step (a), until the current frame disappears from the network
   d) when the current frame disappeared from the network and it is no longer transmitted by any intermediate device (hub, bridge), move to the next frame in the trace and repeat the process from step (a)

Please remember also that:

1. entries in the filtering database remain till the \textit{max}\_age parameter expires, unless refreshed
2. those entries are refreshed only if another frame coming from the MAC source address under consideration is received
3. due to the topology of the network, a unicast frame may not be able to refresh the filtering databases in all the switches present in the network, while a broadcast frame does
4. broadcast frames are always issued when an ARP cache is found empty; however, beware of the different expiration times we may have in the ARP cache and in the filtering database, which may lead an entry to expire on one cache and to be still valid in the other table.
Part II.

Exercises
3. Filtering database

3.1. Exercise n. 1

Assuming the network topology depicted below, a 48-ports switch (SW-1) is connected to 47 hosts, while the last port is used to connect to the other switches of the LAN. Globally, the total number of hosts connected to the LAN is 100. Determine the number of entries we can expect in the filtering database of the switch SW-1, considering that all the hosts are reasonably active all the time and that exchange data with all the other hosts in the network.
3.2. Exercise n. 2

In a LAN, a 48-ports switch (SW-1) is connected to 47 hosts, while the remaining port (uplink) connects to another switch. Globally, the network includes 98 hosts, one router (that all the stations use to connect to the Internet) and a server that exchanges only traffic from and to the Internet and is always busy. The global topology is depicted in the picture below.

Assuming that:

- The ARP cache on all the stations (hosts, server and router) expires after 20 mins
- The aging time of the filtering database of the switches is set to the default value

Calculate the number of entries we can expect in average in the filtering database of the switch SW-1, considering:

1. a first scenario in which all the hosts are reasonably active all the time and exchange data with all the other hosts in the network;

2. a second scenario in which the hosts exchange data mostly with the Internet and/or the server S and do not exchange any data between themselves.
4. Traffic Analysis

4.1. Exercise n. 3

Referring to the network topology depicted below, answer to the following questions:

- List all the frames forwarded by the switch on the network when the user on host H1 types “ping 10.10.10.2”, assuming that the ARP caches of all the hosts and the filtering database of the switch are empty.

- List the ARP cache of all the hosts when the ping program terminates.

- Describe, for each frame, which port of the switch will be involved in receiving and/or sending the frame out.

- List the filtering database of the switch when the ping program terminates, ignoring the values associated to the ageing time.
4.2. Exercise n. 4

Referring to the network topology depicted below, answer to the following questions:

- List all the frames forwarded by the switches when host H1 types “ping 10.10.10.2”, assuming that the ARP cache of all the hosts and the filtering database of the switch are empty.

- List the ARP cache of all the hosts when the ping program terminates.

- Describe, for each frame, which port of the switch will be involved in receiving and/or sending the frame out.

- List the filtering database of the switches when the ping program terminates, ignoring the values associated to the ageing time.

![Network Topology Diagram]
4.3. Exercise n. 5

Referring to the network topology depicted below, let us suppose that while a continuous stream of ICMP packets (generated by executing the command “ping -t 10.10.10.5” on host H1) is in progress, host H5 is moved from Ethernet B to Ethernet A. Assume that the entries in the ARP caches have infinite lifetime.

- Determine if host H5 can still receive the ICMP Echo Request from host H1.
- List the entries that are present some seconds after host H5 is moved in the filtering database of the switch SW-1.
4.4. Exercise n. 6

Referring to the network topology depicted below, let us suppose that while a continuous stream of ICMP packets (generated by executing the command “ping -t 10.10.10.5” on host H3) is in progress, host H5 is moved from Ethernet B to Ethernet A. Assume that the entries in the ARP caches have infinite lifetime.

- Determine if host H5 can still receive the ICMP Echo Request from host H3.
- List the entries in the filtering database a couple of minutes after host H5 is moved and after about 10 minutes, including a possible value for the Ageing Time.
4.5. Exercise n. 7

Referring to the network topology depicted below, let us suppose that while a continuous stream of ICMP packets (generated by executing the command “ping -t 10.10.10.5” on host H3) is in progress, host H5 is moved from Ethernet B to Ethernet A. Assume that the entries in the ARP caches have a timeout of 120 seconds.

Determine if host H5 can still receive the ICMP Echo Request from host H3.

