Computer Networks - Midterm

November 10, 2023

Duration: 2h

- This is a closed-book exam. You can use two A4 "cheat-sheets."
- Write your answers clearly, in English or in French, using extra sheets if necessary.
- It consists of 3 problems. The total number of points is 50.
- This document contains 17 pages.

Good luck!

Last Name:
First Name:

SCIPER No:

(answers to the questions are shown in italic and blue) (grades in red)

1 Short questions (5 points)

For each question, circle a single best answer.

1. Your home is connected to the Internet over Fiber to the Home (FTTH). On Saturday night, you often experience poor network performance when communicating with your favorite game server. What could be the reason?
   (a) The links that connect your home to the Internet are congested because many of your neighbours are downloading movies.
   (b) The link that connects the game server to the Internet is congested because many players are using it. *(Correct)*
   (c) Either of the above could be the reason.
   (d) None of the above could be the reason.

2. Which of the following may read and update the network-layer header of a packet?
   (a) An end-system.
   (b) A packet switch.
   (c) Either of the above. *(Correct)*
   (d) None of the above.

3. Alice and Bob are connected over a network link of transmission rate R and propagation delay D. The following is always true:
   (a) The round-trip time (RTT) from Alice to Bob and back is approximately D.
   (b) The maximum throughput achievable from Alice to Bob is R. *(Correct)*
   (c) Both of the above.
   (d) None of the above.

4. Consider a queue inside a packet switch; the queue feeds a network link. If you change the processing delay of the switch, you may affect:
   (a) The transmission delay experienced by the packets when they are transmitted on the link.
   (b) The queuing delay experienced by packets in the queue. *(Correct)*
   (c) Either of the above.
   (d) None of the above.

5. Two packets of the same size traverse the same network path at different times and experience significantly different end-to-end delays. You may conclude that the dominant delay factor for the packet that took longer was:
   (a) Queuing delay. *(Correct)*
   (b) Transmission delay.
   (c) Propagation delay.
   (d) It could be any of the above.

6. The administrator of an authoritative DNS server wants to change a mapping provided by the server (i.e., change the IP address that corresponds to a DNS name). Can the administrator be 100% sure that the old mapping (which is not valid any more) is never cached at any other DNS server around the world?

   (a) Yes, that is guaranteed by the TCP protocol.
   (b) Yes, that is guaranteed by the DNS protocol.
   (c) Yes, if the time-to-live (TTL) of the old mapping is 0. *(Correct)*
   (d) No, it is not possible.

7. Alice distributes a file to 100 friends using the client/server approach. The resulting file distribution time (time for all friends to get the file) is X. Then, Alice distributes another file, of the same size, to the same friends, using the peer-to-peer approach we saw in class. The resulting file distribution time is approximately X/100. Assume network conditions never change. Which of the following statements is plausible?

   (a) In both approaches, the bottleneck is Alice's Internet connection (in particular, her upload capacity). *(Correct)*
   (b) In both approaches, the bottleneck is the Internet connection of one of Alice's friends (in particular, the friend's download capacity).
   (c) It could be either of the above.
   (d) It could not be any of the above.

8. Suppose a network guarantees that packets are never corrupted, lost, or unpredictably delayed. Which of the following elements of reliable data delivery are unnecessary for this network?

   (a) Checksums.
   (b) Timeouts.
   (c) Retransmissions.
   (d) All of the above. *(Correct)*

9. Based on what we saw in class, how can we prevent TCP highjacking attacks?

   (a) With web cookies.
   (b) With random sequence numbers. *(Correct)*
   (c) By pushing the relevant state to the TCP client, hence removing the need for an incomplete-connection buffer.
   (d) We cannot prevent it.

10. What would happen to processes comminicating over TCP if we removed from TCP the fast-retransmit mechanism?

   (a) Nothing.
   (b) The processes would experience less loss.
   (c) The processes would experiene less congestion.
   (d) The processes would achieve lower throughput *(Correct)*

2 Web/DNS, delay computation, TCP (29 points)

Consider the network in figure 1.

