Faculty of Arts and Science
University of Toronto
CSC 457 - Principles of Computer Networks, Fall 2020

Cover sheet for Assignment 3

Due Friday Nov. 6, 11:00pm

Complete this page and attach it to the front of your assignment.

Name: ______________________________
(Underline your last name)

Student number: ______________________________

I declare that this assignment is solely my own work, and is in accordance with the University of Toronto Code of Behavior on Academic Matters.

Signature: ______________________________

Question 1 (8 Points): Delay Performance Analsysis

In class, we discussed queues with infinite buffer space. However, in reality, buffers are not infinite but finite. We consider this more realistic situation in this question, where we analyze the $M/M/1/m$ queue. The $M/M/1/m$ queueing system is the same as the $M/M/1$ system, except that there can be no more than m packets in the system (that is waiting in the buffer or in service), and packets arriving when the system is full are dropped and lost. Packets arrive according to a Poisson process with rate λ and are served at rate μ. For this system, the he steady-state probabilities p_n, $n = 0, 1, ..., m$, that there are n packets in the system are given as follows.

For $\rho = \lambda/\mu \geq 0$, $\rho \neq 1$, we have

$$p_n = \frac{1-\rho}{1-\rho^{m+1}}\rho^n, \qquad n = 0, ..., m,$$

and for $\rho = 1$ we have

$$p_n = \frac{1}{m+1}, \qquad n = 0, 1, ..., m.$$

Using these probabilities, answer the following questions.

(a) Find the probability that a new packet is lost and the rate at which packets are dropped.

(b) Compute the throughput of the system.

(c) Assume that $\rho^m << 1$ (when is this the case?), and redo part (a).

(d) Using Little's formula, find the expected delay (queuing plus transmission delay) of a packet that enters the system.

Question 2 (10 Points): Performance Analsysis of Stop-and-Wait ARQ

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).

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

(b) 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, $k = 1, 2, ...$, that A has to transmit a packet k times to get it accepted at switch C?

(c) (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) (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).

(e) Evaluate the answers for (c) and (d) for $P_{packet} = 0.99,\ 0.2,\ 0.002$.

(f) Using the result of (e), in what situation would you use Hop-by-Hop ARQ (End-to-End ARQ)?