CSC 458/2209: Computer Networking Systems, Winter 2025

Department of Computer Science, University of Toronto

Problem Set 1	**Date:** Monday, January 27 2025
Name:	**Student ID:**

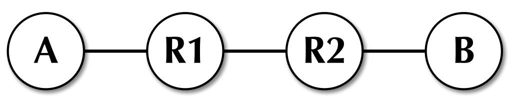
Instructions:

(i) This assignment has 5 problems and a total of 30 points. Some problems have multiple parts.
(ii) This assignment covers 10% of your final grade in this course.
(iii) Please be clear and concise in your answers. Explain in your reasoning if needed. If the final answer is wrong, but your reasoning is correct you are going to receive partial credit for the problem.
(iv) For deadline and submission instructions, please see class website.

1. Fragmentation. Hosts **A** and **B** are connected through intermediate routers **R1** and **R2**. The maximum transmission unit (MTU) for the link are:

- **A** → **R1**: 8000 bytes
- **R1** → **R2**: 1500 bytes
- **R2** → **B**: 9000 bytes

The IP **header size is 20 bytes**; link layer and transport layer headers are ignored. An IP Datagram with **7000 bytes of data** is sent from **A** to **B**.

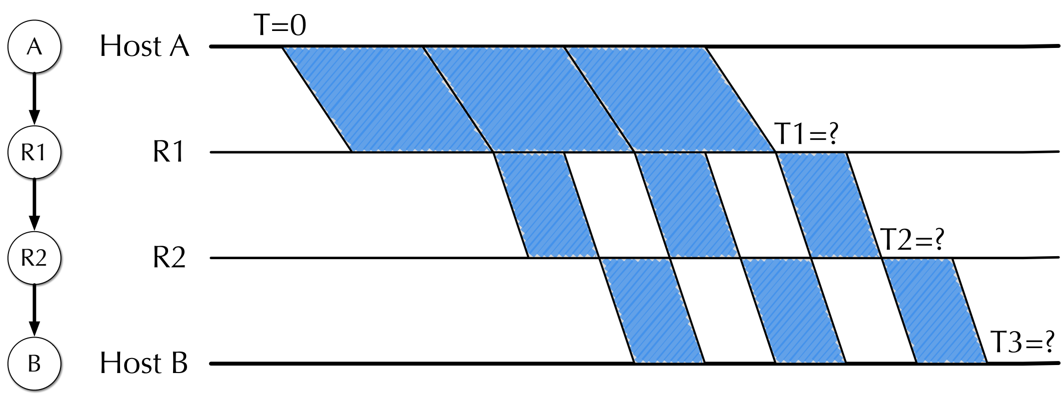


1a) [2 points]. Determine **where** fragmentation occurs and **how many fragments** are generated.

1b) [2 points]. Calculate **how many total bytes** (including IP headers) Host **B** ultimately receives.

1c) [2 points] Suppose a corporate network deploys a specialized middlebox between two routers **R1** and **R2** to perform **deep packet inspection (DPI)** for security purposes. When a large IP datagram arrives at **R1**, it is fragmented to comply with the outgoing MTU. The fragments then pass through the middlebox on their way to **R2** and ultimately reach Host **B**.

The middlebox *could* attempt to reassemble fragments to perform a more thorough DPI. Discuss two major challenges (e.g., buffer management, route variations, performance implications) that the middlebox would face if it tried to reassemble fragments.



2. Latency. Consider two end-host **A** and **B** connected through routers **R1** and **R2** as depicted in the figure above. **A** has three packets to transmit to **B**. Each packet (including all headers) is 1000 bytes. The **transmission rates** and **one-way latencies** (propagation delays) are as follows:

- **A** to **R1**: 400 KB/s (here we assume 1 KB is 1,000 bytes) with 3ms (millisecond) latency;
- **R1** to **R2**: 800 KB/s with 1.5ms latency; and
- **R2** to **B**: 800 KB/s and 1ms latency.

Here, we assume each router uses **store-and-forward** (meaning the router receives the whole packet before forwarding).

2a) [2 points]. Assuming there are **no queuing delays** (no extra waiting time in buffers), when will router **R1** receive all three packets completely (time **T1** in the figure above)? When will **R2** receive all three packets (Time **T2** in the figure)? When will the destination host **B** receive all three packets (**T3** in the figure)? Give your answers in milliseconds.

2b) [2 points]. Suppose we change the final link **R2 → B** such that:

- Its transmission rate drops from 800 KB/s to 400 KB/s, and
- Its latency increases from 1 ms to 2.5 ms.

Recalculate **T1**, **T2**, and **T3** under these new link parameters. How do these times compare to your part (a) answers?

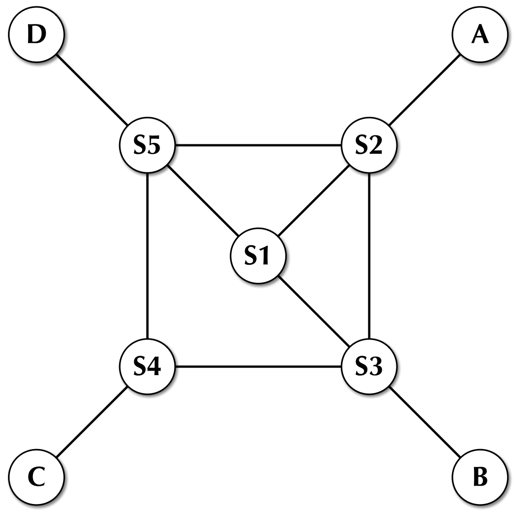
2c) [2 points]. In the original setting of the problem (part a), assume we change the order of the first two links, that is the **transmission rates** and **one-way latencies** (propagation delays) are as follows:

- **A** to **R1**: 800 KB/s with 1.5ms latency; and
- **R1** to **R2**: 400 KB/s with 3ms latency;
- **R2** to **B**: 800 KB/s and 1ms latency.