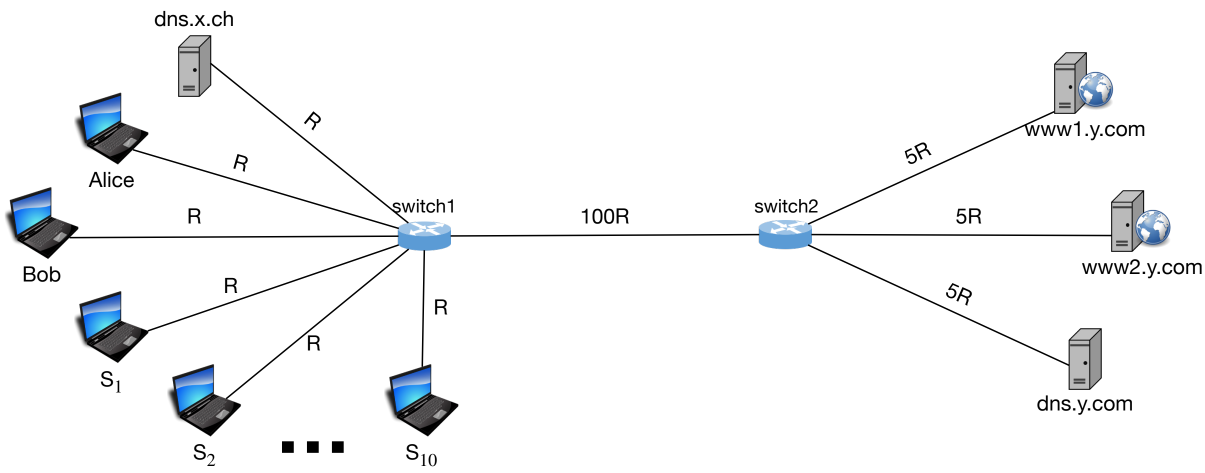


Figure 1: Network topology for Problem 2

- The maximum segment size is MSS.
- Each link has propagation delay D.
- For each link, the transmission rate has (in each direction) the value shown in the figure.
- **switch1** and **switch2** are store-and-forward packet switches with 0 processing delay.
- **dns.x.ch** acts as the local DNS server of all computers connected to **switch1**. It performs iterative DNS requests.
- **dns.y.com** is the only authoritative DNS server for the **y.com** low-level domain.
- Web browsers and web servers communicate through persistent TCP connections (i.e., they reuse each established TCP connection to exchange as much traffic as possible).
- At the beginning of this problem, all caches (of all kinds) are empty, and there are no established TCP connections.
- All DNS records have time-to-live (TTL) 24 hours.
- There is no other traffic on the Internet other than the traffic caused by the actions described in this problem.
- There is no packet loss or corruption in this problem.

Packet sizes:

- DNS requests and responses, HTTP requests, and TCP connection-setup packets experience 0 transmission delay.
- All headers (including HTTP headers) are insignificant, i.e., you can assume they have size 0.
- Size of `www2.y.com/index.html`: MSS
- Size of `www2.y.com/logo.jpg`: 6 MSS

Question 1 (7 **points):**

Alice types in her web browser `http://www1.y.com/index.html` and presses enter.

Soon after Alice visits `http://www1.y.com/index.html`, Bob types in his browser `http://www2.y.com/index.html` and presses enter. This web page references one embedded image file, `http://www2.y.com/logo.jpg`.

List all the packets that are sent or received by any computer as a result of Bob's action. Include any TCP connection-setup packets, but ignore any packets that carry only TCP ACKs. For each packet, list which computer sends it (e.g., "Bob") and which computer receives it (e.g., "www2.y.com"), the source and destination port numbers, and briefly its purpose (e.g., request for ...). Use " if the value of a cell is the same as that of the cell above.

Packet #	Source	Destination	Source port	Dest. port	Purpose
1	bob	dns.x.ch	1000	53	DNS request for www2.y.com's IP address
2	dns.x.ch	dns.y.com	2000	53	DNS request for www2.y.com's IP address
3	dns.y.com	dns.x.ch	53	2000	DNS response
4	dns.x.ch	bob	53	1000	DNS response
5	bob	www2.y.com	3000	80	connection-setup request
6	www2.y.com	bob	80	3000	connection-setup response
7	bob	www2.y.com	3000	80	HTTP GET request for base file
8	www2.y.com	bob	80	3000	HTTP GET response
9	bob	www2.y.com	3000	80	HTTP GET request for image
10	www2.y.com	bob	80	3000	HTTP GET response, first part
11	www2.y.com	bob	80	3000	HTTP GET response, second part
12	www2.y.com	bob	80	3000	HTTP GET response, third part
13	www2.y.com	bob	80	3000	HTTP GET response, fourth part
14	www2.y.com	bob	80	3000	HTTP GET response, fifth part
15	www2.y.com	bob	80	3000	HTTP GET response, sixth part

Table 1: Table to fill in for Problem 2, Question 1.

