



# Computer Networks - Final Exam

January 23, 2023

Duration: 2:15 hours, closed book.

- This is a closed-book exam.
- Please write your answers on these sheets in a readable way, in English or in French.
- Please do **not** use a red pen.
- You can use extra sheets if necessary (don't forget to put your name on them).
- The total number of points is 50.
- This document contains 23 pages.
- Good luck!

**Last Name (Nom):**

**First Name (Prénom):**

**SCIPER No:**

**Division:**  Communication Systems  Computer Science  
 Other (mention it): .....

**Year:**  Bachelor Year 2  Bachelor Year 3  
 Other (mention it): .....

Problem	Points achieved	Out of
1		5
2		25
3		20
<b>Total</b>		<b>50</b>

## Problem 1

(5 points)

For each question, please circle a single best answer.

1. The larger a packet is,
  - (a) the higher the transmission delay it experiences.
  - (b) the higher the propagation delay it experiences.
  - (c) the higher the queuing delay it experiences.
  - (d) the lower the processing delay it experiences.
2. The longer a link is, the higher...
  - (a) the transmission delay it introduces.
  - (b) the propagation delay it introduces.
  - (c) the queuing delay it introduces.
  - (d) the throughput it enables.
3. Two packets of the same size traverse the same path (the same sequence of links and packet switches) but at different points in time. They may experience different...
  - (a) transmission delays.
  - (b) propagation delays.
  - (c) queueing delays.
  - (d) nothing (they cannot experience different delays).
4. Paths  $P_1$  and  $P_2$  have zero queuing and processing delays. Path  $P_1$  has a significantly higher propagation delay than path  $P_2$ . This means that the following is necessarily (always) true:
  - (a) A small packet traversing  $P_1$  experiences significantly higher end-to-end delay than a small packet traversing  $P_2$ .
  - (b) The maximum throughput achievable over  $P_1$  is significantly smaller than the maximum throughput achievable over  $P_2$ .
  - (c) Both of the above.
  - (d) None of the above.
5. During a given time interval, Path  $P_1$  offers higher throughput than path  $P_2$ . This means that the following is necessarily (always) true:
  - (a)  $P_1$ 's lowest-capacity link has a higher transmission rate than  $P_2$ 's lowest-capacity link.
  - (b)  $P_1$  is experiencing less congestion than  $P_2$  during the given time interval.
  - (c) Both of the above.
  - (d) None of the above.

6. End-systems A and B are connected over a sequence of two links (with one packet switch between them). A is sending equally sized packets to B, and there is no other traffic on the Internet. Is it possible that A's traffic experiences queuing delay at the switch?
  - (a) No, because this is a very simple topology.
  - (b) No, because there is no other traffic on the Internet.
  - (c) Yes, because queuing delay is always possible no matter what.
  - (d) Yes, if the second link has a smaller transmission rate than the first link.
7. End-system A is sending traffic to end-system B over a TCP connection. A link on the path from A to B becomes congested and starts dropping and delaying packets. How will TCP's congestion-control algorithm react?
  - (a) It will send the traffic through a different path.
  - (b) It will adapt the receiver window.
  - (c) It will adapt the congestion window.
  - (d) It will end the TCP connection.
8. Alice sends messages to Bob. What information is needed to achieve confidentiality using public-key cryptography?
  - (a) Alice needs to know Bob's public key.
  - (b) Bob needs to know Alice's public key.
  - (c) They need to know each other's public key.
  - (d) They don't need to know anything.
9. Alice sends messages to Bob. What information is needed to achieve authenticity and data integrity using public-key cryptography?
  - (a) Alice needs to know Bob's public key.
  - (b) Bob needs to know Alice's public key.
  - (c) They need to know each other's public key.
  - (d) They don't need to know anything.
10. Which of the following is true about "default gateway" and "proxy ARP"?
  - (a) They are the exact same mechanism.
  - (b) They both have the same goal: for an end-system or IP router to map an IP address to a MAC address.
  - (c) They both have the same goal: for a link-layer switch to map an IP address to a MAC address.
  - (d) The former is used by end-systems, whereas the latter is used by IP routers.

