DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES
E INFORMÁTICA

MESTRADO INTEGRADO EM ENG. DE COMPUTADORES E TELEMÁTICA

ANO 2018/2019

DESEMPENHO E DIMENSIONAMENTO DE REDES

ASSIGNMENT GUIDE NO. 4

PERFORMANCE ESTIMATION OF PACKET SWITCHED NETWORKS

Simulator 1

Using MATLAB, develop an event driven simulator, named Simulator 1, to estimate the performance of a point-to-point IP link between a company router and its ISP (Internet Service Provider) router. The simulator should be a MATLAB function following the input and output formats as specified in Appendix A.

Consider only the packet flow in the downstream direction, *i.e.*, from ISP to the company, usually the direction with highest traffic load. The link has a capacity of 10 Mbps. Consider that the queuing discipline in router is FIFO (*First-In-First-Out*) and that the queue is of size *f* bytes.

Consider the packet arrivals as a Poisson process with data throughput *r* (in bps). Consider also the packet size as a random number of bytes between 64 and 1518 bytes (which includes the layer 2 overhead) with the following probabilities: 19% for 64 bytes, 48% for 1518 bytes and all other values with equal probability.

Input parameters of Simulator 1:

- *r* – data throughput (in bps)
- *f* – size of the queue (in Bytes)
- *S* – number of seconds of a simulation run

Performance parameters to be estimated:

- Average packet loss (percentage of packets discarded due to buffer overflow)
- Average packet delay (in milliseconds)
- Transmitted throughput (in Mbps)

Simulator stopping criteria:

- When the simulated time reaches *S* seconds.

SUGGESTIONS: Take as reference the diagram in Appendix C where:

Events: ARRIVAL (the arrival of a packet), DEPARTURE (the termination of a packet transmission) and TERMINATE (the termination of the simulation).

State variables: STATE (binary variable indicating if the link is free or busy with a packet transmission), QUEUEOCCUPATION (total number of bytes of the queued packets) and QUEUE (structure with (i) the arrival time and (ii) the size of each queued packet).

Statistical counters: TOTALPACKETS (number of packets arrived to the system), LOSTPACKETS (number of packets discarded due to buffer overflow), DELAYS (sum of the delays of all transmitted packets), TRANSMITTEDPACKETS (number of transmitted packets) and TRANSMITTEDBYTES (total number of transmitted bytes).

Auxiliary variables: INSTANT (arrival time instant of the packet that is being transmitted) and SYZE (size, in bytes, of the packet that is being transmitted).

With the proposed statistical counters, the performance parameters are determined at the end of the simulation as:

- Average packet loss = 100% × LOSTPACKETS / TOTALPACKETS
- Average packet delay = 1000 × DELAYS / TRANSMITTEDPACKETS
- Transmitted throughput = 8 × TRANSMITTEDBYTES × 10^{-6} / *S*

a) Consider a stopping criteria of S = 1000 seconds. Using Simulator 1, estimate the performance parameters for the cases defined in Table I. Run the simulator 10 times for each case and present the 90% confidence intervals.

Table I

Case	r (Mbps)	f (Bytes)	Avg. Packet Loss (%)	Avg. Packet Delay (msec.)	Transmitted Throughput (Mbps)
A	6	150000			
B	8	150000			
C	9	150000			
D	9.5	150000			
E	9.75	150000			
F	10.0	150000			
G	6	15000			
H	8	15000			
I	9	15000			
J	9.5	15000			
K	9.75	15000			
L	10	15000			

b) With the previous results, draw some conclusions concerning the performance of the link for the different input values of packet throughput (r) and queue size (f).

c) For the cases in Table I with null average packet loss, determine the theoretical values of the average packet delay assuming first the $M/M/1$ queuing model and, then, the $M/G/1$ queuing model (determine the appropriate values from the packet size statistics used in the simulator). Compare the theoretical values with the simulation results. Justify the observed differences and determine which model better approximates the system performance.

d) For the cases in Table I such that the packet loss is not null, determine the theoretical values of average packet delay and average packet loss assuming the $M/M/1/X$ model (on each case, choose the most appropriate value of X). Compare the theoretical values with the simulation results. Justify the observed differences and determine the cases for which this model is still adequate.

Simulator 2

Using MATLAB, develop an event driven simulator, named Simulator 2, to estimate the performance of a network of IP point-to-point links between different routers. Each unidirectional link has a unique ID $j = 1, \ldots, J$. The capacity of link j is given by C_j (in bps) and its queue size is f_j bytes. For all links, the queuing discipline is FIFO (*First-In-First-Out*). The simulator should be a MATLAB function following the input and output formats as specified in Appendix B.

Consider that there is a set of packet flows $i = 1, \ldots, I$ and each flow i has an associated routing path composed by an ordered set of unidirectional links J_i. For each packet flow, consider the packet arrivals as a Poisson process with data throughput r_i (in bps). As before, the packet size in all flows is a random number of bytes between 64 and 1518 bytes with the following probabilities: 19% for 64 bytes, 48% for 1518 bytes and all other values with equal probability.

Input parameters of Simulator 2:

- r_i – data throughput of flow $i = 1, \ldots, I$ (in bps)
- J_i – ordered set of links of routing path of flow $i = 1, \ldots, I$
- C_j – capacity of link $j = 1, \ldots, J$ (in bps)
- f_j – size of queue of link $j = 1, \ldots, J$ (in Bytes)
- S – number of seconds of a simulation run

Performance parameters to be estimated:

- Packet loss of flow $i = 1, \ldots, I$
- Average packet delay of flow $i = 1, \ldots, I$

Simulator stopping criteria:

- When the simulated time reaches S seconds.