![Network Topology Diagram]

MAC: 00:00:00:11:11:11
IP: 10.10.10.1/24

MAC: 00:00:00:22:22:22
IP: 10.10.10.2/24

MAC: 00:00:00:44:44:44
IP: 10.10.10.4/24

MAC: 00:00:00:33:33:33
IP: 10.10.10.3/24

MAC: 00:00:00:55:55:55
IP: 10.10.10.5/24

MAC: 00:00:00:55:55:55
IP: 10.10.10.5/24
4.6. Exercise n. 8

Referring to the network topology depicted below, let us suppose that while a continuous stream of ICMP packets (generated by executing the command “ping -t 10.10.10.1” on host H4) is in progress, that host is moved from switch SW-2 to switch SW-1. Assume that the entries in the ARP caches have infinite lifetime.

- Determine if host H4 can still receive the ICMP Echo Reply from host H1.
- List the entries in the filtering databases 2 minutes after host H4 is moved, including a possible value for the Ageing Time.
4.7. Exercise n. 9

Referring to the network topology depicted below, let us suppose that while a continuous stream of ICMP packets (generated by executing the command “ping -t 10.10.10.4” on host H1) is in progress, the cable that connects host H4 to the network breaks just after the ARP Reply.

Describe what happens to the ICMP Echo packets sent by host H1 to host H4, assuming that the entries in the ARP caches have infinite lifetime.
4.8. Exercise n. 10

Referring to the network topology depicted below and assuming that the router and the hosts are correctly configured, answer to the following questions:

- List all the frames generated on the network when host H1 pings host H3, assuming that all the ARP caches are empty.
- List the filtering database of the switches when the ping program ends, ignoring the values associated to the ageing time.
4.9. Exercise n. 11

Referring to the network topology depicted below, answer to the following questions:

- List all the frames forwarded by the switch when the user on host H1 types “**ping 10.10.10.4**”, assuming that the ARP caches of all the hosts and the filtering database of the switch are empty.

- Describe, for each frame, which port of the switch and of the hub will be involved in receiving and/or sending the frame out.

- List the filtering database of the switch/hub when the ping program terminates, ignoring the values associated to the ageing time.
4.10. Exercise n. 12

Referring to the network topology depicted below, answer to the following questions:

- List all the frames forwarded by the switch when the user on host H1 types “ping 10.10.10.2”, assuming that the ARP caches of all the hosts and the filtering database of the switch are empty.

- Describe, for each frame, which port of the switch and of the hub will be involved in receiving and/or sending the frame out.

- List the filtering database of the switch when the ping program terminates, ignoring the values associated to the ageing time.
4.11. Exercise n. 13

Referring to the network topology depicted below, answer to the following questions:

- List all the frames forwarded by the switch when the user on host H3 types “ping 10.10.10.2”, assuming that the ARP caches of all the hosts and the filtering database of the switch are empty.

- Describe, for each frame, which port of the switch and of the hub will be involved in receiving and/or sending the frame out.

- List the filtering database of the switch when the ping program terminates, ignoring the values associated to the ageing time.
4.12. Exercise n. 14

Referring to the network topology depicted below, answer to the following questions:

- List all the frames forwarded by the switch when the user on host H3 types “ping 10.10.10.5”, assuming that the ARP caches of all the hosts and the filtering database of the switch are empty.

- Describe, for each frame, which port of the switch and of the hub will be involved in receiving and/or sending the frame out.

- List the filtering database of the switch when the ping program terminates, ignoring the values associated to the ageing time.
4.13. Exercise n. 15

Assuming the network topology depicted below (scenario 1), let us suppose that host H3 wants to capture all the traffic exchanged between hosts H1 and H2. Is it possible?

If the network topology changes in such a way that hosts H2 and H3 are connected to different switches (scenario 2), does the behavior of the network change?
5. Performance

5.1. Exercise n. 16

In a network where clients exchange traffic mainly with the departmental server S, a 48-ports hub operating at 10Mbps is replaced by an equivalent switch, operating at the same speed.

Determine if the network clients experience a better service after the upgrade.
5.2. Exercise n. 17

A small network is made up of a 48-switch whose ports operate at 100Mbps. This network includes 47 clients and one server; clients generate a continuous stream of UDP traffic to the server, and the server re-sends each received packets back to the sender using the same protocol.

Determine:

- The aggregate bandwidth of the switch, both in case ports are operating in Half-Duplex and Full-Duplex mode
- The total amount of traffic forwarded by the switch, both in case ports are operating in Half-Duplex and Full-Duplex mode
Part III.

Solutions
6. Filtering database

6.1. Solution for exercise n. 1

The filtering database keeps track of all the MAC addresses present in the LAN, independently from the position of the hosts, provided that the hosts are reasonably active (i.e. that they are able to refresh the entries in the database, which is one of the assumptions in the text).