## Problem 2

(25 points)

Consider the Autonomous System AS0 shown in Figure 1, which includes:

- End-systems  $A_1, \dots, A_{1000}$  (there are 1000 of them).
- End-systems  $B_1, \dots, B_{600}$  (there are 600 of them).
- End-systems  $C_1, \dots, C_{100}$  (there are 100 of them).
- DNS server `dns.epfl.ch`.
- Web server `www.epfl.ch`.
- IP routers  $R_1, R_2, R_3$ , and  $R_4$ .
- Various link-layer switches (not explicitly shown).

The orange boxes represent network interfaces. For example, IP router  $R_2$  has network interfaces  $y, z, v$ , and  $u$ .

Each link between IP routers shown in the figure is annotated with its routing cost, and it has the same cost in each direction.

All end-systems in AS0 use `dns.epfl.ch` as their local DNS server.

The intra-domain routing protocol of AS0 uses the Dijkstra algorithm that we saw in class.

The time-to-live (TTL) of DNS records and ARP-table entries is 24 hours.

You can find a copy of this network topology at the end of the exam (next to last page). You can detach it so that you can look at the topology while solving the problem, without having to turn the pages back and forth.

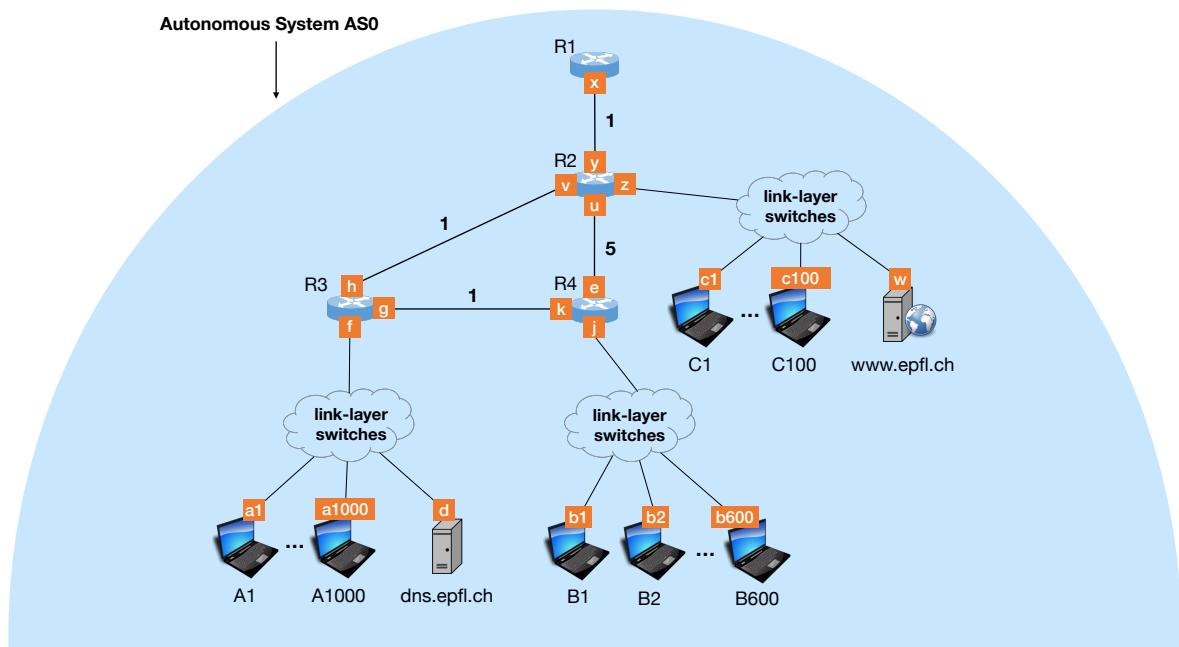


Figure 1: Network topology for Problem 2.

**Question 1 (5 points):**

Allocate an IP prefix to each IP subnet of AS0 following these rules:

- All IP prefixes must be allocated from 5.0.0.0/8.
- Each IP subnet must be allocated the smallest possible IP prefix.
- Assume one IP address per end-system and per-IP-router interface (but not for link-layer switches).
- Assume one broadcast IP address per IP subnet.
- You do not need to assume a network address per IP subnet (but it's not a mistake if you do).

Explain in one or two sentences how you compute each IP prefix.