Question 2(a) (4 **points):**

How much time passes from the moment Bob presses enter until Bob's computer downloads the base file for `http://www2.y.com/index.html`? Justify your answer.

The base file fits in a single packet. The bottleneck for transferring this packet from the web server to Bob is Bob's link, which has the smallest transmission rate. Hence:

- DNS request + DNS response: $10D$
- TCP connection-setup request + response: $6D$
- HTTP GET request for base file: $3D$
- HTTP GET response: $3D + \frac{MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R}$
- Total: sum of all

Question 2(b) (6 **points):**

How much time passes from the moment Bob's computer has downloaded the base file until it downloads all elements needed to display `http://www2.y.com/index.html`? Justify your answer.

The image file fits in 6 packets. The web server cannot send these 6 packets one after the other: After it sends the base file and receives Bob's ACK, it sets its window to 2, hence it can send the first two packets. After it sends these packets and receives Bob's ACKs, it sets its window to 4, hence it can send the remaining four packets. The bottleneck for transferring these packets from the web server to Bob is still Bob's link. Hence:

- HTTP GET request for image file: $3D$
- HTTP GET response, first 2 pieces: $3D + \frac{MSS}{5R} + \frac{MSS}{100R} + \frac{2MSS}{R}$
- ACK from Bob: $3D$
- HTTP GET response, last 4 pieces: $3D + \frac{MSS}{5R} + \frac{MSS}{100R} + \frac{4MSS}{R}$
- Total: sum of all

Question 3(a)* (5 points):

This question is unrelated to Alice and Bob.

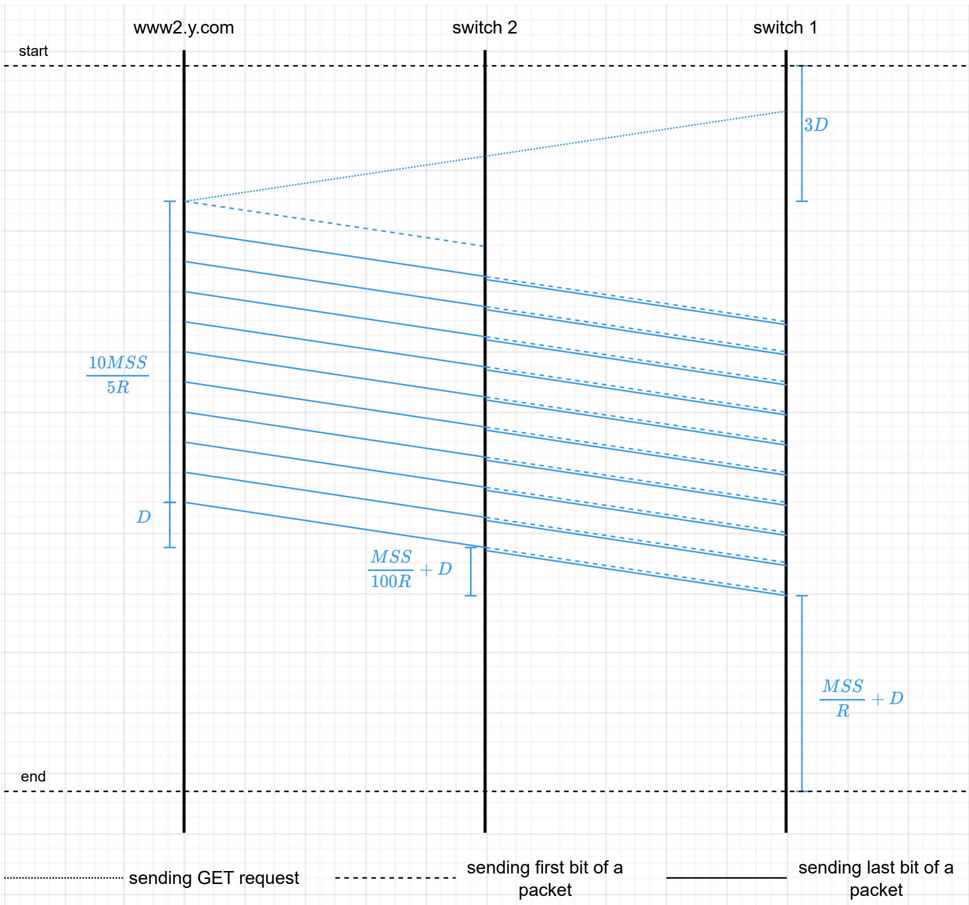
Each of end-systems S_1 to S_{10} (there are 10 of them) has already established a TCP connection with `www2.y.com` and has already exchanged a very large amount of data.

