UNIVERSITY OF TORONTO
Faculty of Arts and Science
APRIL/MAY EXAMINATIONS 2017
CSC 358H1 S

Duration - 3 hours
Examination Aids: no examination aids are allowed.

Last Name: First Name:
Student ID:

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Notes to students: There are 8 questions and 21 pages in total for this examination. There are 100 marks possible.

Question 1	20 points total
Question 2	10 points
Question 3	10 points
Question 4	10 points
Question 5	20 points total
5 (a)	10 points
5 (b)	10 points
Question 6	10 points
Question 7	10 points total
7 (a)	1 points
7 (b)	1 points
7 (c)	4 points
7 (d)	4 points
Question 8	10 points total
8 (a)	4 points
8 (b)	3 points
8 (c)	3 points
Total	100 points

Useful Formulas

Poisson process:

$$P\{N(T) = n\} = e^{-\lambda T} \frac{(\lambda T)^n}{n!}$$

$$E[N(T)] = \lambda T$$

Exponential distribution:

$$P\{s \leq t\} = 1 - e^{-\mu t}$$

$$E[s] = \frac{1}{\mu}$$

Series:

$$\sum_{n=0}^{\infty} \rho^n = \frac{1}{1-\rho}$$

$$\sum_{n=1}^{\infty} n(1-p)^{n-1} p = \frac{1}{p}$$

$$\sum_{n=0}^{\infty} \frac{\alpha^n}{n!} = e^{\alpha}$$

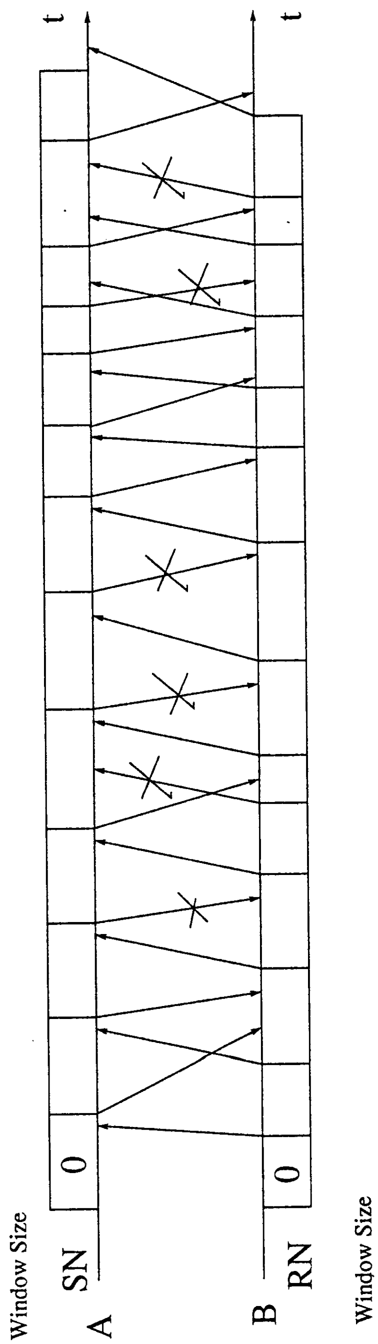
Little's Theorem:

$$N = \lambda T$$

 Continued

Question 1 (20 points)

Consider **Selective Repeat ARQ** to ensure reliable data transfer between a sender A and a receiver B. Use the convention that B always acknowledges the last error-free packet from A, and when A has to retransmit packets it starts with the SN at the beginning of the window and retransmits packets that have not yet been acknowledge by B in order of their sequence number. For the figure on the next page, fill in the values for SN and RN, indicate the window size at A and B, the information that is needed to be stored/buffered at the sender and receiver as part of the Selective Repeat ARQ as discussed in class, as well as the packets delivered to the next higher layer. For the window, use **n** =4.


t
t
0
0
Window Size
SN
A
B
RN
Window Size

Question 2 (10 points)

In class, we discussed Stop-and-Wait ARQ for a sender A and a receiver B under the following assumptions: all packets with error are detected, delay can be arbitrarily long, some packets maybe lost, and packets that arrive are in the same order. In this question, you are asked to design a variant of this protocol for different assumptions on the channel between A and B.

