



# Computer Networks - Final Exam

January 27, 2022

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 21 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>		50

## Problem 1

(5 points)

For each question, please circle a single best answer.

1. Which of the following is always true for a Tier-1 Internet service provider (ISP)?
  - (a) It does not have a provider.
  - (b) It does not have customers.
  - (c) It does not have peers.
  - (d) None of the above.
2. Two packets traverse the same path (sequence of devices and links). Could they experience different transmission delays?
  - (a) Yes, if they have different sizes.
  - (b) Yes, if they carry different content.
  - (c) Yes, if they encounter different levels of congestion.
  - (d) Any of the above.
3. Two packets traverse the same path (sequence of devices and links). Could they experience different propagation delays?
  - (a) Yes, if they have different sizes.
  - (b) Yes, if they carry different headers.
  - (c) Yes, if they encounter different levels of congestion.
  - (d) No, unless the properties of a link change between packet traversals.
4. Process  $P_1$  running on end-system  $E_1$  sends a continuous stream of data to process  $P_2$  running on end-system  $E_2$ . The throughput from  $P_1$  to  $P_2$  is  $T$ . What does this say about the network links between  $E_1$  and  $E_2$ ?
  - (a) Each link has transmission rate at least  $T$ .
  - (b) Each link has transmission rate at most  $T$ .
  - (c) The sum of the transmission rates of the links is  $T$ .
  - (d) None of the above.
5. You type in your web browser `www.epfl.ch`. Your browser times out (fails to show you the requested page). What could be the reason?
  - (a) Your computer is not connected to the Internet.
  - (b) Your local DNS server is unreachable.
  - (c) The web server that hosts `www.epfl.ch` is broken.
  - (d) Any of the above.

6. You visit a given URL. Then you change laptops and you visit again the same URL, but you get a different web page (different colors, some differences in content). What is the likeliest explanation?
- (a) Your new laptop has a different IP address.
  - (b) Your new laptop uses a different proxy web server(\*).
  - (c) The web server that hosts the given URL uses cookies.
  - (d) None of the above makes sense.
7. Alice communicates with Amazon over the secure sockets layer (SSL), as we saw in class: Alice establishes a TCP connection to Amazon and sends an “SSL Hello” message. Amazon responds with its public key and certificate. As a result of this exchange:
- (a) Alice is certain(\*\*) that she is communicating with Amazon.
  - (b) Amazon is certain(\*\*) that it is communicating with someone named Alice.
  - (c) Both of the above.
  - (d) None of the above.
8. TCP provides reliable data delivery. Some link layers also provide reliable data delivery. Why provide reliable data delivery at two different layers?
- (a) Just in case one of the two layers malfunctions.
  - (b) Each layer recovers from different loss/corruption events.
  - (c) As a performance optimization.
  - (d) No good reason—it’s a bad idea.
9. A link-layer switch normally never does the following:
- (a) Generates or responds to an ARP request.
  - (b) Updates its forwarding table.
  - (c) Broadcasts a packet.
  - (d) Participates in the spanning tree protocol.
10. Which of the following is true?
- (a) The Internet contains multiple Autonomous Systems (ASes).
  - (b) An Autonomous System (AS) typically contains multiple IP routers and IP subnets.
  - (c) An IP subnet contains at least one network link and potentially link-layer switches.
  - (d) All of the above.

(\*) Assume that all proxy web servers work correctly.

(\*\*) Certain, assuming the certificate authority and Amazon’s keys are not compromised.

## Problem 2

(25 points)

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

- End-systems  $E_1, \dots, E_{10000}$  (there are 10000 of them).
- End-systems  $B_1, \dots, B_{99}$  (there are 99 of them).
- DNS server `dns.xxx.com`.
- IP routers  $R_2, R_3,$  and  $R_4$ .
- Link-layer switches  $S_1, S_2,$  and others (not explicitly shown).

The orange boxes represent network interfaces.

For example, router  $R_3$  has network interfaces f, g, and h.

All the links shown in the figure have cost 1 in each direction.

All end-systems in AS0 use `dns.xxx.com` as their local DNS server.