They all send an HTTP GET request for `http://www2.y.com/index.html` at the same time.

How much time passes from the moment they start sending their requests until the last of them downloads the base file for `http://www2.y.com/index.html`? Justify your answer.

The difference from Question 2(a) is that the web server is sending 10 base-file responses (so, 10 packets), which are going to 10 different end-systems. As a result, the bottleneck for transferring these packets is the web server's link (which must carry all the packets), as opposed to the end-systems' links (as each of them carries only one packet since the 10 packets are sent in parallel to the 10 end-systems). Hence:

- HTTP GET requests for base file: $3D$
- HTTP GET responses: $3D + \frac{10MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R}$
- Total: sum of all



Problem 2, Question 3(a), Solution

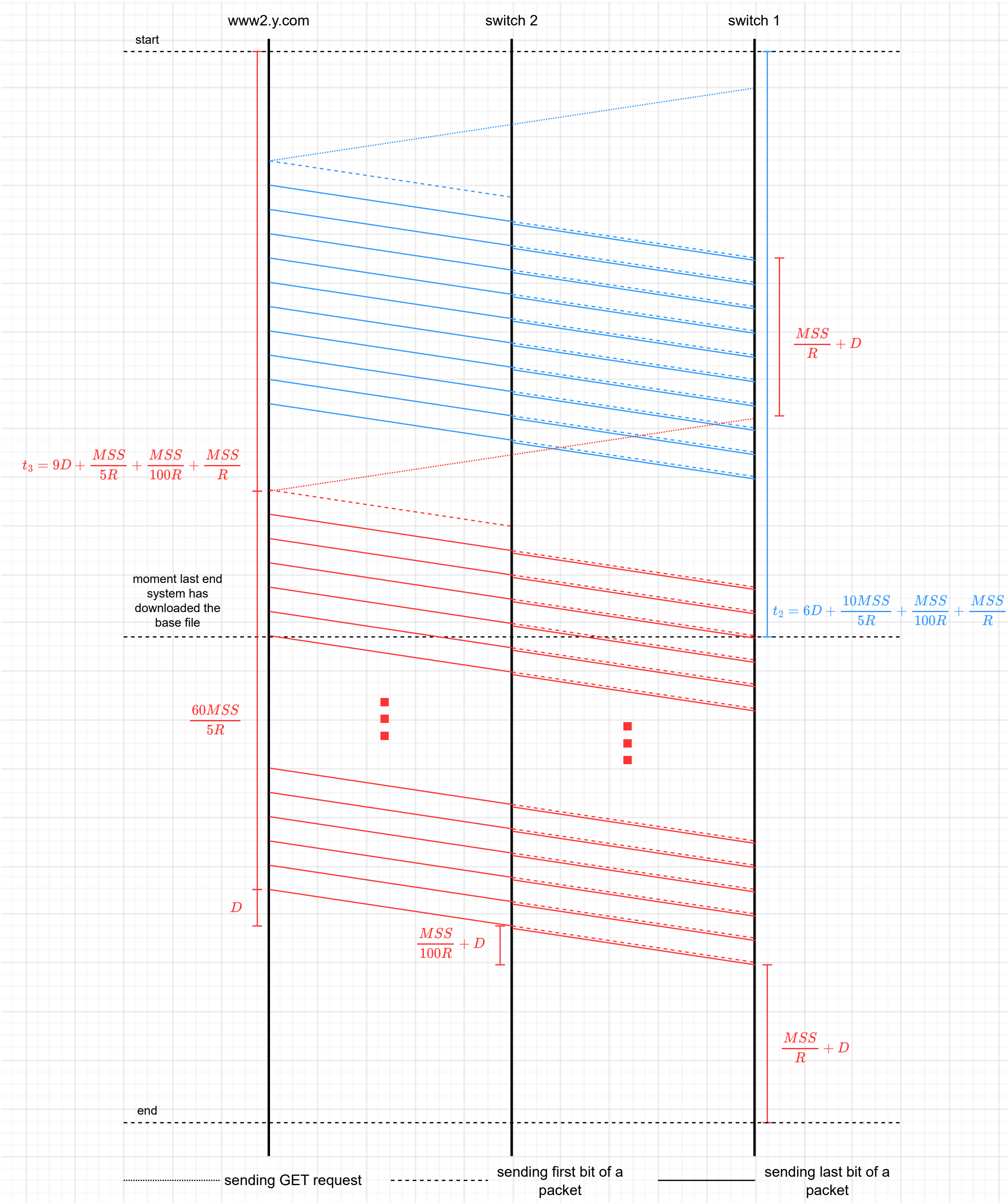
Question 3(b)** (7 points):**

How much time passes from the moment the last end-system has downloaded the base file until the last end-system downloads all the elements needed to display `http://www2.y.com/index.html`? Justify your answer.

Assume that $D \gg \frac{MSS}{R}$, if that makes your life easier.

Since all end-systems have exchanged a large amount of data with the web server, we assume that the web server's window in each TCP connection has opened enough that the web server can send all the logo responses one after the other. Hence:

- The web server receives the requests for the base file at $t_0 = 3D$ and takes $\frac{10MSS}{5R}$ to transmit the responses. The last base-file response takes an additional $3D + \frac{MSS}{100R} + \frac{MSS}{R}$ to reach the last end-system.
- Hence, the web server finishes transmitting the base-file responses at $t_1 = 3D + \frac{10MSS}{5R}$, and the last end-system receives the last base-file response at $t_2 = 6D + \frac{10MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R}$.