Assume that packets (from A to B) and ACK's (from B to A) can have an arbitrary and variable, but the delay is always finite.. Furthermore assume that packets and ACK's are **never lost** and that **ACK's always arrive error free**. However, **packets might arrive with errors**.
Design a stop-and-wait protocol that can communicate reliably over this channel which uses sequence numbers for packets (SN), and the ACK's (RN), only if this is necessary to achieve reliability (use the same notion of reliability that we used in class when we discussed the ARQ protocol).

Question 2 continued

Question 3 (10 points)

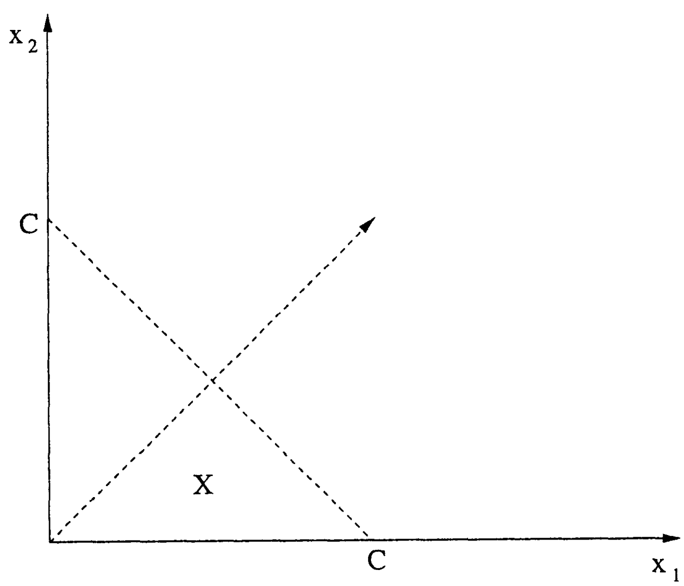
Consider two sessions, 1 and 2, which share a single link with capacity C. Assume that both sessions use a congestion window (as in TCP) to control the transmission rate. Let w_1, and w_2, be the window size of session 1, and 2, respectively; and let x_1, and x_2, be the corresponding transmission rate of sessions 1, and 2, respectively.

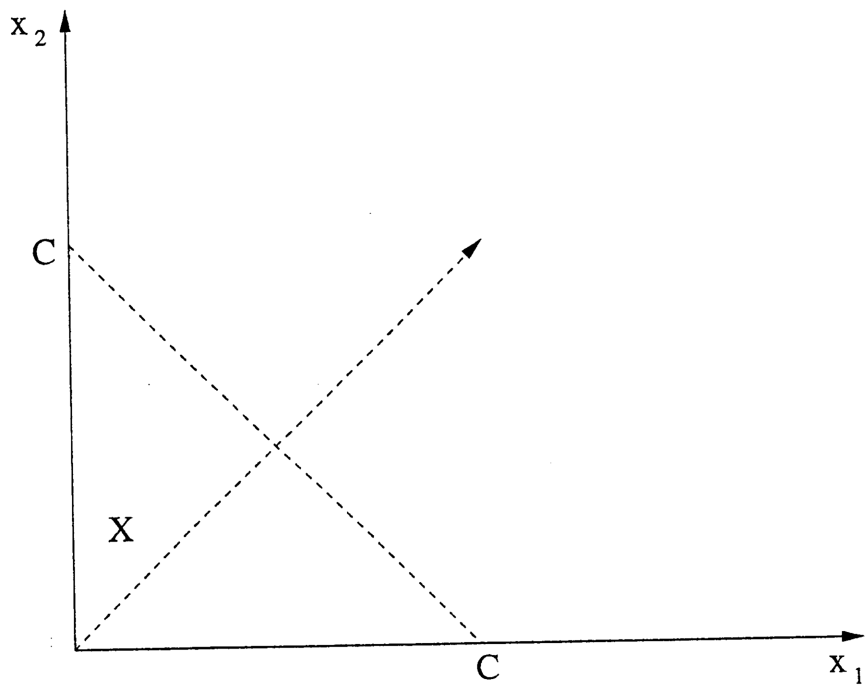
For this situation, we used in class a simplified model to analyze the TCP congestion control, where we ignored the slow start phase. Using the same model, consider the following algorithm for adjusting the congestion window size w_1 and w_2, where we set for $n = 1, 2$