The intra-domain routing protocol of AS0 is the Bellman-Ford protocol with poisoned reverse that we saw in class.

Web server `www.yyy.com` and IP router  $R_1$  belong to other ASes.

The time-to-live (TTL) of DNS records, L2-forwarding-table entries, and ARP-table entries is an hour.

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.

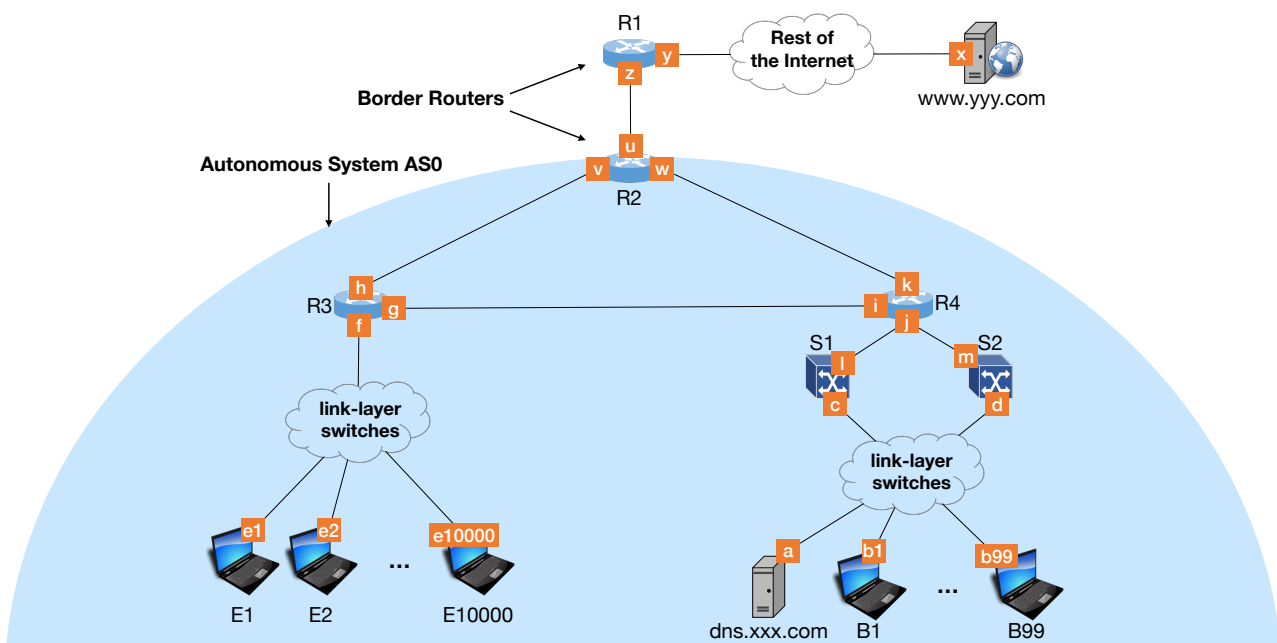


Figure 1: Network topology for Problem 2.

**Question 1 (5 points):**

Allocate an IP prefix to each IP subnet of AS0 (the blue bubble only) following these rules:

- All IP prefixes must be allocated from 4.0.0.0/8.
- 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.

The user of end-system  $E_1$  visits web page `www.yyy.com`, which contains no embedded objects (e.g., no images). Immediately after  $E_1$ 's user views `www.yyy.com`, the user of end-system  $E_2$  visits the same web page.

State all the packets that are **received, forwarded, or transmitted by router  $R_3$  as a result of  $E_2$ 's actions and until  $E_2$ 's user can view the web page**. For example, if a packet follows path  $E_2 \rightarrow R_3 \rightarrow \dots \text{www.yyy.com}$ , then you should state it 2 times: when it is received by  $R_3$ , and when it is forwarded by  $R_3$ .

Answer by filling in Table 1. To denote the IP address or the MAC address of interface  $s$ , write " $s$ ". 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.