- Each base-file response takes $\delta_1 = 3D + \frac{MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R}$ to reach the target end-system. Each request for the logo takes $\delta_2 = 3D$ to reach the web server. Hence, the web server receives the first request for the logo at $t_3 = t_0 + \delta_1 + \delta_2 = 9D + \frac{MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R}$.
- Assuming $D \gg \frac{MSS}{R}$, $t_3 \gg t_1$; hence, the web server starts sending the first logo response at t_3, when it receives the corresponding request.
- From the moment the web server starts sending the logo responses, it takes $\delta_3 = 3D + \frac{60MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R}$ until the last logo response reaches the last end-system. Hence, the last end-system receives the last logo response at $t_4 = t_3 + \delta_3 = 12D + \frac{61MSS}{5R} + \frac{2MSS}{100R} + \frac{2MSS}{R}$.
- The answer to the question is $t_4 - t_2 = 6D + 51\frac{MSS}{5R} + \frac{MSS}{100R} + \frac{MSS}{R} = 6D + \frac{11.21MSS}{R}$.



Problem 2, Question 3(b), Solution

3 TCP and throughput (16 points)

Assume the following for all the questions in this problem:

- Alice and Bob communicate using TCP at the transport layer.
- 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 and back.
- A TCP receiver sends an ACK every time it receives a data segment.

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 (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 establishes a TCP connection with a process running on Bob's computer and sends 17 bytes to it.

Alice's 9th segment (counting from her TCP SYN packet) is lost. No other segment is lost, corrupted, unpredictably delayed, or reordered.

Fast retransmit/fast recovery are DISabled for this question.

Show all the segments sent by Alice and Bob. 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.