**Question 2 (8 points):**

All link-layer switches have just been rebooted, and all end-system caches/ARP tables are initially empty. All routers have populated their forwarding tables according to the intra-domain routing protocol.

The user of end-system  $A_1$  visits web page `www.epf1.ch`, which contains no embedded objects (e.g., no images). Immediately after  $A_1$ 's user views `www.epf1.ch`, the user of end-system  $B_1$  visits the same web page.

State all the packets that are **received, forwarded, or transmitted by router  $R_3$  as a result of  $B_1$ 's actions and until  $B_1$ 's user can view the web page**. For example, if router  $R_3$  receives and forwards an IP packet, you should state that packet twice: once to state that  $R_3$  received it, and once to state that  $R_3$  forwarded it.

Answer by filling in Table 1. To denote the IP address or the MAC address of interface  $x$ , write “ $x$ ”. If a field is not applicable, write “ $-$ ”. To repeat a field from the above cell, write “ $:$ ”. To illustrate the format, we have provided a hypothetical example entry (thee first entry in the table).

#	Source MAC	Dest MAC	Source IP	Dst IP	Transp. prot.	Src Port	Dst Port	Application & Purpose
	$x$	$y$	$x$	$y$	UDP	5000	6000	HTTP GET image.png
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
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21								
22								
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24								
25								

Table 1: Packets received, forwarded, or transmitted by router  $R_3$  in Question 2.

**Question 3 (4 points):**

(a) Show the entries of  $R_3$ 's forwarding table that match packets addressed to AS0.

(b) Suppose the link between  $R_2$  and  $R_3$  is cut (and cannot be repaired). Show the entries of  $R_3$ 's forwarding table that match packets addressed to AS0 after the intra-domain routing protocol reconverges. Show only the entries that change after the cut.

(c) Suppose that, after the link between  $R_2$  and  $R_3$  is cut, the link between  $R_1$  and  $R_2$  is also cut (and cannot be repaired). Show the entries of  $R_3$ 's forwarding table that match packets addressed to AS0 after the intra-domain routing protocol reconverges. Show only the entries that change after the (second) cut.

**Question 4 (4 points):**

Ignore the events of Question 3 (pretend they didn't happen).

Suppose the IP subnet behind interface  $j$  of IP router  $R_4$  is a private IP subnet (i.e., it uses private IP addresses), and  $R_4$  acts as a Network Address Translation (NAT) gateway (for both TCP and UDP traffic).

(a) How does this change your answer to Question 2? Write down only the modified lines; use the '#' column to refer to the designated row in Table 1. If a field between the original and modified line remains the same, leave it empty. To illustrate the format, we have provided a hypothetical example entry (the first entry in the table).

Table 2: Packets received, forwarded, or transmitted by router  $R_3$  in Question 4.

(b) What state (information for ongoing communications) does  $R_4$  need to keep to operate as a NAT gateway? Show its state at the end of the events of Question 2 (i.e., after  $B_1$ 's user has received all the packets needed to view the web page).

**Question 5 (4 points):**

Considering the conditions of **Question 4**:

(a) Does the fact that  $R_4$  is a NAT gateway restrict the number of parallel (simultaneous) TCP connections that  $B_1$  can establish with other end-systems located in the same IP subnet? Justify your answer.

(b) Does the fact that  $R_4$  is a NAT gateway restrict the number of parallel (simultaneous) TCP connections that  $B_1$  can establish with other end-systems located in different IP subnets? Justify your answer.

### Problem 3

**(20 points)**

Assume the following for all the questions in this problem:

- Alice and Bob communicate using TCP at the transport layer.
- Fast Retransmit/Fast Recovery are DISABLED.
- The maximum segment size is  $MSS = 1$  byte.
- The TCP timeout is 2 RTT, where RTT is the sender's estimate of the round trip time from sender to receiver. Both RTT and the TCP timeout stay fixed throughout the TCP connection.
- Transmission delays are negligible.
- A TCP receiver sends an ACK every time it receives a data segment.
- Alice and Bob do not use the Secure Sockets Layer (SSL) or any other security mechanism.

