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First name: ______________________ Family name: ______________________

EXAM
TCP/IP NETWORKING
Duration: 3 hours
With Solutions

Jean-Yves Le Boudec

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INSTRUCTIONS

1. Write your solution into this document and return it to us (you do not need to return the figure sheet). You may use additional sheets if needed. Do not forget to write your name on **each of the four problem sheets** and **all** additional sheets of your solution.
2. All problems have the same weight.
3. You may need to make additional assumptions in order to solve some of the questions. If that happens, please describe such assumptions explicitly.
4. Figures are on a separate sheet, for your convenience.
5. No documents, no electronic equipments are allowed.
6. Justify every answer with a short explanation.

PROBLEM 1

Consider the network for problem 1 in the figure sheet. A, B, C and D are hosts; $X1, X2, X3, X4$ and Y are network boxes that can be configured in different ways, as explained next. $O1, O2, O3$ and $O4$ are observation points where we observe traffic in both directions of the link. Some selected IPv4 addresses are shown, as well as some selected MAC addresses (denoted with $A1, B1, C1, D1$, $X1w, X3e, Y1, Y2$ and $S1$). You may need to specify other IP or MAC addresses. All links are full duplex Ethernet. We assume that all machines are correctly configured (unless otherwise specified) and proxy ARP is not used (unless otherwise specified).

1. In this question $X1, X2, X3, X4$ and Y are routers, running RIP with all link costs equal to 1.

   (a) Give one possible value for the netmask at A and one for the netmask at B.

   Solution. For example, `255.255.255.0` would be a valid netmask for A as well as B.
   Any netmask less than or equal to /31 is valid for B.
   Any netmask less than or equal to /30 is valid for A.
   Each is in its own LAN, so they can be different.
   If we choose the netmasks /22 or less, then some hosts will think that other hosts are in the same LAN. This leads to the problem in Question 5 and needs to be properly explained to get credit here.

   (b) A sends one ping message to S. We observe the ping request packets resulting from this activity at observation points $O1$ and $O4$. What are the MAC and IP source and destination addresses in such packets ? What is the TTL field, knowing that the TTL value is equal to 64 in all IPv4 packets generated by all hosts in this problem ? Put your answers in the tables below.

At observation point $O1$:				
MAC source	MAC dest	IP source	IP dest	TTL
A1	X1w	3.3.1.2 (A)	9.9.9.9 (S)	64

At observation point $O4$:				
MAC source	MAC dest	IP source	IP dest	TTL
X3e	Y1	3.3.1.2 (A)	9.9.9.9 (S)	61

   (c) A downloads a huge file from a web server at S using HTTP. A uses the local port 4567. At the same time, B also downloads a file from S, also using HTTP. By coincidence, B uses the same local port number, namely 4567. We observe the IP headers and transport layer headers in the packets resulting from this transfer at $O4$ and $O5$, in the direction from S to A and from S to B. Give possible values of the protocol, the source and destination port numbers and the source and destination IP addresses. Give the answers in the tables below.

At observation point $O4$, from S to A and B:				
IP source	IP dest	protocol	source port	dest. port
9.9.9.9 (S)	3.3.1.2 (A)	TCP	80	4567
9.9.9.9 (S)	3.3.2.2 (B)	TCP	80	4567

At observation point $O5$, from S to A and B:				
IP source	IP dest	protocol	source port	dest. port
9.9.9.9 (S)	3.3.1.2 (A)	TCP	80	4567
9.9.9.9 (S)	3.3.2.2 (B)	TCP	80	4567

(d) A sends one ping message to B, B sends one ping message to C, C sends one ping message to D and D sends one ping message to A. We observe the ping request packets resulting from this activity at observation points $O2$ and $O3$. What are the IP source and destination addresses in the packets that are visible at these observation points ? What is the TTL field, knowing that the TTL value is equal to 64 in all IPv4 packets generated by all hosts in this problem ? Put your answers in the tables below.

At observation point $O2$:		
IP source	IP dest	TTL
3.3.2.2 (B)	3.3.3.2 (C)	63

At observation point $O3$:		
IP source	IP dest	TTL
3.3.3.2 (C)	3.3.4.2 (D)	63

2. In this question $X1$, $X2$, $X3$ and $X4$ are bridges and Y is a router.

(a) Give one possible value for the netmask at A and one for the netmask at B.

Solution. For example, `255.255.0.0` would be a valid netmask for A as well as B
Since A, B, C, D, and $Y1$ are on the same LAN, they must have a proper netmask.
Any netmask less than or equal to /21 is valid for both. Both should be the same.

(b) A sends one ping message to S. We observe the ping request packets resulting from this activity at observation points $O1$ and $O4$. What are the MAC and IP source and destination addresses in such packets ? What is the TTL field, knowing that the TTL value is equal to 64 in all IPv4 packets generated by all hosts in this problem ? Put your answers in the tables below.

At observation point $O1$:				
MAC source	MAC dest	IP source	IP dest	TTL
A1	Y1	3.3.1.2 (A)	9.9.9.9 (S)	64

At observation point $O4$:				
MAC source	MAC dest	IP source	IP dest	TTL
A1	Y1	3.3.1.2 (A)	9.9.9.9 (S)	64

(c) A sends one ping message to B, B sends one ping message to C, C sends one ping message to D and D sends one ping message to A. We observe the ping request packets resulting from this activity at observation points $O2$ and $O3$. What are the IP source and destination addresses in the packets that are visible at these observation points ? What is the TTL field, knowing that the TTL value is equal to 64 in all IPv4 packets generated by all hosts in this problem ? Put your answers in the tables below.