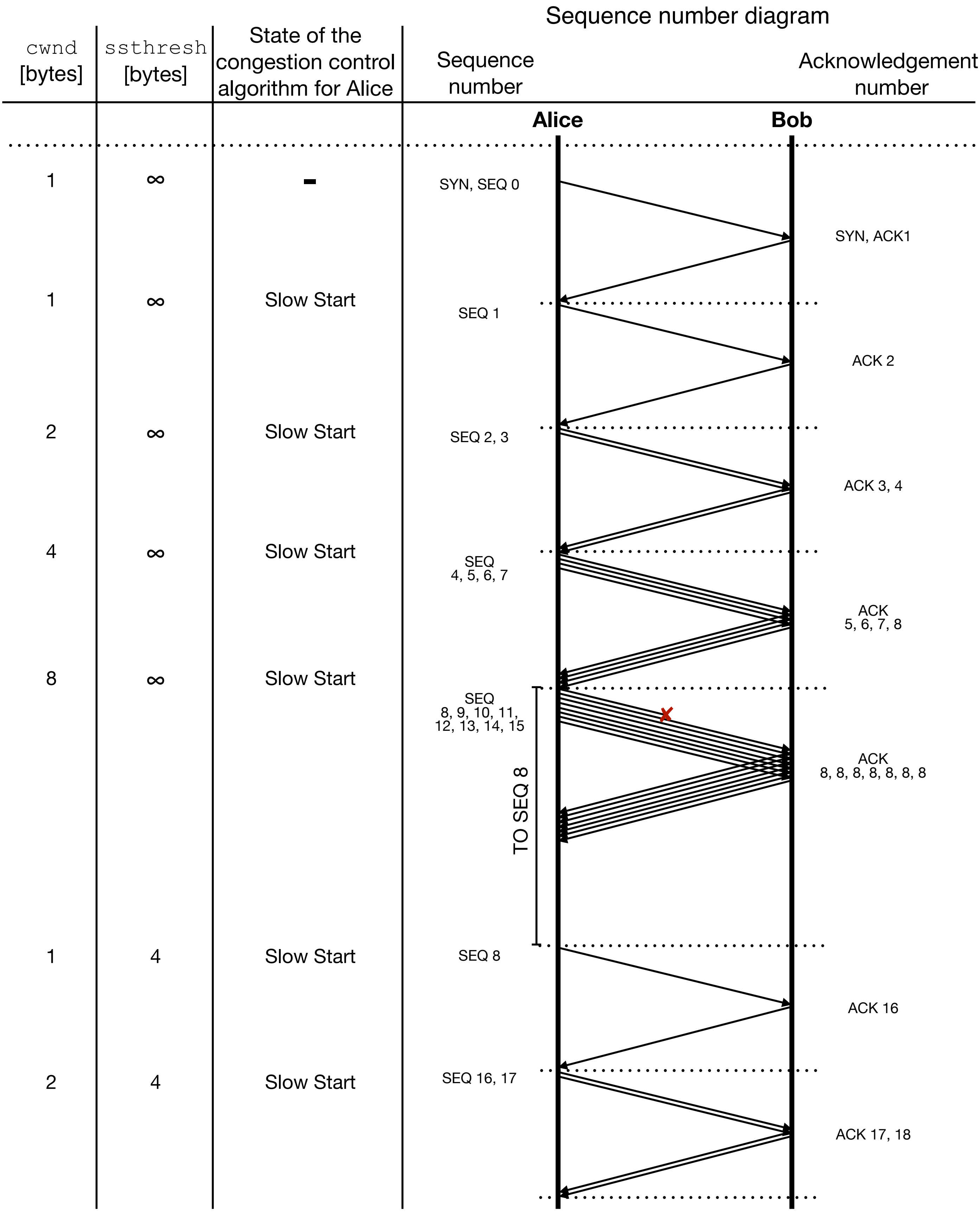


Figure 2: Sequence diagram to be completed for Problem 3, Question 1.

Question 2 (3 **points):**

What is the average throughput from Alice's to Bob's process achieved in Question 1?

Assuming the transmission delay of a small number of packets is insignificant relative to the RTT, the average throughput is 17 bytes / 7.5 RTTs:

- 4 RTTs until Alice transmits her 9th segment;
- 2 RTTs until the timeout occurs;
- 1 RTT for Bob to ACK Alice's retransmission;
- 0.5 RTT for Alice to transmit the last two bytes.

Question 3 (8 **points):**

After the events of Question 1, Alice's process continues to send bytes to Bob's proccess.

Fast retransmit/fast recovery are ENabled for this question.

Figure 3 shows Alice's **sender** window at the end of every RTT, over some period of time. Throughout this period, Alice's process has an infinite amount of data to send to Bob's process. Remember that the sender window is related to the congestion window, but it is not the same thing.