#	Source MAC	Dest MAC	Source IP	Dst IP	Transp. prot.	Src Port	Dst Port	Application & Purpose
	<i>s</i>	<i>d</i>	<i>s</i>	<i>d</i>	UDP	5000	6000	HTTP GET image.png
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
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15								
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25								

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

**Question 3 (5 points):**

(a) In which routing protocol do routers  $R_1$  and  $R_2$  participate together? Justify your answer.

(b) Show the entry or entries of  $R_1$ 's forwarding table that match/matches packets addressed to AS0. Keep in mind that only the part of 4.0.0.0/8 that you allocated to AS0's IP subnets belongs to AS0; the rest of 4.0.0.0/8 may be allocated/belong to other ASes.



**Question 4 (5 points):**

Assume the link between IP routers  $R_2$  and  $R_4$  breaks, and the intra-domain routing protocol of AS0 converges again.

(a) Which IP routers send/receive new routing announcements as a result of the failure? Justify your answer.

(b) Show the forwarding table of IP router  $R_3$  after the failure and subsequent convergence of the intra-domain routing protocol by filling in Table ??.

Destination IP prefix	Output interface

Table 2:  $R_3$ 's forwarding table for Question 4(b).

(c) Will IP router  $R_3$  have any poisoned reverses in its Bellman-Ford table? If yes, how many? Justify your answer.

**Question 5 (2 points):**

Assume the link between IP router  $R_4$  and link-layer switch  $S_2$  breaks.

Which IP routers send/receive new routing announcements as a result of this failure? 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  $1.5$  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 any security mechanism (like SSL), i.e., any network device that sees their packets could modify them without Alice and Bob realizing it.

When you complete the diagram in Question 1, 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 and indicate the sequence number of the data segment that timed out.

**Question 1 (5 points):**

A process running on Alice's computer establishes a TCP connection with a process running on Bob's computer and sends to it some large number of bytes. Bob's process does not send any data to Alice's process.

No segment, sent by Alice or Bob, is corrupted or dropped. The 4th segment sent by Alice (not the TCP SYN, not the 1st or the 2nd segment carrying data, the 3rd segment carrying data) takes 2RTT to reach Bob. All other segments sent by Alice take RTT to be acknowledged by Bob.

Show all the segments sent by Alice and Bob, including connection setup, until the point where Alice has transmitted 7 distinct bytes of data. 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.