Assumption: Spanning tree established such that X4-X1 link not used.
Note: Under any assumption, there will be either 0 or 2 messages visible at each observation point, never just 1.

At observation point $O2$:		
IP source	IP dest	TTL
3.3.2.2 (B)	3.3.3.2 (C)	64
3.3.4.2 (D)	3.3.1.2 (A)	64

At observation point $O3$:		
IP source	IP dest	TTL
3.3.3.2 (C)	3.3.4.2 (D)	64
3.3.4.2 (D)	3.3.1.2 (A)	64

3. In this question $X1, X2, X3$ and $X4$ are VLAN switches and Y is a router. A, B and C belong to the VLAN labeled $L1$ whereas D belongs to the VLAN labeled $L2$ (with $L1 \neq L2$).

   (a) Are the netmasks in Question 1 still valid ? If no, give possible values for the netmasks at A and B.

   Solution. No, A, B and C need to be on one LAN, and D on another.
   So `255.255.252.0`, is valid as a netmask.

   (b) Do we have full connectivity in the network if the configuration is as shown in the figure, with the netmask you proposed above? If not, give a possible modification that works.

   Solution. No, the 2 VLANs cannot communicate with each other. They need to communicate through a router, namely Y, in which case hosts in both VLANs need to be able to reach Y1. A solution would be to configure the Y1 interface with two different IP addresses, each belonging to a different VLAN.

   (c) A sends one ping message to D. We observe the ping request packets resulting from this activity at observation point $O1$. What are the IP source and destination addresses in the packet that is visible at this observation point ? Put your answers in the table below.

At observation point $O1$:			
MAC source	MAC dest	IP source	IP dest
A1	Y1	3.3.1.2 (A)	3.3.4.2 (D)

4. In this question $X1, X2, X3, X4$ are routers, running RIP with all link costs equal to 1. Y is a NAT box; the WAN port is $Y2$.

   (a) Are the netmasks in Question 1 still valid ? If no, give possible values for the netmasks at A and B.

   Solution. Yes, nothing changed. `255.255.255.0` is valid for all.

   (b) A downloads a huge file from a web server at S using HTTP. A uses the local port 4567. At the same time, B also downloads a file from S, also using HTTP. By coincidence, B uses the same local port number, namely 4567. We observe the IP headers and transport layer headers in the packets resulting from this transfer at $O4$ and $O5$, in the direction from S to A and from S to B. Give possible values of the protocol, the source and destination port numbers and the source and destination IP addresses. Give the answers in the tables below.

At observation point $O4$, from S to A and B:				
IP source	IP dest	protocol	source port	dest. port
9.9.9.9 (S)	3.3.1.2 (A)	TCP	80	4567
9.9.9.9 (S)	3.3.2.2 (B)	TCP	80	4567

At observation point $O5$, from S to A and B:				
IP source	IP dest	protocol	source port	dest. port
9.9.9.9 (S)	7.7.7.7 (Y2)	TCP	80	5000 (or any)
9.9.9.9 (S)	7.7.7.7 (Y2)	TCP	80	5001 (or any != 5000)

5. In this question $X1, X2, X3, X4$ and Y are again routers, running RIP with all link costs equal to 1, as in Question 1. However, the netmasks at A, B, C and D are as in Question 2. In spite of this mis-configuration, we would like this system to work without changing anything in the hosts; $X1, X2, X3, X4$ and Y have to continue to work as routers, but some function in these or other boxes may be modified or added. Propose one such solution.

   Solution. If the netmasks are `255.255.0.0` as in Question 2, the hosts will think that other hosts are on the same LAN, and will try to ARP to get their MAC addresses. To solve this, one solution is to use proxy ARP in all routers $X1, X2, X3, X4$.

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PROBLEM 2

Consider the network for problem 2 in the figure sheet, first page. Boxes $A1$, $A2$, ...$C4$ are routers.

1. In this question all routers in AS B, namely $B1$, ..., $B4$, run an IPv4 distance vector routing protocol with route poisoning and with infinity $= 256$. BGP is not enabled and there is no routing protocol in other routers of the figure, so that, in this question, routers in AS B are not aware of external network prefixes.

   Unless otherwise specified, the cost of a link between two routers is 1 and the cost from a router to a directly attached network is 1. There is one IPv4 network between consecutive routers on the figure, with subnet prefix of length 24. All networks shown on the figure, including the border networks `78.1.1.0/24`, `78.2.4.0/24`, `89.2.1.0/24`, and `89.3.2.0/24` are considered interior by all routers in B. All routers in AS B originate their directly attached networks into the distance vector routing protocol.

   (a) Give a possible value of the routing table at router $B1$, at a time t_1 such that the interior routing protocol has stabilized. Give the values in the table below (do not give the value of the "interface" field).

   Solution.