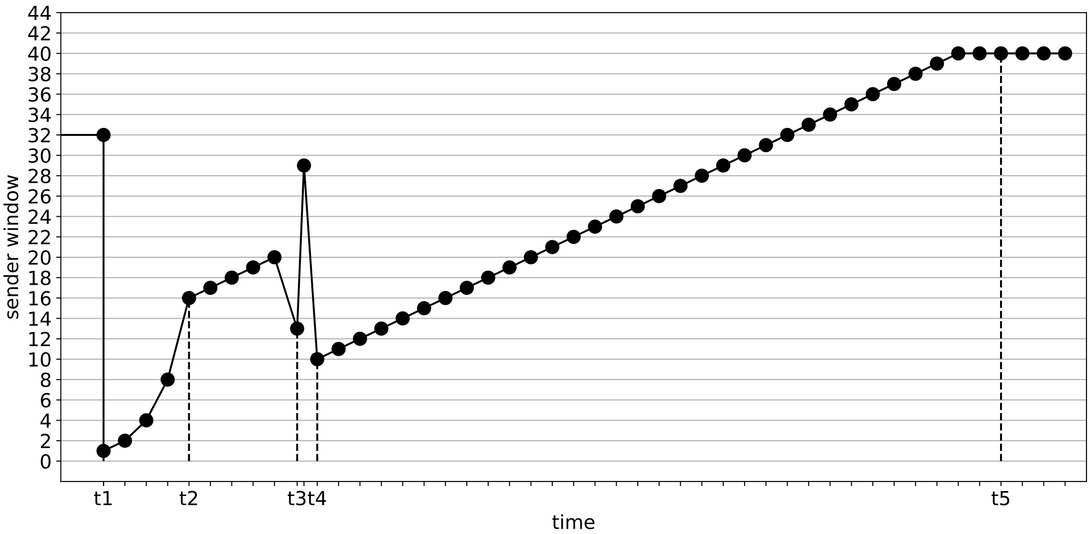


Figure 3: Alice's sender window in Problem 3, Question 3.

Explain what may have caused the sender window to change or remain the same at each of the following moments:

At time t_1:

A timeout. We can tell because the sender window was reset to 1.

At time t_2:

Alice's congestion-control algorithm entered the congestion avoidance phase. We can tell because the sender window increases linearly (by 1 every RTT) from this point on.

At time t_3*:

Alice received 3 duplicate ACKs, which caused her to decrease her window, do a fast-retransmit, and enter fast recovery. In particular, she decreased her window by half (from 20 to 10), then inflated it by 3 (to 13) to account for the segments that Bob implicitly acknowledged through the duplicate ACKs.

At time t_4**:

Alice received a new ACK, which caused her to deflate her window, exit fast recovery, and go to acongestion avoidance. In particular, she set her window to ssthresh (half of what it was when Alice received the three duplicate ACKs), which is 10 in this case.

At time t_5**:

Bob signalled to Alice that his receiver window is 32. Hence, Alice does not increase her sender window beyond this value (even though she keeps increasing her congestion window).

Scratch Paper

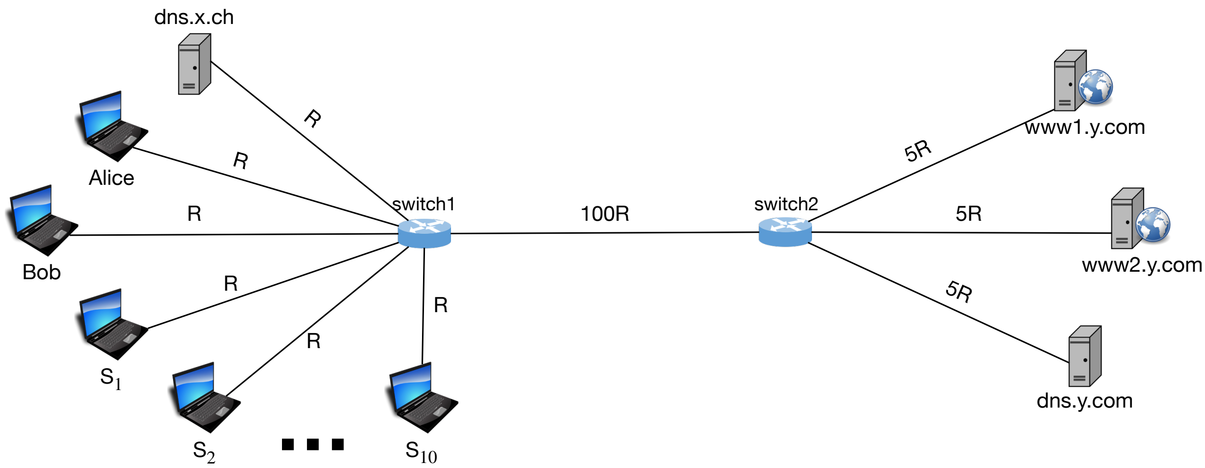


Figure 4: The network topology used in Problem 2.