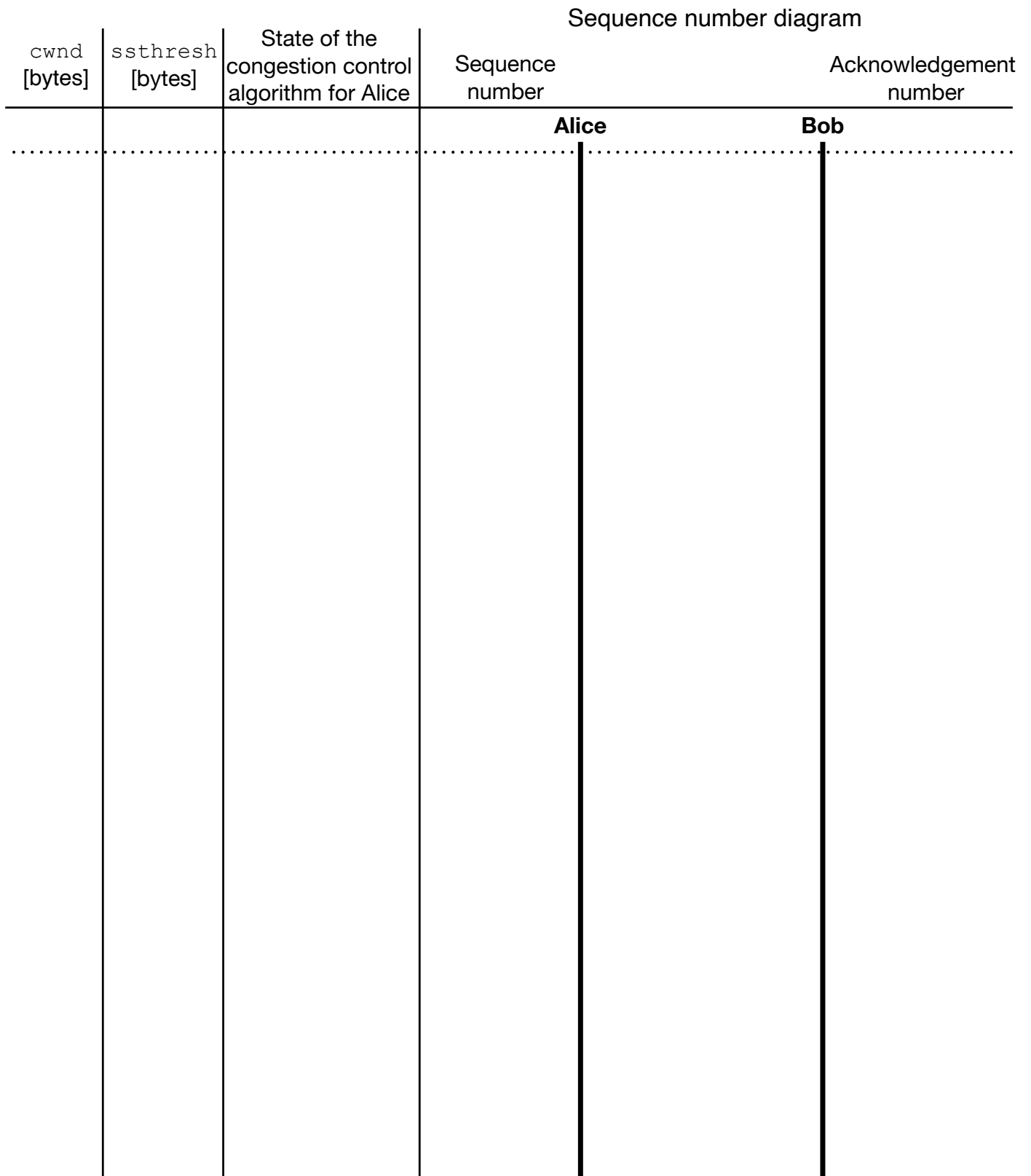


Figure 2: Sequence diagram to be completed for Question 1.

**Question 2 (5 points):**

Fig. 3 shows the network topology between Alice and Bob:

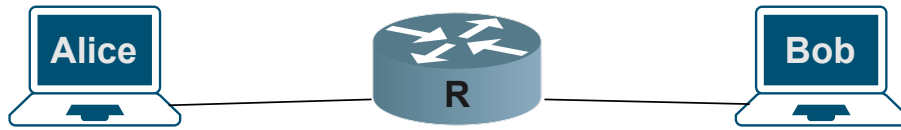


Figure 3: Network topology for Question 2.

The operator of IP router  $R$  wants to force Alice to send up to 100 bytes every RTT. Ideally, the operator would like the throughput from Alice to Bob to be as stable as possible at 100 bytes every RTT (e.g., ideally, the throughput should not fluctuate between 1 to 100 bytes per RTT). How should router  $R$  behave to achieve this goal? Describe clearly what  $R$  will do and how that will achieve the operator's goal.

**Question 3 (5 points):**

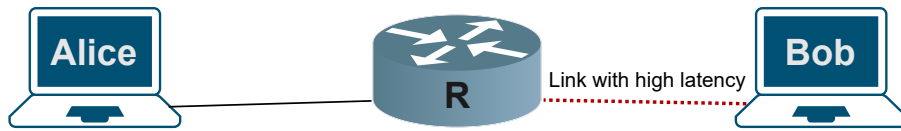


Figure 4: Network topology for Question 3.

The operator of IP router  $R$  wants to hide from Alice the fact that the link between itself and Bob has unusually high latency. How should router  $R$  behave to achieve this goal, while affecting Alice's throughput to Bob as little as possible? Describe clearly what  $R$  will do and how that will achieve the operator's goal.