Destination Network	Next-Hop	Distance
8.1.4.0/24	on link	1
8.1.2.0/24	on link	1
8.3.4.0/24	8.1.4.4	2
8.2.3.0/24	8.1.2.2	2
89.2.1.0/24	8.1.2.2	2
78.1.1.0/24	on link	1
89.3.2.0/24	8.1.4.4 (OR 8.1.2.2)	3
78.2.4.0/24	8.1.4.4	2

   (b) At time $t_2 > t_1$, for some reason $B2$ changes the cost of the directly attached network `8.2.3/24` to 6 (instead of 1) and sends a routing update to its neighbours. The routing update is received by $B1$ at time $t_3 > t_2$. No other message was sent by any router between t_1 and t_3. Explain which processing is performed by $B1$ on receiving this update and explain which modification, if any, results in $B1$'s routing table.

   Solution. Before receiving the update from $B2$, $B1$ uses $B2$ as Next-Hop to reach 8.2.3.0/24 (distance equals to 2). After receiveng the update from $B1$, distance become 7 and since the routing protocol did not converge yet the Next-Hop will unchanged.

   (c) At time $t_4 > t_3$, $B1$ sends a routing update to its neighbours. The routing update is received by $B4$ at time $t_5 > t_4$. No message other than those already mentioned was sent by any router between t_1 and t_5. Explain which processing is performed by $B4$ on receiving this update and explain which modification, if any, results in $B4$'s routing table.

   Solution. The will be not changes in $B4$'s routing table. The updates form $B1$ will be discharged.

2. AS B continues to run its interior routing protocol with all link costs equal to 1 except for the cost of `8.2.3/24`, which is set to 6 (by both $B2$ and $B3$). Inside ASs A and C there is also an interior

routing protocol which uses shortest path with all link costs equal to 1. At time $t_6 > t_5$ the interior routing protocols in A, B and C have converged.

Then BGP is enabled in all routers shown on the figure. All BGP routers originate into BGP their directly attached networks. The import and export policies accept all announcements. No aggregation is performed and BGP routers do not redistribute BGP into their interior routing protocols. `LOCAL-PREF`, `MED` and `WEIGHT` are not used, unless otherwise specified.

(a) At time $t_7 > t_6$, $A1$ sends to $B1$ the BGP announcement:

```
1.1/16, AS path = A, NEXT-HOP=78.1.1.7
```

No other BGP announcement for network `1.1/16` has been received before this one by any router in B. Explain what processing $B1$ performs on receiving this announcement; also mention which BGP messages are sent by $B1$ as a result of this processing.

Solution. Route will be stored in Adj-RIB-in and since no other routes towards this destination is known it will be promoted to best by the BGP decision process. Then, the Adj-RIB-out is updated to include the route and B1 will send the announcements to its BGP-peers.

(b) At time $t_8 > t_7$, $A2$ sends to $B4$ the BGP announcement:

```
1.1/16, AS path = A, NEXT-HOP=78.2.4.7
```

No other BGP announcement has been received from AS A by any router in B in the time interval $[t_7, t_8]$. Explain what processing $B4$ performs on receiving this announcement; also mention which BGP messages are sent by $B4$ as a result of this processing.

Solution. B4 will store the new information in its Adj-RIB-in. Route via A2 will be promoted to be best by the BGP decision process, since it was learned by E-BGP. Finally, B2 will send the announcements to its BGP-peers.

(c) At time $t_9 > t_8$ BGP has stabilized inside AS B. No message other than previously mentioned was received by AS B from AS A during $[t_6, t_9]$. An IP packet with destination IP address `1.1.1.1` is forwarded by $B3$; which path does it take ? (Justify your answer).

Solution. The path is via B4-A2, since it takes less hops to reach AS A.

Same question for a packet with destination IP address `1.1.1.1` forwarded by $B2$.

Solution. The path is B1-A1, the reason is the same as in previous question.

(d) At time $t_{10} > t_9$, $C2$ sends to $B3$ the bogus BGP announcement:

```
1.1/16, AS path = C, NEXT-HOP=89.3.2.9
```

At time $t_{11} > t_{10}$ BGP has stabilized again inside AS B. No other BGP announcement has been received by any router in B from external ASs in the time interval $[t_8, t_{11}]$. Which route to `1.1/16` does $B2$ select ? (Justify your answer).

Solution. Here, the B3 will choose between two paths: one with AS path = C, and second one with AS path = A. Both of the are learned by I-BGP. So in this case B2 will choose the path which has less cost. Since the cost of link between B2 and B3 equals to 6, B2 will choose path B2-A1 via AS A in order to reach 1.1/16.

(e) At time $t_{12} > t_{11}$, $C1$ sends to $B2$ the bogus BGP announcement:

```
1.1.1/24, AS path = C, NEXT-HOP=89.2.1.9
```

At time $t_{13} > t_{12}$ BGP has stabilized again inside AS B. No other BGP announcement has been received by any router in B from external ASs in the time interval $[t_8, t_{13}]$. An IP packet with destination IP address `1.1.1.1` is forwarded by $B2$; which path does it take ? (Justify your answer).

Solution. Both routes will be in the routing table (to 1.1.1/24 and to 1.1/16). By the longest prefix match B2 will forward the packet to C1.

Same question for a packet with destination IP address `1.1.1.1` forwarded by $B4$.

Solution. By the same reason, the path will be B1-B2-C1.