$$w_n = w_n + 1, \quad \text{when } (x_1 + x_2) < C$$

$$w_n = \tfrac{1}{2} w_n, \quad \text{when } (x_1 + x_2) \geq C$$

Show the dynamic behavior of this algorithm using the two diagrams below, where X indicates the initial values for x_1 and x_2.

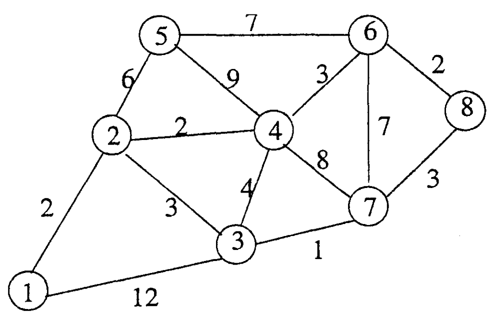




x_2
C
X
C
x_1

Question 4 (10 points)

Consider the network topology given below, where we assume that the costs are the same for both directions of the link. Use the Bellman-Ford algorithm



to find the shortest path from nodes 2, 3, 4, 5, 6, 7, and 8, to node 1. Use a table with the following entries to illustrate each step of the algorithm, and identify the shortest path for each node.

Step	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
...	...	...	...	...	...	...	... ...	...

Use the above table to determine the shortest paths from all nodes to node 1.

Question 4 continued

Question 5 (20 points)

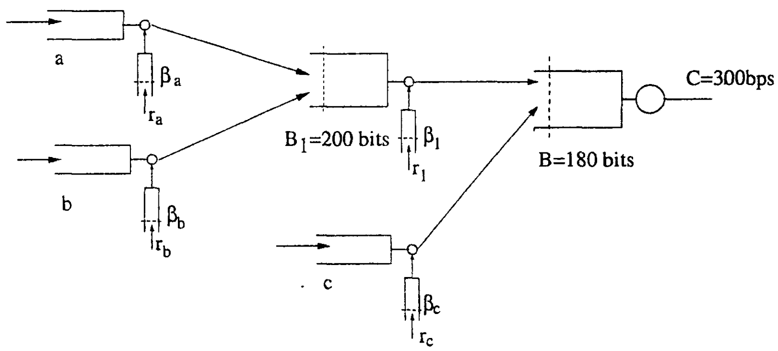
In this question, we analyze the $M/M/m$ queueing system which is identical to the $M/M/1$ system, except that there m servers. Packets arrive according to a Poisson process with rate λ, and each server serves packets at rate μ, independently from the other servers. A packet at the head of the buffer is routed to any server that is currently not busy, or to the first server that becomes available.

(a) (10 points) Draw the state-transition diagram for the $M/M/m$ queue.

(b) (10 points) Find the steady-state probabilities p_n, $n = 0, 1, 2, ...$, that there are n packets in the system. Show all steps in your derviation of the result.

Question 6 (10 points total)

Consider the figure below, where we use the leaky bucket mechanism to regulate/police the sessions a, b, and c. Assume that all packets have the same length $L = 20$ bits. Furthermore, assume that the transmission capacity C_0 of the link after the "leaky-bucket-controlled" buffers are equal to ∞ ("very fast")



The three sessions access a single link with transmission capacity $C = 300$ bits per second and space (in queue or in service) for $B = 180$ bits. However, before accessing the link, the session a and b go through the buffer 1 which is again controlled by a leaky bucket. Buffer 1 has space (in queue or in service) for $B_1 = 200$ bits and can again transmit data at a speed of $C_0 = \infty$. The parameters for the system are as follows,

$$\beta_a = 3 \text{ permits,}$$

$$r_b = 5 \text{ permits per second,}$$

$$\beta_1 = 6 \text{ permits,}$$

$$r_c = 4 \text{ permits per second}$$

What are the maximal rates r_a, r_1, and the maximal number of saved permits β_b, β_c, that we can allocate to the corresponding leaky buckets so that we can guarantee that there will never be a buffer overflow (packet loss) at either of the two buffers?