Therefore we expect the filtering database of Switch SW-1 to contain 100 entries: 47 entries point to stations connected to its ports, while the remaining 53 entries will be associated to port Fe47, i.e., the uplink toward SW-2.
7. Traffic Analysis

7.1. Solution for exercise n. 3

7.1.1. Frames generated on the network

The frames generated on the network are the following:

<table>
<thead>
<tr>
<th>N.</th>
<th>L2</th>
<th>L3</th>
<th>Appl-layer protocol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00:00:00:11:11:11 →</td>
<td>FF:FF:FF:FF:FF:FF</td>
<td>—</td>
<td>ARP Request. Who has IP=10.10.10.2 please reply with its MAC address</td>
</tr>
<tr>
<td></td>
<td>FF:FF:FF:FF:FF:FF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>00:00:00:22:22:22 →</td>
<td>00:00:00:11:11:11</td>
<td>—</td>
<td>ARP Reply. Host 10.10.10.2 has MAC = 00:00:00:22:22:22</td>
</tr>
<tr>
<td></td>
<td>00:00:00:11:11:11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>00:00:00:11:11:11 →</td>
<td>10.10.10.1 → 10.10.10.2</td>
<td>ICMP</td>
<td>ICMP Echo Request</td>
</tr>
<tr>
<td></td>
<td>00:00:00:22:22:22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>00:00:00:22:22:22 →</td>
<td>10.10.10.2 → 10.10.10.1</td>
<td>ICMP</td>
<td>ICMP Echo Reply</td>
</tr>
<tr>
<td></td>
<td>00:00:00:11:11:11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td></td>
<td></td>
<td></td>
<td>Packets 3 and 4 are replicated 3 times</td>
</tr>
</tbody>
</table>

7.1.2. ARP cache of the all hosts

Assuming that the operating system adds an entry in its ARP cache only if it takes an active part in the transaction (i.e., the host that requires the ARP resolution and the requested host), the ARP caches of the hosts will be the following:

**Host H1**

<table>
<thead>
<tr>
<th>IP address</th>
<th>MAC address</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.10.10.2</td>
<td>00:00:00:22:22</td>
</tr>
</tbody>
</table>

**Host H2**

<table>
<thead>
<tr>
<th>IP address</th>
<th>MAC address</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.10.10.1</td>
<td>00:00:00:11:11</td>
</tr>
</tbody>
</table>
Host H3, Host H4

<table>
<thead>
<tr>
<th>IP address</th>
<th>MAC address</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 7.1.3. Ports of the switch involved in receiving/transmitting frames

The ports of the switch involved in receiving/transmitting frames are the following:

<table>
<thead>
<tr>
<th>Frame#</th>
<th>Description</th>
<th>Fe0</th>
<th>Fe1</th>
<th>Fe2</th>
<th>Fe3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ARP Request</td>
<td>IN</td>
<td>OUT</td>
<td>OUT</td>
<td>OUT</td>
</tr>
<tr>
<td>2</td>
<td>ARP Reply</td>
<td>OUT</td>
<td>IN</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>ICMP Echo Request</td>
<td>IN</td>
<td>OUT</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>ICMP Echo Reply</td>
<td>OUT</td>
<td>IN</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 7.1.4. Filtering database of the switch

The filtering database of the switch is the following:

<table>
<thead>
<tr>
<th>MAC address</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00:00:11:11:11</td>
<td>Fe0</td>
</tr>
<tr>
<td>00:00:00:22:22:22</td>
<td>Fe1</td>
</tr>
</tbody>
</table>
7.2. Solution for exercise n. 6

7.2.1. Possibility to continue the PING

Host H5 can no longer receive the ICMP Echo Request sent by host H3 because, after its relocation, the corresponding entry in the filtering database of the switch SW-1 is wrong (in fact, it associates the MAC 00:00:00:55:55:55 to port Fe2).

Therefore, any frame directed to host H5 will be forwarded on the port Fe2 by the switch and will never reach host H5, which then will not reply to the ICMP Echo Request.

This misbehavior will be recovered when the aging time of the above entry in the filtering database will expire, i.e. after 300 seconds. At that time, the switch SW-1 will no longer know the exact position of the host H5 and will forward the ICMP Echo Request frame on all its ports, and hence the frame will reach host H5 as well.

Therefore, after a blackout of approximately 300 seconds in which host H5 appears unreachable, ICMP Echo Reply frames will be delivered again to host H3, which will then see the answers to its ping requests.