3. After an economical reorganization the networks of ASs A, B, C are bought by the same company and now constitute a single, large autonomous routing domain in which they want to run OSPF as interior routing protocol. The addressing plan is unchanged. They would like to use three areas, as shown on the second page of the figure sheet. Router $C1$ wants to send a packet to the destination IP address `1.1.1.1`. Explain by which means $C1$ obtains the routing information to reach the `1.1/16` network (give all steps).

   Solution. First, $B1$ will compute shortest path to $A3$ using Dijkstra inside area 1. Then $B1$ will inject the route into area 0, and router $B2$ will compute shortest path using Dijkstra to $A3$ inside area 0. Afterwards, $B2$ will inject the route into area 2, and finally $C1$ will compute shortest path (using Dijkstra) to $A3$ inside area 2.

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PROBLEM 3

Consider the network for problem 3 on the figure sheet.

- Hosts A, B and C are downloading content from server S. $R1, R2$ and $R3$ are routers, unless otherwise specified.
- The link rates are indicated on the figure. All links are full duplex with same rate in both directions.
- There is no other system than shown on the figure, and we neglect all flows other than between A, B, C and S. We also neglect the impact of the acknowledgement flows in the reverse direction.
- The round trip times (RTTs) are: 30 ms between A and S; 170 ms between B and S; 20 ms between C and S. These numbers include all processing times.
- We neglect all overheads and assume that the link capacities can be fully utilized at bottlenecks.
- The MSS is the same for all flows and is equal to 1250 Bytes = 10^4 bits.

1. Assume that some bandwidth manager is used, which allocates rates to flows according to max-min fairness. What are the values of the rates of the flows $S \to A$, $S \to B$ and $S \to C$?
   Solution. The rates of the flows according to max-min fairness are obtained by water-filling. Initially all flows receive $5Mb/s$. The flow $S \to C$ becomes frozen due to using a saturated link (between R_2 and C). The rates of flows $S \to A$, $S \to B$ increase to $10Mb/s$, where they froze due to the saturated link between R_1 and R_2. Thus, according to the max-min fair solution the rates of $S \to A$, $S \to B$, $S \to C$ are $10Mb/s$, $10Mb/s$, $5Mb/s$, correspondingly.
   (We assume no overheads.)
2. Same question with proportional fairness instead of max-min fairness.
   Solution. Let x, x, z, correspond to the source rates of flows $S \to A$, $S \to B$, $S \to C$. Since we do not consider the RTTs, the flows $S \to A$, $S \to B$ can be regarded as symmetric. We solve the optimization problem:

$$\max_{x,z}(logx + logx + logz)$$

   subject to

$$0 \le z \le 5$$
$$2x \le 20$$
$$0 \le x$$

   The problem is re written as follows:

$$\max_{x,z}(logx + logx + logz)$$

   subject to

$$0 \le z \le 5$$
$$0 \le x \le 10$$

   The value $x = 10Mb/s$, $z = 5Mb/s$ is feasible and is an upper bound to any other feasible solution, therefore, since $\log$ is an increasing function, it is the optimal solution. Note that it is exactly the same with the max-min fair allocation.
   (We assume no overheads.)

3. We now assume that the three flows are using TCP with ECN. What is the value of the rate of each flow ?

Solution. By using ECN the RTTs are not further affected by queueing delays. Let x, y, z (non-negative values), correspond to the source rates of flows $S \to A$, $S \to B$, $S \to C$. (The rates are now affected by the RTTs compared to the previous question.)

There are at two possible ways to solve this question.

Solution 1. We use the fact that TCP rates can be approximated by the solution of the following optimization problem:

$$\max_{x,y,z}\left(\frac{\sqrt{2}}{0.03}\arctan\frac{x0.03}{\sqrt{2}} + \frac{\sqrt{2}}{0.17}\arctan\frac{y0.17}{\sqrt{2}} + \frac{\sqrt{2}}{0.02}\arctan\frac{z0.02}{\sqrt{2}}\right)$$

subject to

$$0 \le z \le 5$$
$$x + y \le 20$$
$$0 \le x, y$$

Obviously, $z = 5Mb/s$ since $S \to C$ does not compete with $S \to A$, $S \to B$ over a bottleneck link and $\arctan$ is an increasing function. Also, due to the maximization of an increasing function, the bottleneck will be fully utilized (i.e., $x + y = 20$) thus we lead to solving the following one variable optimization problem:

$$\max_{x}\left(\frac{\sqrt{2}}{0.03}\arctan\frac{x0.03}{\sqrt{2}} + \frac{\sqrt{2}}{0.17}\arctan\frac{(20-x)0.17}{\sqrt{2}}\right)$$
$$0 \le x \le 20$$

By taking the derivative of the above objective and setting it to zero, we have:

$$\frac{1}{1+(\frac{x0.03}{\sqrt{2}})^2} - \frac{1}{1+(\frac{(20-x)0.17}{\sqrt{2}})^2} = 0$$

which gives

$$-1 - \left(\frac{x0.03}{\sqrt{2}}\right)^2 + 1 + \left(\frac{(20-x)0.17}{\sqrt{2}}\right)^2 = 0$$

By replacing, we show that

$$x = 17Mb/s,\ y = 3Mb/s$$

is the optimal solution satisfying

$$0 \le x \le 20.$$

The second solution can be found by solving the trinomial but it is not feasible.