**Question 4 (5 points):**

(a) Fig. 5 shows part of the server code that was given as a solution to Lab 5.

```
1 public static void main(String args[]) {
2     ServerSocket welcomeSocket = null;
3     Socket connectionSocket = null;
4
5     try {
6         // Create a socket that listens to port 6789
7         welcomeSocket = new ServerSocket(6789);
8
9         while(true) {
10            try {
11                // Get a new connection
12                System.out.println("Waiting for a new client...");
13                connectionSocket = welcomeSocket.accept();
14
15                // pass the connection socket to the handler
16                System.out.println("Handling new client...");
17                handleConnection(connectionSocket);
18            } catch (IOException ioex) {}
19        }
20    } catch (IOException ioex) {
21        System.out.println("Failed to open welcomeSocket : " + ioex.getMessage());
22    } finally {
23        try { if (welcomeSocket != null) welcomeSocket.close(); } catch(IOException e) {}
24    }
25 }
```

Figure 5: Server code for Question 4(a).

Which line is invoked (executed) when the server receives a TCP SYN segment? Which line causes a TCP SYN ACK segment to be sent in response?



(b) Google likes TCP's reliable data delivery(\*) but not TCP's performance. So, it wants Google Chrome browsers and Google's web servers to communicate reliably but without using TCP. Is this possible? I.e., is it possible for Google Chrome browsers and Google's web servers to achieve the same kind of reliable data delivery that they would achieve if they communicated over TCP but without actually communicating over TCP? Describe how or explain why it is not possible.

(\*) Packets that are corrupted or dropped by the network are retransmitted by the sender until received or until some timeout occurs.

## Scratch Paper



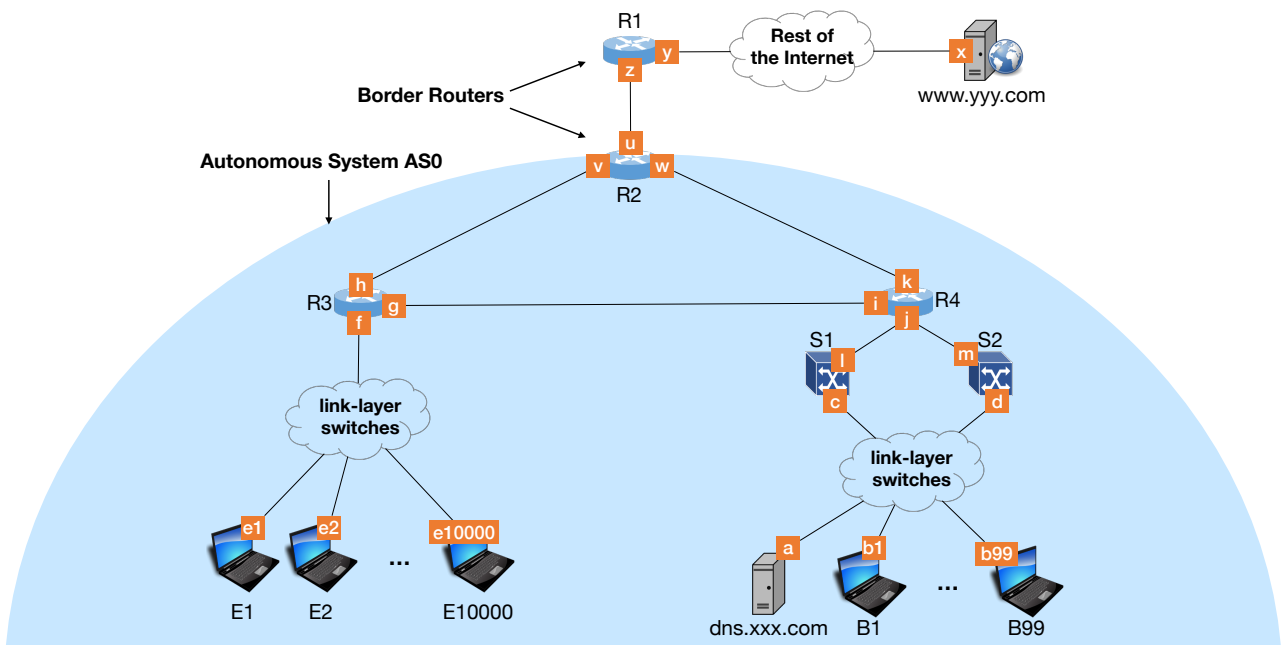


Figure 6: The Network Topology used in Problem 2.

