Name:

Pledge:

EE/CPE 345: Modeling and Simulation
Midterm Exam – Fall 2021

1. (20 points) Consider that you are simulating an ARQ protocol (as studied for our case study examples. The probability of a packet to be received in error is p = 0.01. Each packet transmission is 20 ms, and an ACK/NACK packet also requires 20 ms to be transmitted and received. You are collecting from the simulation the total delay of packet transmissions (from when packets are created until they are correctly received).

a) What is the expected distribution for the packet delay (based on the statistical description of the process)?
b) What is the average delay experienced by the packets (using the statistical model)?
c) Assuming now that only ACK is sent (no NACK) and a packet is retransmitted if a timeout event for the source occurs – what should you choose the timeout time value for the protocol to work efficiently (after how much time source should timeout and resend packet)? Assume fixed propagation delays of 20 ms both for the forward link and reverse link (direct transmission and acknowledgements, respectively). Assume also error free transmission for the ACK's link.
d) Assume that you are now collecting the samples for the delay. Propose a method to verify that the samples are indeed coming from the distribution you hypothesized. Just describe the method.

Solution:

a) Geometric, success probability: 1-p
b) E[delay] = E[#of transmissions}*40 ms = 1/(1-p) = 1/0.99*40 ms = 1.01*40ms = 40.4 ms
c) Round trip time for acknowledgement is 40 ms – timeout > 40 ms – just slightly larger for efficiency purposes (note – saying T= 40 ms will be considered for full credit)
d) You can use either Q-Q plots or chi-square test to verify that the delay samples come indeed from a Geometric PMF.
   For Q-Q plots – order the samples in increasing order and plot against $F^{-1}((j-1/2)/n)$ for the Geometric distribution – if plot approx. line with slope 1 – distribution is Geometric
   Chi-square – long tail distribution – needs equal intervals test
   - determine the number of classes: k <n/5
   - compute the intervals
   - determine Ei for each interval (all equal)
   - count the number of observed samples in a given interval Oi
   - compute error per class: (Ei-Oi)^2/Ei
   - add error across classes = total error

- determine critical value based on number of samples and significance level from table
- If total error<critical value → samples come from a Geometric Distribution

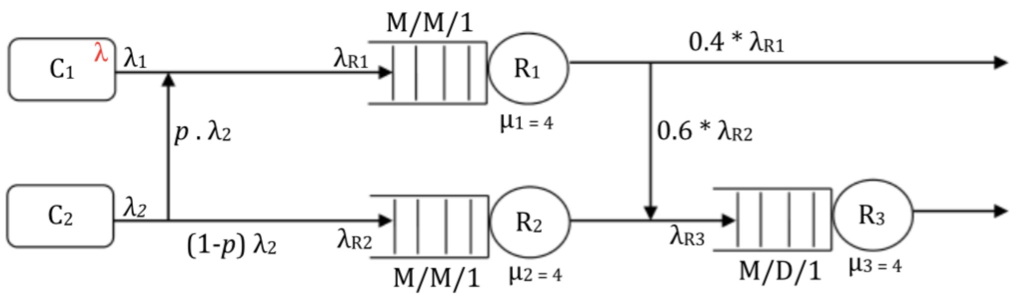
2. **(15 points)** Consider a traffic intersection system that is coordinated by a stop light in each direction: North-South and East-West. Your objective for simulating this system is to determine the delay experienced by the cars in this intersection.
   (a) Characterize the system model (identify entities and attributes)
   (b) What is the state for this system?
   (c) What are the events?

   Solution: There are 4 queues: North, South, East, West.
   Each queue state can be described as (number of cars in queue, server state (B/I));
   The server will be busy, if either the traffic light is RED or if it is Green but there are cars clearing the intersection. The server is IDLE if the traffic light is Green and there are no cars in intersection.

   a. Entities:
      Queues - Attributes: buffer length, server time for a car to clear intersection
      Traffic light – green/red time pattern
      Car generators – distribution of arrivals
   b. System state: (no of cars in queueN, serverN state (B/I), no of cars in queueS, serverS state (B/I)); no of cars in queueE, serverE state (B/I)); no of cars in queueW, serverW state (B/I))).
   c. Arrivals event: new cars arrive at intersection
      Stop light color changes.
      Departure event for cars clearing the intersection.