Solution 2. Same result can be attained using the throughput-loss formula assuming the drop rate is the same for flow x and y (which is true with ECN and a fair router) and the fact that TCP allocated rates in a Pareto-efficient way (i.e. here the bottleneck links are fully utilized).

Obviously, $z = 5Mb/s$ since $S \to C$ does not compete with $S \to A$, $S \to B$ over a bottleneck link. For x, y we solve the following:

$$y = \frac{30}{170}x$$
$$x + y = 20$$

which gives:

$$x = 17Mb/s,\ y = 3Mb/s.$$

The first equation comes from the throughput loss formula $\theta = \frac{C \cdot MSS}{T\sqrt{q}}$ by applying it for the flows $S \to A$, $S \to B$, i.e., $x = \frac{C \cdot MSS}{0.03\sqrt{q}}$, $y = \frac{C \cdot MSS}{0.17\sqrt{q}}$, assuming same drop rate (fraction q) for both flows. (We assume no overheads.)

4. We continue to assume that the flows are using TCP with ECN. We observe the IP headers of packets on the link from $R2$ to C. Which proportion of packets do we see marked as "Congestion Experienced" ?

   Solution. If the flows were using TCP without ECN we could obtain by the loss throughput formula the loss ratio of the link i.e., the fraction q of the packets that is in average lost. Now, with ECN we could think that q is in average the fraction of packets that should be marked as congestion experienced in order to avoid having losses. Thus,the loss throughput formula tells us that

$$\theta = \frac{C \cdot MSS}{T\sqrt{q}}.$$

   Therefore the fraction of marked packets is $q = (\frac{C \cdot MSS}{T\theta})^2$. Replacing with values of flow $S \to C$, we obtain:

$$q = \left(\frac{1.22 \cdot 10^4 bits}{0.02sec \cdot 5 \cdot 10^6 bits/sec}\right)^2 = (1.22/10)^2 = 0.122 * 0.122 \approx 0.015 = 1.5\%$$

5. Assume now that $R3$ is an application layer gateway instead of a router. We assume that all flows are using TCP with ECN. The round trip time from S to $R3$ is 30 msec; from $R3$ to B it is 165 msec; the other round trip times are unchanged. We assume that the application layer gateway has infinite processing power and storage. What is the value of the rate of each flow ?

   Solution. The application layer gateway terminates the TCP connection. Thus, we assume four flows in this case. Let x, y_1, y_2, z (non-negative values), correspond to the source rates of flows $S \to A$, $S \to R3$, $R3 \to B$, $S \to C$. There are at two possible ways to solve this question as in question 3. We present one of the two.

   Obviously, $z = 5Mb/s$ since $S \to C$ does not compete with $S \to A$, $S \to R3$, $R3 \to B$ over a bottleneck link. For x, y_1, y_2 we solve the following:

$$y_1 = \frac{30}{30}x = x$$

   (from throughput-loss formula)

$$x + y_1 = 20$$

$$y_2 = y_1$$

   (as there does not practically exist bottleneck link for y_2 compared to the maximum value of y_1) which gives:

$$x = 10Mb/s,\ y_2 = y_1 = 10Mb/s.$$

   Thus, for $S \to B$, the rate is equal to $10Mb/s$.
   (We assume no overheads)

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PROBLEM 4

Consider the network for problem 4 in the figure sheet. $O1, O2, O3$, and $O4$ are observation points.

- A is an IPv6 only-host, $R1$ is an IPv6 only router, P is a dual-stack host and $R11$ is a dual-stack router. $R11$ receives an IPv4-only service from its provider. The IPv6 addresses a, $r1w$, $r1e$, $r11w$, $r11n$ and p are to be determined later.
- $S6$ is an IPv6-only host, connected to the IPv6 internet. $S4$ is an IPv4-only host, connected to the IPv4 internet. $S5$ is a dual-stack host connected to both IPv4 and IPv6 internet.
- $R22$ is a dual stack router, configured as a 6to4 relay router.

1. Give the non-compressed form of $S6$'s IPv6 address. What are the 3rd and 64th bits of this address? (the first bit is the leftmost one).
   Solution. The first hexa digit of $S6$'s IPv6 address comprises the bits 1 to 4. Hence, since $(2)_{16} = (0010)_2$, the 3rd bit is 1. Similarly, the 64th bit is 0.
   Solution. `2001:000b:00ab:0000:0000:0000:0000:0002`
2. The network goodthings.com uses 6to4 to provide IPv6 connectivity internally. Furthermore, we want that all IPv6 traffic inside the internal network goodthings.com, such as between A and P is native, i.e., does not use tunnels. Give a possible value for each of the following:
   - The IPv6 addresses a, $r1w$, $r1e$, $r11w$, $r11n$ and p
   - The network mask at A and P
   - A's default gateway.