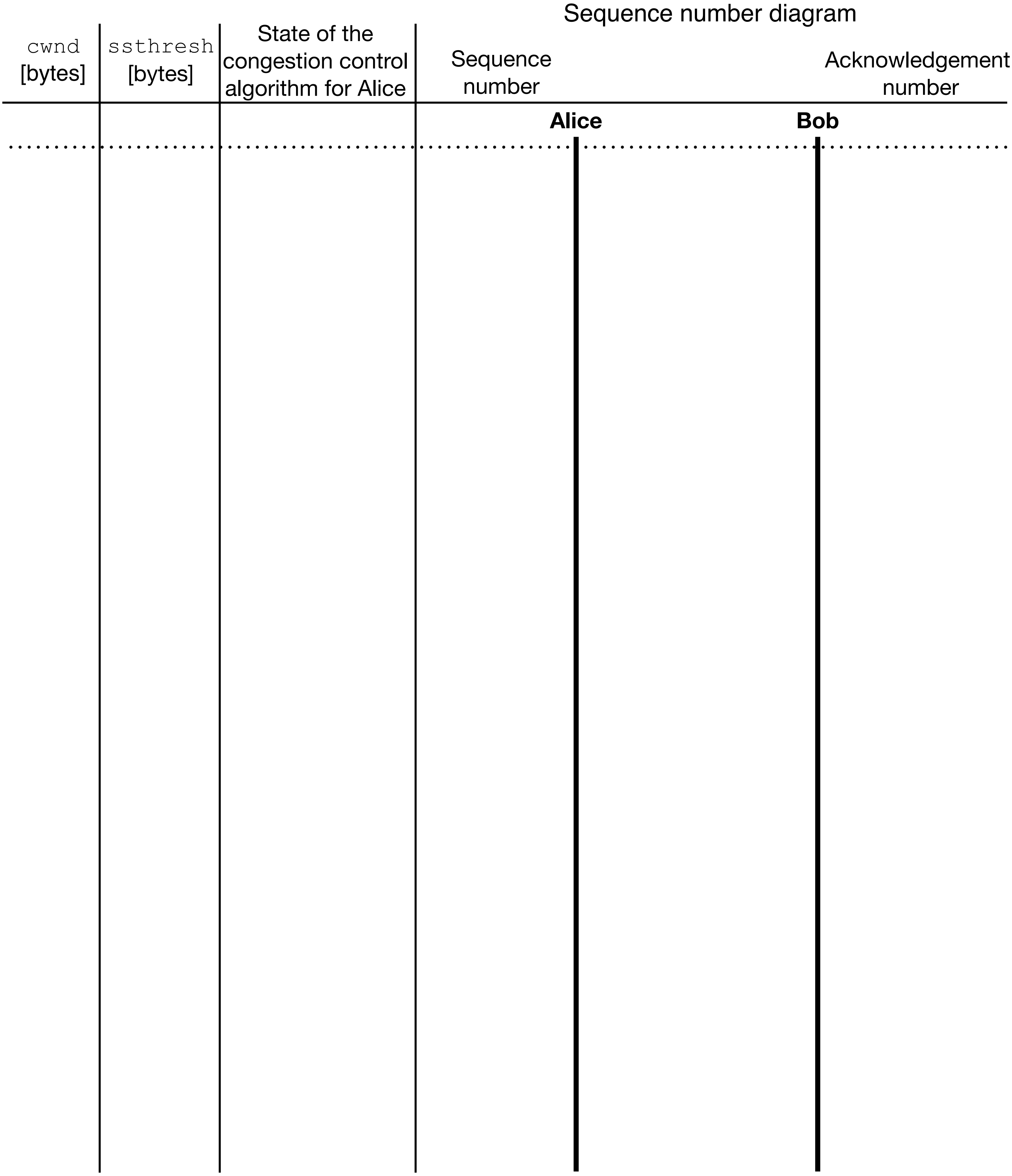


Figure 5: Sequence diagram to be completed for Problem 3, Question 1.