When you complete the diagram in Questions 1 and 2, the following information should be visible:

- All the segments (including the ACKs) exchanged between the communicating end-systems.
- The sequence numbers of all data segments sent from Alice to Bob.
- The acknowledgment numbers of all ACKs sent from Bob to Alice.
- The state of Alice's congestion-control algorithm.
- The size of Alice's congestion window ( $cwnd$ ) in bytes.
- The value of Alice's congestion threshold ( $ssthresh$ ) in bytes.
- Any dropped segments.
- If your answer includes any timeouts, mark them clearly (on the side where the timeout occurs) and indicate the sequence number of the data segment that timed out.

**Question 1 (5 points):**

A process running on Alice's computer has established (sometime in the past) a TCP connection with an online-store process running on Bob's computer and has sent to it some number of bytes. Bob's process does not send any data to Alice's process throughout this question. Bob always advertizes a receiver window of 1000 bytes to Alice.

At time  $t_0$  Alice's congestion window is 4 bytes, and no packet loss has occurred since the establishment of the TCP connection. At that moment, Alice's process produces 12 bytes to send to Bob's process. Each byte produced by Alice's process carries a distinct query (command). The next sequence number (that Bob is expecting) is 1.

Alice's 3rd segment (counting from time  $t_0$ ) is lost. No other segment is lost, corrupted, unpredictably delayed, or reordered.

Show all the segments sent by Alice and Bob starting at time  $t_0$ . Use the diagram in Figure 2 on the next page. You can find a copy of the same diagram at the end of the exam, to first do a draft, if you wish.

		State of the congestion control algorithm for Alice	Sequence number diagram	
cwnd [bytes]	ssthresh [bytes]		Sequence number	Acknowledgement number
.....	.....	.....	Alice	Bob

Figure 2: Sequence diagram to be completed for Question 1.

**Question 2 (5 points):**

Answer again Question 1 but under the following changed condition:

No segment is lost (not even Alice's 3rd segment), corrupted, or unpredictably delayed. However, starting at time  $t_0$ , a malicious switch on the path from Alice to Bob wants Bob's process to execute the queries produced by Alice's process in a different order than the one in which she produced and sent them. To this end, the malicious switch swaps each pair of segments sent by Alice, causing Bob to receive Alice's 2nd segment, then her 1st segment, then her 4th segment, then her 3rd segment, and so on.

Show all the segments sent by Alice and Bob starting at time  $t_0$ . Use the diagram in Figure 3 on the next page. You can find a copy of the same diagram at the end of the exam, to first do a draft, if you wish.

		State of the congestion control algorithm for Alice	Sequence number diagram	
cwnd [bytes]	ssthresh [bytes]		Sequence number	Acknowledgement number
.....	.....	.....	Alice	Bob

Figure 3: Sequence diagram to be completed for Question 2.

**Question 3 (4 points):**

Consider again the events of Question 2.

Does the malicious switch succeed in its attack? I.e., does it manage to convince Bob that Alice produced and sent her queries in a different order than she actually did? If yes, explain why. If not, explain what exactly the malicious switch should have done to succeed in its attack.

**Question 4 (6 points):**

Ignore the previous questions. Consider the following topology, where  $R$  denotes transmission rate:

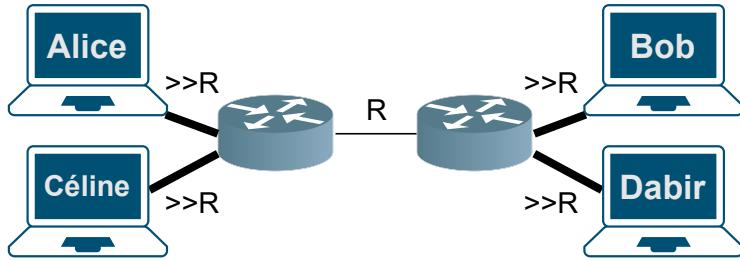


Figure 4: Network topology for Problem 3 question 4.

At time  $t_0$ , a process in Alice's computer and a process in Bob's computer establishes a TCP connection between them. From that point on, Alice's process produces a random amount of bytes for Bob's process, then stays silent for a random amount of time, then again produces a random amount of bytes for Bob's process, and so on; this continues indefinitely. Alice and Bob use the first TCP congestion-control algorithm that we saw in class (TCP-Tahoe, which does not do Fast Retransmit).