Does that change the overall transmission time of the three packets? If yes, recalculate **T1**, **T2**, and **T3** in this setting.

3. Learning Switches. In switched Ethernet networks, loops can cause broadcast storms and duplicated frames. To avoid this, switches run a Spanning Tree Protocol (STP) that disables certain links, producing a tree with no cycles. However, because STP may not always choose the shortest paths, traffic can flow through suboptimal routes.

Consider four hosts **A**, **B**, **C**, and **D** connected by a network of switches named **S1** to **S5** as shown in the figure below. Here, the IDs of switches **S1** to **S5** are **1** to **5**, respectively. All links have equal cost (cost = 1) and STP uses the lowest switch ID to break ties.



3a) [2 points] Switches **S1** to **S5** run the STP in order to make sure there are no loops in the network. Which switch is the root of the tree? Which links are discarded after running the spanning tree algorithm?

3b) [2 points] Let us assume all forwarding tables are initially empty. The switches learn about hosts using the learning algorithm we discussed in class. Give the forwarding tables for switches **S1**, **S2**, and **S3** after all of the following transmissions are completed:

- **A** sends to **B**.
- **A** sends to **C**.
- **D** sends to **A**.
- **B** sends to **D**.

Destination	Next Hop

Destination	Next Hop

Destination	Next Hop

3c) [2 points] Let us assume the following packets are also sent in this network:

- **C** sends to **B**.
- **B** sends to **C**.

How the the forwarding tables for switches **S1**, **S2**, and **S3** change (assuming we started with the results of part (b) and not with empty tables) after these transmissions? Show the final forwarding tables after all these transmissions in the tables below.

Forwarding Table for S1

Destination	Next Hop

Forwarding Table for S2

Destination	Next Hop

Forwarding Table for S3

Destination	Next Hop

3d) [2 points] As you can see in this example using a spanning tree can lead to non-optimal routing, i.e., the path taken between two hosts is not necessarily the shortest path (in the original graph).

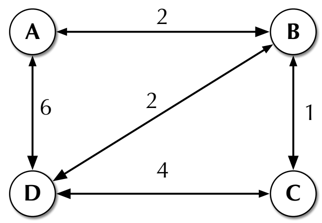
For two hosts **A** and **B** we define the *spanning tree stretch factor* of **A** and **B** as the ratio of the length of the path between **A** and **B** when we use the spanning tree and the length of the shortest path between **A** and **B**. For example, let us assume that the shortest path between **A** and **B** is of length 2 (i.e., there is 1 hop and two links between **A** and **B**). If the path from **A** to **B** goes through 3 links when using the spanning tree, we say the stretch factor is 3 divided by 2 or 1.5.

What is the stretch factor of the following pair of hosts in the spanning tree shown in part a.

- **C** and **B**:
- **C** and **A**:
- **C** and **D**:

3e) [2 points] The stretch factor of a given network is defined as the maximum stretch factor for any two hosts A and B in the network. Imagine you could change the ID of one of the switches to an arbitrary number (without changing the topology of the network). Which switch would you choose to change and what would be the new ID of that switch so as to minimize the stretch factor of this network? Explain your answer in 2-3 sentences.

4. Bellman Ford [4 points]. In the topology shown below, the links are bidirectional (work in both directions) and the number next to each link shows the cost. Find the routing tables using the Bellman-Ford algorithm.



Step 1:

Table for A

Dest	Cost	Next Hop
A	0	A
B	2	B
C		
D		

Table for B

Dest	Cost	Next Hop
A		
B		
C		
D		

Table for C

Dest	Cost	Next Hop
A		
B		
C		
D		

Table for D

Dest	Cost	Next Hop
A		
B		
C		
D		

Step 2:

Table for A

Dest	Cost	Next Hop
A	0	A
B		
C		
D		

Table for B

Dest	Cost	Next Hop
A		
B		
C		
D		

Table for C

Dest	Cost	Next Hop
A		
B		
C		
D		

Table for D

Dest	Cost	Next Hop
A		
B		
C		
D		

Step 3:

Table for A

Dest	Cost	Next Hop
A	0	A
B		
C		
D		

Table for B

Dest	Cost	Next Hop
A		
B		
C		
D		

Table for C

Dest	Cost	Next Hop
A		
B		
C		
D		

Table for D

Dest	Cost	Next Hop
A		
B		
C		
D		

5. Longest Matching Prefix [4 points]. A router **R** has a forwarding table shown below. For any incoming packet with a destination IP address **Dest**, the router checks which entries match **Dest** and chooses the longest (most specific) matching prefix to decide the next hop.

Prefix	Next Hop
140.20.0.0/16	**A**
140.20.100.0/24	**B**
140.20.101.0/24	**C**
*	**D** (Default)

The last row is a catch all entry, i.e., if matches every packet that does not match the rows before. For each packet with destination addresses below, identify which outgoing port (**A**, **B**, **C**, or **D**) is chosen by router **R**:

a) Destination = 140.20.100.15 →

b) Destination = 140.20.250.1 →

c) Destination = 140.20.101.200 →

d) Destination = 141.0.1.5 →