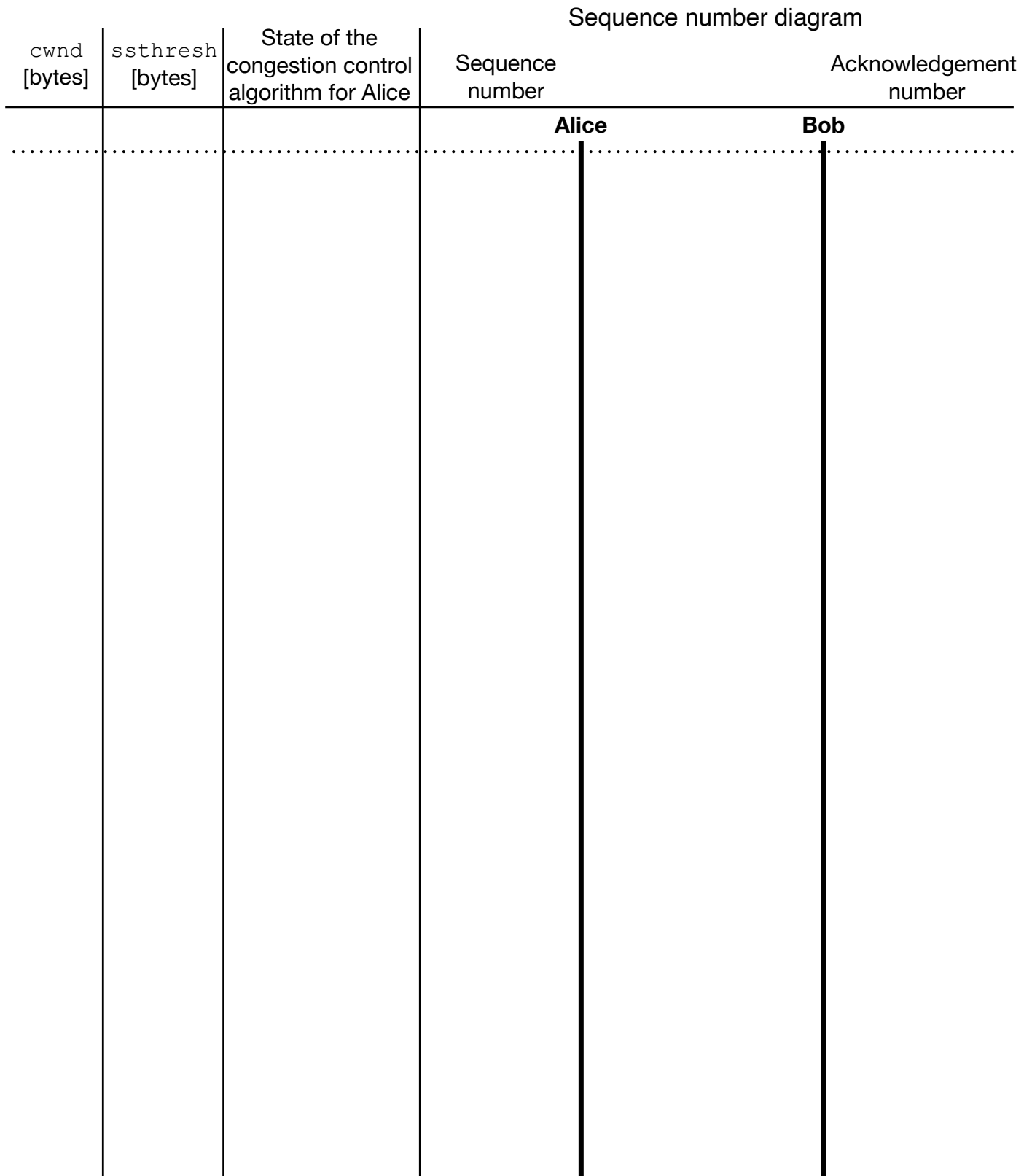


Figure 7: Copy of the sequence diagram to be completed for Problem 3, Question 1.