7.2.2. Filtering database of the switch SW-1

The content of the filtering database 2 min after the relocation can be the following:

<table>
<thead>
<tr>
<th>MAC address</th>
<th>Interface</th>
<th>Ageing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00:00:33:33:33</td>
<td>Fe1</td>
<td>0</td>
</tr>
<tr>
<td>00:00:00:55:55:55</td>
<td>Fe2</td>
<td>120</td>
</tr>
</tbody>
</table>

Vice versa, the filtering database after 10 minutes can be the following:

<table>
<thead>
<tr>
<th>MAC address</th>
<th>Interface</th>
<th>Ageing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00:00:33:33:33</td>
<td>Fe1</td>
<td>0</td>
</tr>
<tr>
<td>00:00:00:55:55:55</td>
<td>Fe0</td>
<td>0</td>
</tr>
</tbody>
</table>
7.3. Solution for exercise n. 11

7.3.1. Frames forwarded by the switch

The frames forwarded by the switch SW-1 correspond to the frames generated on the network:

<table>
<thead>
<tr>
<th>N.</th>
<th>L2</th>
<th>L3</th>
<th>Appl-layer protocol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00:00:00:11:11:11</td>
<td>FF:FF:FF:FF:FF:FF</td>
<td>—</td>
<td>ARP Request Who has IP=10.10.10.4 please reply with its MAC address</td>
</tr>
<tr>
<td>2</td>
<td>00:00:00:44:44:44</td>
<td>00:00:00:11:11:11</td>
<td>—</td>
<td>ARP Reply Host 10.10.10.4 has MAC = 00:00:00:44:44:44</td>
</tr>
<tr>
<td>3</td>
<td>00:00:00:11:11:11</td>
<td>10.10.10.1 → 10.10.10.4</td>
<td>ICMP</td>
<td>ICMP Echo Request</td>
</tr>
<tr>
<td>4</td>
<td>00:00:00:44:44:44</td>
<td>10.10.10.4 → 10.10.10.1</td>
<td>ICMP</td>
<td>ICMP Echo Reply</td>
</tr>
</tbody>
</table>

5-10 Packets 3 and 4 are replicated 3 times

7.3.2. Ports of the switch involved in receiving/transmitting frames

The ports of the switch involved in receiving/transmitting frames are the following:

<table>
<thead>
<tr>
<th>PKT#</th>
<th>Description</th>
<th>Fe0</th>
<th>Fe1</th>
<th>Fe2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ARP Request</td>
<td>IN</td>
<td>OUT</td>
<td>OUT</td>
</tr>
<tr>
<td>2</td>
<td>ARP Reply</td>
<td>OUT</td>
<td>-</td>
<td>IN</td>
</tr>
<tr>
<td>3</td>
<td>ICMP Echo Request</td>
<td>IN</td>
<td>-</td>
<td>OUT</td>
</tr>
<tr>
<td>4</td>
<td>ICMP Echo Reply</td>
<td>OUT</td>
<td>-</td>
<td>IN</td>
</tr>
</tbody>
</table>

For the hub (which does not have any frame filtering capabilities), the ports involved in receiving/transmitting frames are the following:

<table>
<thead>
<tr>
<th>Pkt#</th>
<th>Description</th>
<th>Fe0</th>
<th>Fe1</th>
<th>Fe2</th>
<th>Fe3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ARP Request</td>
<td>IN</td>
<td>OUT</td>
<td>OUT</td>
<td>OUT</td>
</tr>
<tr>
<td>2</td>
<td>ARP Reply</td>
<td>OUT</td>
<td>OUT</td>
<td>IN</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ICMP Echo Request</td>
<td>IN</td>
<td>OUT</td>
<td>OUT</td>
<td>OUT</td>
</tr>
<tr>
<td>4</td>
<td>ICMP Echo Reply</td>
<td>OUT</td>
<td>OUT</td>
<td>IN</td>
<td></td>
</tr>
</tbody>
</table>

7.3.3. Filtering database of the switch

The filtering database of the switch is the following:
<table>
<thead>
<tr>
<th>MAC address</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00:00:11:11:11</td>
<td>Fe0</td>
</tr>
<tr>
<td>00:00:00:44:44:44</td>
<td>Fe2</td>
</tr>
</tbody>
</table>

Vice versa, the hub does not have any filtering database.
8. Performance

8.1. Solution for exercise n. 16

Due to the client-server model of the traffic exchanged in the network (hosts H1-H47 toward S and vice versa), we expect that the bottleneck will be the bandwidth of the server S, which will remain unchanged after the upgrade.

The network will improve its behavior with respect to collisions, which are no longer present. However this may be a secondary problem in this network where traffic is mainly driven by the server.

Therefore we expect that the service perceived by the users will remain almost equivalent after the upgrade.