At time  $t_1 > t_0$ , a process in Céline's computer and a process in Dabir's computer establish a TCP connection between them. Once the connection is established, Céline's process produces an infinite amount of bytes for Dabir's process.

(a) Suppose Céline and Dabir use the same TCP congestion-control algorithm as Alice and Bob. Does the Céline-Dabir communication affect the throughput of the Alice-Bob communication? Justify your answer.

(b) Suppose Céline and Dabir have the following goal for their communication: maximize their throughput, as long as they cause zero packet loss to the Alice-Bob communication.

Propose a congestion-control algorithm, to be used by Céline and Dabir, that achieves this goal. In particular, answer the following questions:

- What event(s) should cause this algorithm to increase its congestion window?
- What event(s) should cause this algorithm to decrease its congestion window?
- By how much would you suggest to increase or decrease the congestion window at each event?

Justify your answers.

## **Scratch Paper**



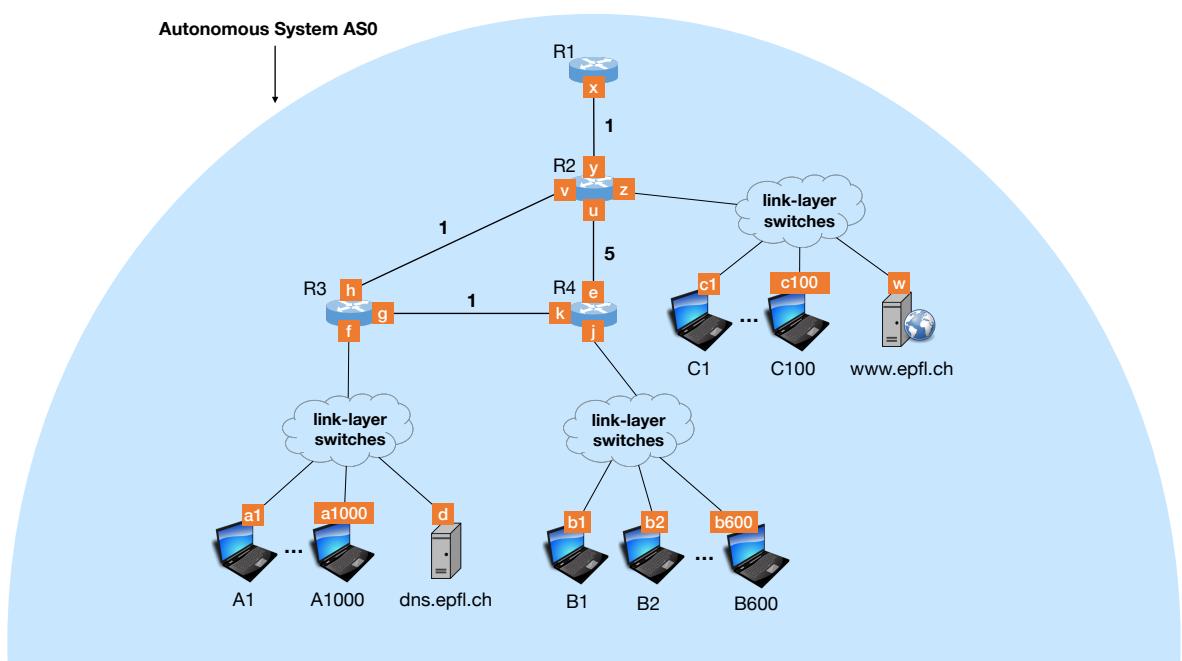


Figure 5: The Network Topology used in Problem 2.

		State of the congestion control algorithm for Alice	Sequence number diagram	
cwnd [bytes]	ssthresh [bytes]		Sequence number	Acknowledgement number
.....	.....	.....	<b>Alice</b>	<b>Bob</b>

Figure 6: Copy of the sequence diagram to be completed for Problem 3, Question 1.

		State of the congestion control algorithm for Alice	Sequence number diagram	
cwnd [bytes]	ssthresh [bytes]		Sequence number	Acknowledgement number
.....	.....	.....	<b>Alice</b>	<b>Bob</b>

Figure 7: Copy of the sequence diagram to be completed for Problem 3, Question 2.