Question 6 continued

Question 7 (10 points total)
In class, we discussed that we can employ the ARQ protocol at any layer - for example, we could implement ARQ at the transport layer (end-to-end ARQ) or at the link layer (hop-by-hop ARQ). In this question, we study how the decision where we use ARQ impacts the network performance (in terms of average packet delay).

In the following we consider a stop-and-Wait protocol between two peer processes X (sender) and Y (receiver) where Y sends immediately an ACK (with the corresponding RN number) to X whenever it receives an error-free a packet from X.

Assume a host A wants to send packets to a (distant) host B. In order to communicate with host B, host A has to send its packets first to a switch C, where packets get forwarded to host B. All packets have the same size of N bits. Switch C must have received the complete packet before it can be forwarded to B (why?). During the transmission of a packet from host A to switch C, bits are corrupted independently with a bit error probability P_{bit}, $0 < P_{bit} < 1$. Similar, during the transmission of a packet from switch C to host B, bits are corrupted independently with the same bit error probability P_{bit}. The transmission rate of the link between host A and switch C is R bits per second - the transmission rate of the link between switch C and host B is also R bits per second. For the questions below, provide all relevant derivations.

(a) (1 point) What is the probability P_{packet} that a packet from host A arrives error-free at switch C?

(b) (1 point) Assume that host A and switch C implement the above Stop-and-Wait ARQ. In addition, make the following assumption regarding the channel between A and C: ACK's from switch C always arrive error-free at A and no packets or ACK's are dropped. Assuming that host A never exceeds the time-out (when waiting for an ACK), what is the probability P_k, $k = 1, 2, \ldots$, that A has to transmit a packet k times to get it accepted at switch C?

(c) (4 points) (Hop-by-Hop ARQ) Assume that switch C and host B also implement the above Stop-and-Wait ARQ to send packets from C to B, and that the same assumption that we made in (b) for the channel between A and C also hold for the channel between C and B. What is the average delay of a packet, i.e. the average length of the interval between the time that host A starts sending a packet for the first time and the time that host B passes the packet to the next higher layer? Ignore queueing and processing delays, as well as transmission delays of ACK's (but not of packets), and assume that host A and switch C never exceed the time-out (waiting for a ACK).

(d) (4 points) (End-to End ARQ) Suppose that switch C does not check packets for errors, but forwards each packet from A immediately to host B (without sending an ACK to host A). However, host A and host B use the above Stop-and-Wait ARQ to ensure a reliable data transfer. Assume that ACK's from host B always arrive error-free at host A and that no ACK's are dropped. For this case, what is the average delay of a packet? Again, ignore queueing and processing delays, as well as transmission delays of ACK's, and assume that host A never exceeds the times-out (waiting for a ACK).

Question 8 (10 points total)

Consider the following simple model for unslotted Aloha.
Assume that new frames arrive according to a Poisson process with rate λ. Furthermore, assume that frames have independent, exponentially distributed transmission times with mean $\frac{1}{\mu}$. Whenever a new frame arrives, it is immediately transmitted (that is we assume that there is an infinite set of nodes and each node has at most 1 packet to transmit). When the transmission time of a frame overlaps with another frame, then this frame will be lost. Assume that lost frames will not be retransmitted.

(a) (4 points) Draw the state-transition diagram for this system, where the state n indicates the number of frames currently being transmitted.

(b) (3 points) Compute the probability that a frame does not collide with its predecessor or its successor.

(c) (3 points) Assume that p_n, $n = 0, 1, 2....$, are the steady-state probabilities for the state-transition diagram in (a). What is the probability that a new frame will be transmitted successfully?