3. **(20 points)** Consider the following network of computers. Computers C1 and C2 generate packets, each producing a Poisson stream with rate $\lambda_1 = 1\, pkts\ per\ sec$, and $\lambda_2 = 2\, pkts\ per\ sec$, respectively. From C1, packets are sent to router R1 where they are queued for processing. From C2, with probability p = 0.2 packets are sent to R1, and with probability (1-p) are sent to R2. R1 and R2 processing times are exponential distributed with a rate $\mu = 4\ per\ second$. From router R1, 40% of the packets are sent to destination (out of network) and the rest are routed to router R3 where they are queued for processing. All packets from R2 are routed to R3. R3 has a deterministic service time of 0.25 seconds for each packet.
   (a) Draw the queueing system
   (b) What types for queues we have in this queueing system?
   (c) Is the system stable? Explain
   (d) Compute average end-to-end delay for this network of queues.

Solution:



(b) M/M/1, M/M/1, M/D/1

The arrival rate at R1 (λ_{R1}) = $\lambda_1 + 0.2 * \lambda_2$
= 1 + 0.4
=1.4 packets/sec

The queue at R_1 is stable because the arrival rate (i.e. 1.4 packets) whereas R_1 is capable to process 4 packets/sec.

The arrival rate at R_2 (λ_{R2}) = $0.8 * \lambda_2$
=1.6 packets/sec

The queue at R_2 is stable because the arrival rate (i.e. 1.6 packets) whereas R_2 is capable to process 4 packets/sec.

The arrival rate at R_3 (λ_{R3}) = 60% of the R_1 departure + R_2 departure
=0.6 * 1.4 + 1.6
= 2.44 packets/sec

The queue at R_3 is stable because the arrival rate (i.e. 2.44 packets) whereas R_3 is capable to process 4 packets/sec.

All queues are stable since arrival rates into the queues < service rates → system is stable

$$L_1 = \frac{\lambda_{R1}}{\mu_1 - \lambda_{R1}} = 0.538\, packet \qquad L_2 = \frac{\lambda_{R2}}{\mu_2 - \lambda_{R2}} = 0.667\, packet$$

$$\rho_3 = \frac{\lambda_{R3}}{\mu_3} = \frac{2.44}{4} = 0.61$$

$$L_3 = \rho_3 + \frac{\rho_3}{2(1-\rho_3)}$$

$$W = \frac{L1 + L2 + L3}{\lambda 1 + \lambda 2}$$

4. **(10 points)** Complete the table for a bank teller simulation starting at time T=0 with an arrival, given that some previously generated random variables for inter-arrival times are 7, 3, 5, 1, and for departure times are 2, 1, 4, 2. (no need to use all the values) The state of the system is characterized by (number of packets in line, busy/idle for server). Busy state for server is marked as "1". The events in FEL are denoted as (type of event, time). For arrival events, type =1, for departure events, type =2.

Clock	Arrival Time	Departure time	System state	FEL
T=0	0		(0,1)	(2,2) (1,7)
T=2		2	(0,0)	(1,7)
T=7	7		(0,1)	(2,8) (1,10)
T=8		8	(0,0)	(1,10)
T=10	10		(0,1)	(2,14) (1,15)

Extra credit problem (5 points):

Consider the following NED code for the network Test. Find the error in the code. Explain.

```
Simple TestNode
{
    gates:
      input in;
      output out;
}

network Test
{
   submodules:
     test1: TestNode;
     test2: TestNode;
     test3: TestNode;
  connections:
    test1.out  --> test2.in;
    test3.out  --> test2.in;
}
```

Solution: you cannot have two connections into the same in gate. In the code, both test1 and test2 connect to test2.in. You need to declare multiple in gates for test2. Can use array of gates declaration in TestNode: input in[];

Then connect as follows:

```
test1.out → test2.in++;
test2.out → test2.in++;
```

Note: the problem does not ask to get the correct implementation, just to identify the problem – so full credit will be received for correctly identifying the problem.

If a student also provides the code for correction – another 3 points will be awarded – for a total of 8 extra points