Question 1 (6 points) Compare circuit-switching and packet-switching networks based on the following criteria:

(a) Reserving network resources ahead of data being sent:

(b) Utilizing network resources efficiently:

(c) Guaranteeing uniform network quality of service during the connection:

Question 2 (6 points)

(a) What are "loss-intolerant" applications? Give an example of a loss-intolerant Internet application.

(b) What are "delay intolerant" applications? Give an example of a delay-intolerant Internet application.

(c) Based on your comparative analysis in Question 1, does the Internet adequately support loss-intolerant applications? And delay-intolerant applications? Explain.

Question 3 (6 points) Consider an Internet application running on two Internet hosts, *Host1* and *Host2*, which are communicating using a path through router R. Assume that the average service time at R is 10 ms, packets are 2,000 bits long, and the propagation delay between *Host1* and *Host2* is 150ms.

(a) Based on the latency expression we covered in class, how is service time defined? Write the mathematical expression for it explaining its terms. (2 points)

Assume all links have the same capacity.

Service time is the time spent inside the router, i.e. queueing and processing.

(b) If the application running on *Host1* and *Host2* cannot tolerate latencies over 200ms, what is the minimum capacity of the link connecting the two hosts? Show your work. (4 points)

Question 4 (4 points) Another way to measure end-to-end network latency is to use the round-trip time (RTT).

(a) What is the RTT? Use a time diagram to illustrate your explanation.

(b) What is the one-way trip time? Illustrate your answer with a time diagram.

Question 5 (8 points) List one advantage and one disadvantage of:

(a) Peer-to-peer model for networked applications (when compared to the client-server model). Explain. (2 points)

(b) Web caching. Explain. (2 points)

(c) Layering. Explain. (2 points)

(d) DNS (compared to a centralized name service). Explain. (2 points)

Question 6 (14 points) TCP

(a) Is TCP a full-duplex protocol? Explain.

(b) When *Host1* initiates a TCP connection to *Host2*, it sends a SYN segment to *Host1*. As part of the SYN segment, it includes a sequence number $SEQX$. What is the purpose of sequence number $SEQX$?

(c) Suppose that the *Host1* application that initiated the TCP connection has data to send to *Host2*. Can Host1's SYN segment carry the data? Explain.

(d) When *Host2* replies to the SYN segment from *Host2*, it uses a SYN-ACK segment and also includes a sequence number $SEQY$. What is the purpose of $SEQY$? Is $SEQX = SEQY$? Explain.

(e) The original TCP protocol only retransmitted upon a timeout event. More modern variants of TCP use the *Fast Retransmit* mechanism. Explain how *Fast Retransmit* works and how it can improve TCP performance.

(f) TCP can "pigyyback" acknowledgments on data segments. What field(s) in the TCP segemnent header are used to do that? Explain.

(g) What is the main advantage of "piggybacked" acknowledgments?

Question 7 (12 points) The reliable data transfer, or *rdt*, protocols we covered in class provide reliable in-order data delivery with duplicate detection.

(a) What mechanism(s) used by *rdt* protocols cause duplicates to be generated? Explain. (2 points)

(b) What mechanism(s) used by *rdt* protocols detect duplicates? Explain. (2 points)

(c) *rdt* protocols can recover from two types of network losses. What mechanism(s) are used to recover from each type of loss? Explan. (3 points)

(d) What is the retransmission timeout, also known as RTO? (2 points)

(e) In class we discussed why retransmission timers are critical to the performance of reliable data transfer. Why are they set as a function of the RTT? (3 points)

Question 9 (20 points) You are studying for the CE 150/L midterm using one of the computers at the UCSC Science Library. During one of your breaks, you want to check out the *Soccer4All.org* Web site for the latest videos of the Soccer World Cup 2018 Qualifyers.

(a) What would be the steps needed before your computer at ucsc.edu can issue a request for *Soccer4All.org*? Assume this is the first time anyone at ucsc.edu requests contents from that Web site and name resolution is done iteratively. (4 points)

(b) Immediately after you downloaded videos, another friend, Gabriela, who is also at UCSC, wants to watch the videos as well. What are the steps needed before Gabriela's request to *Soccer4All.org* is issued? Explain. (4 points)

(c) You finally manage to access the Soccer World Cup 2018 Qualifyers page from the *Soccer4All.org* site. The page has 10 videos embedded in it. The processing/service time within the network is 10ms each way, and the one-way propagation delay is 100ms. Assume that transmission delay is negligible. What would be the response time, i.e., the time it takes between when your browser requests the page and when the videos are delivered, if your browser uses non-persistent HTTP (with no parallel connections)? Explain. (4 points)

(d) What would be the response time if the browser uses persistent HTTP? Explain. (4 points)

(e) It is now Gabriela's turn to download the videos. Assuming that the steps in (b) have already been executed and that you have already been able to download the videos, what is the average response time Gabriela will experience for each video in Seth's Web page if the ucsc.edu's cache hit ratio is 60%? Suppose that the delay to access an object within ucsc.edu's network is 20ms. Assume persistent HTTP is used. (4 points)