   Solution. Solution 1

   - $r1e$ and $r11w$ are in the same LAN and they have a 6to4 IP address. The constraint is the IPv4 address that $R11$ receives from its provider. Hence, $r11w$ is 2002:0909:0101:aaaa:EUI$_{r11w}$/64 and $r1e$ is 2002:0909:0101:aaaa:EUI$_{r1e}$/64.
   - p and $r11n$ use the same 6to4 address. p is 2002:0909:0101:abcd:EUI$_p$/64,
     $r11n$ is 2002:0909:0101:abcd:EUI$_{r11n}$/64.
   - A also receives a 6to4 address from R1 and $r1w$ is in the same IPv6 LAN as A. Hence, A is 2002:0909:0101:bbbb:EUI$_A$/64 and $r1w$ is 2002:0909:0101:bbbb:EUI$_{r1w}$/64
   - Network mask at A is 64 bits and at P is 64 bits for the IPv6 interface and 32 bits for IPv4 interface.
   - Default gateway at A is $r1w$.

   Solution 2

   - $r1e$ and $r11w$ are in the same LAN and they have a 6to4 IP address. The constraint is the IPv4 address that $R11$ receives from its provider. Hence, $r11w$ is 2002:0909:0101:aaaa:EUI$_{r11w}$/64 and $r1e$ is 2002:0909:0101:aaaa:EUI$_{r1e}$/64.
   - Similarly for p and $r11n$. p is 2002:0909:0902:abcd:EUI$_p$/64, and
     $r11n$ is 2002:0909:0902:abcd:EUI$_{r11n}$/64.
   - A also receives a 6to4 address from R1 and $r1w$ is in the same IPv6 LAN as A. Hence, A is 2002:0909:0101:bbbb:EUI$_A$/64 and $r1w$ is 2002:0909:0101:bbbb:EUI$_{r1w}$/64
   - Network mask at A is 64 bits and at P is 64 bits for the IPv6 interface and 32 bits for IPv4 interface.

- Default gateway at A is $r1w$.

3. A downloads a file from $S6$ using HTTP. We observe the IPv4 packets resulting from this activity and flowing from A to $S6$ at observation point $O2$ and the IPv6 packets at observation point $O3$. Give the IP source and destination addresses and protocol types in the tables below.

In IPv4 header, at observation point $O2$, from A to $S6$:		
Source IP address	Destination IP address	Protocol
In IPv4 header, at observation point $O2$, from A to $S6$:		
Source IP address	Destination IP address	Protocol
9.9.1.1	192.88.99.1	41

In IPv6 header, at observation point $O3$, from A to $S6$:		
Source IP address	Destination IP address	Protocol
In IPv6 header, at observation point $O3$, from A to $S6$:		
Source IP address	Destination IP address	Protocol
2002:0909:0101:bbbb:EUI_A	2001:b:ab::2	6

4. P is a web proxy, i.e., an application layer gateway for the HTTP protocol. In this question, A's browser is statically configured to use P as proxy; this means that all HTTP traffic sent by A, is sent to the IPv6 address of P, over IPv6. P then does store-and-forward on behalf of A. We can say that P is a "client-side proxy".

   (a) When P connects to a web server such as $S4$ or $S6$, how does P know whether to use IPv4 or IPv6 ?
   Solution. Through DNS. If P receives an A record it uses IPv4. If it receives an AAAA record, it uses IPv6.

   (b) A downloads again a file from $S6$ using HTTP. We observe the IPv4 packets resulting from this activity and flowing to $S6$ at observation point $O2$ and the IPv6 packets at observation point $O3$. We also observe the packets going from $R11$ to P at the observation point $O1$. Give the IP source and destination addresses and protocol types in the tables below.

In IPv4 header, at observation point $O2$, towards $S6$:		
Source IP address	Destination IP address	Protocol
In IPv4 header, at observation point $O2$, towards $S6$:		
Source IP address	Destination IP address	Protocol
9.9.1.1	192.88.99.1	41

In IPv6 header, at observation point $O3$, towards $S6$:		
Source IP address	Destination IP address	Protocol
In IPv6 header, at observation point $O3$, towards $S6$:		
Source IP address	Destination IP address	Protocol
(1) 2002:0909:0901:abcd:EUI_p	2001:b:ab::2	6
(2) 2002:0909:0902:abcd:EUI_p	2001:b:ab::2	6

The outermost IP header, at observation point $O1$, towards P:		
Source IP address	Destination IP address	Protocol
The outermost IP header, at observation point $O1$, towards P:		
Source IP address	Destination IP address	Protocol
(1) 2001:b:ab::2	2002:0909:0101:abcd:EUI_p	6
(2) 192.88.99.1	9.9.9.2	41

(c) A downloads a file from $S4$ using HTTP. A continues to use P as a proxy, which means that the HTTP request is first sent by A to P using IPv6. We observe the IPv4 packets resulting from this activity and flowing to $S4$ at observation point $O4$. Give the IP source and destination addresses and protocol types in the table below.

In IPv4 header, at observation point $O4$, towards $S4$:		
Source IP address	Destination IP address	Protocol
In IPv4 header, at observation point $O4$, towards $S4$:		
Source IP address	Destination IP address	Protocol
9.9.9.2	1.2.3.4	6

5. From now on, $S5$ acts as a server-side proxy on behalf of $S4$ for IPv6 hosts. This means that when an IPv6 host wants to contact `coolstuff.ao`, it connects to $S5$ that then does store-and-forward towards $S4$, where the content of `coolstuff.ao` is.

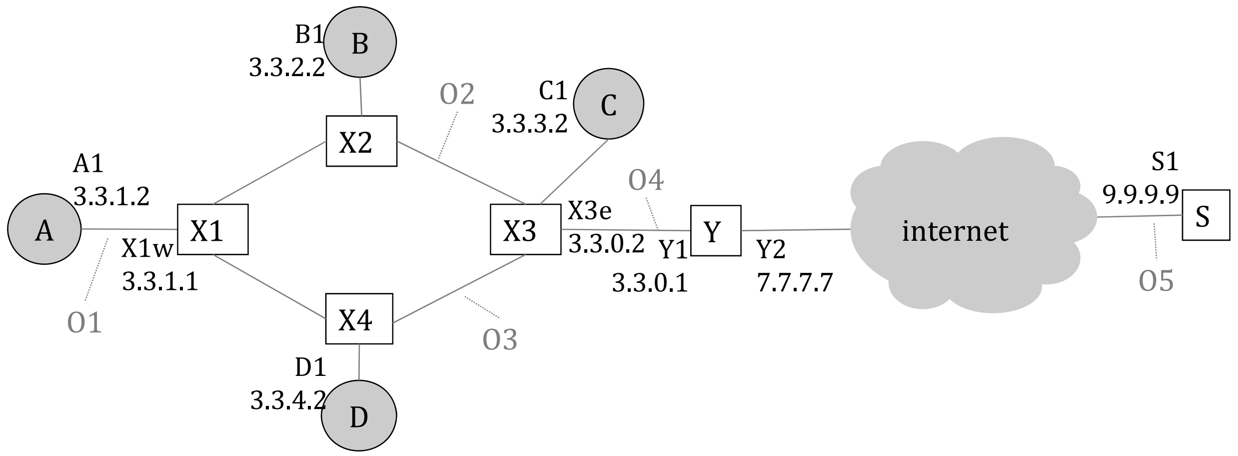
   (a) By which mechanism can we induce all IPv6 hosts that want to contact `coolstuff.ao` to connect to $S5$ rather than $S4$ (without changing any configuration in such hosts) ?
   Solution. By changing the DNS entry for `coolstuff.ao` from 1.2.3.4 to 2001:c:cd::2. and 5.6.7.8

   (b) Assume that A does not use P as proxy (i.e., directly connects to web servers). A downloads some content from `coolstuff.ao`. Explain what will happen, say in particular which path the data will follow.
   Solution. HTTP request
   $A \rightarrow R1 \rightarrow R11$ using IPv6. $R11 \rightarrow R22 \rightarrow S5$ using IPv6 in IPv4 tunnel through the 6to4 relay router $R22$. Now, $S5$ sends the request to $S4$ using IPv4 by-passing.
   HTTP reply $S4 \rightarrow S5$ (IPv4). $S5 \rightarrow R22 \rightarrow R11 \rightarrow R1 \rightarrow A$. Using 6to4

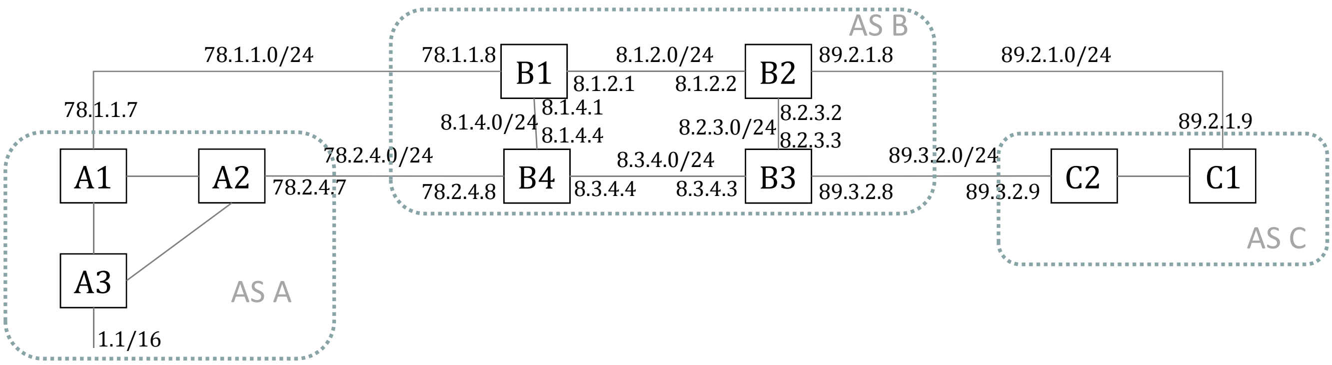
   (c) Assume that A continues to use P as client-side web proxy. A downloads some content from `coolstuff.ao`. Being a dual-stack host, P has a choice whether to use IPv4 or IPv6 to communicate with $S5$. Which is a better choice?
   Solution.
   If P uses IPv6, it suffers two performance penalties: one due to the tunnel to 6to4 $R22$ and the other due to proxy $S5$. The tunnel can be avoided if it uses IPv4.
   In another case, if $S5$ were a proxy for $S6$, then also, using IPv4 would have only a single performance penalty as opposed to the two when using IPv6. So, using IPv4 is better.

TCP IP EXAM - FIGURES

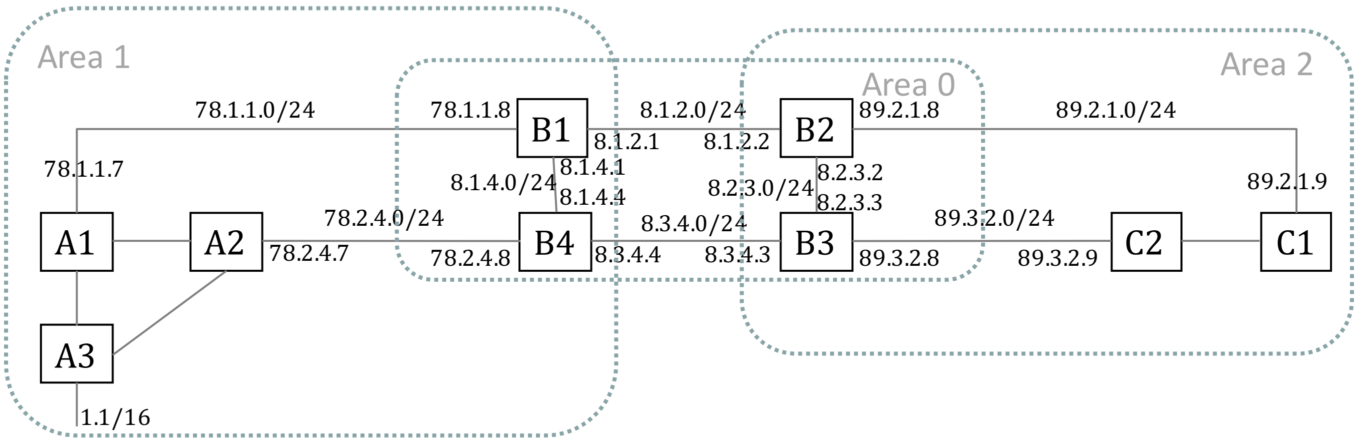
For your convenience, you can separate this sheet from the main document. Do not write your solution on this sheet, use only the main document. Do not return this sheet.



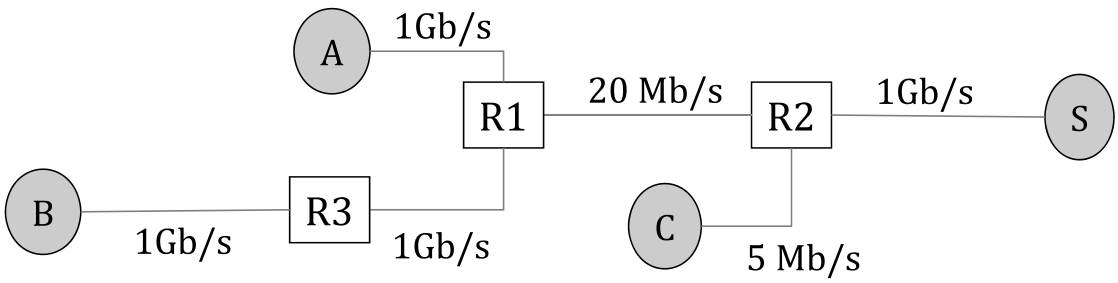
Problem 1: The network used in Problem 1, showing some selected addresses. You may need to specify other addresses.



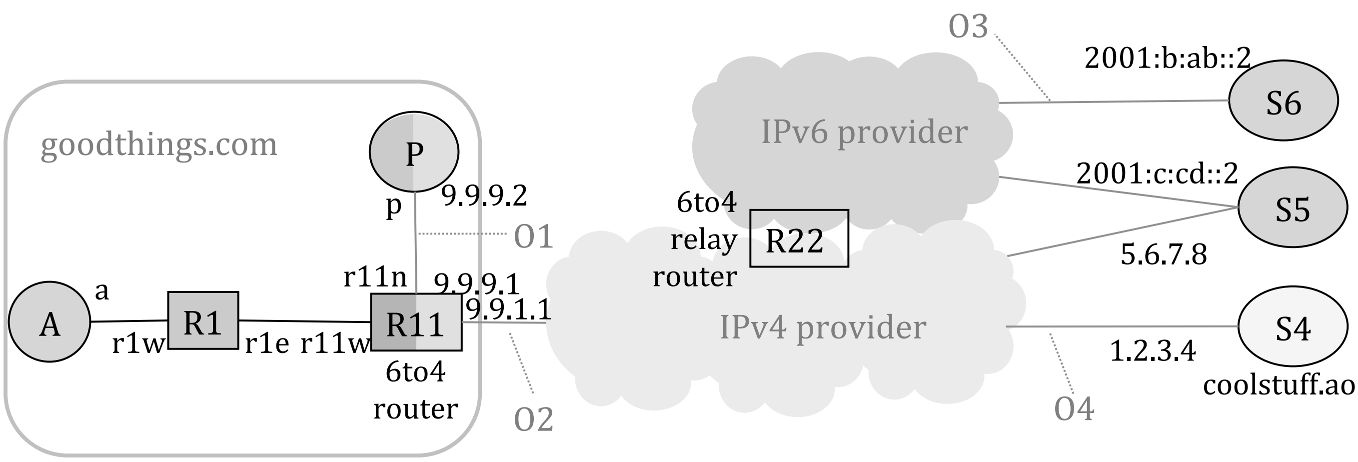
Problem 2: questions 1 and 2.



Problem 2: question 3.



Problem 3.



Problem 4.