SUGGESTIONS: Change your previous developed Simulator 1 considering:

Events: ARRIVAL (the arrival of a packet to the first link of its routing path), RETRANSMIT (the arrival of a packet to all links of its routing path except the first), DEPARTURE (the termination of a packet transmission on the last link of its routing path) and TERMINATE (the termination of the simulation).

Event List: Each row of the Event List must contain 4 fields: the type of event, the time instant of the event, the flow ID value i of the event and the link ID value j of the event.

State variables: STATE(j) (one binary variable for each link $j = 1, \ldots, J$ indicating if the link is free or busy), QUEUEOCCUPATION(j) (total number of bytes of the queued packets on queue of link $j = 1, \ldots, J$) and QUEUE{j} (cell array with a structure per link; each structure must contain one row per queued packet with: (1) the packet arrival time instant, (2) the packet size and (3) the packet flow).

Statistical counters: TOTALPACKETS(i) (number of packets of flow i arrived to the first link of its routing path), LOSTPACKETS(i) (number of packets of flow i discarded in any of the links of its routing path), DELAYS(i) (sum of the delays of all packets of flow i transmitted in the last link of its routing path), TRANSMITTEDPACKETS(i) (number of packets of flow i transmitted in the last link of its routing path).

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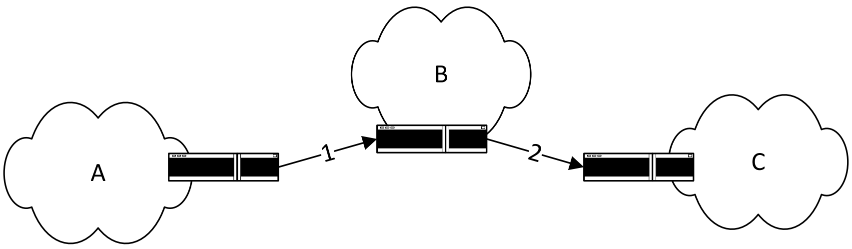
Auxiliary variables: INSTANT(j) (arrival time instant of the packet that is being transmitted on link j) and SYZE(j) (size of the packet that is being transmitted on link j).

ARRIVAL(i,j) event processing: similar to Simulator 1; if STATE(j) is free, add to the Event List either a RETRANSMIT(i,k) in the next link k if the current link j is not the last link of the routing path of flow i or a DEPARTURE(i,j) if the current link j is the last link of the routing path of flow i.

RETRANSMIT(i,j) event processing: similar to ARRIVAL(i,j) but the packet size and arrival time instant of the packet are given by SYZE(j) and INSTANT(j), respectively.

DEPARTURE(i,j) event processing: similar to Simulator 1; if QUEUEOCCUPATION(j) > 0, take the first packet of QUEUE{j} and consider its flow i to add to the Event List either a RETRANSMIT(i,k) in the next link k if the current link j is not the last link of the routing path of flow i or a DEPARTURE(i,j) if the current link j is the last link of the routing path of flow i.

e) Consider the following network composed by 3 routers connecting 3 networks: A, B and C. Connection 1 has a capacity of 10 Mbps and connection 2 has a capacity of 5 Mbps. Both queues are of size f = 150000 bytes.



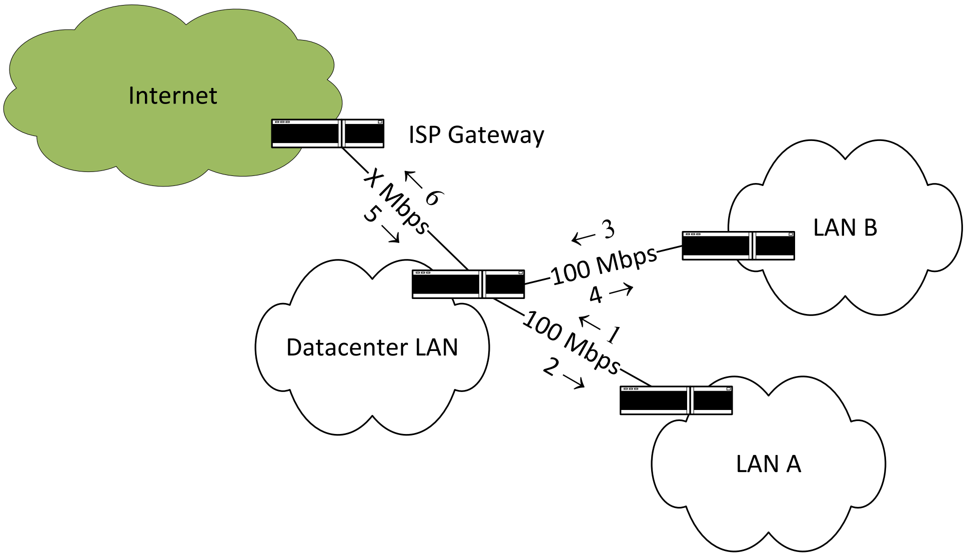
Using Simulator 2, estimate the performance parameters when the network supports a single packet flow, from A to C, with r = 4 Mbps. Run the simulator 10 times with a stopping criteria of S = 1000 seconds and present the obtained confidence intervals.

f) Using Simulator 2, estimate the performance parameters when the network supports 3 packet flows: (i) flow 1, from A to B, with r_1 = 7.4 Mbps, (ii) flow 2, from A to C, with r_2 = 2.3 Mbps and (iii) flow 3, from B to C, with r_3 = 2.5 Mbps. Run the simulator 10 times with a stopping criteria of S = 1000 seconds and present the obtained confidence intervals.

g) Using the Kleinrock approximation, estimate theoretically the performance of the cases simulated in **e)** and **f)**. Compare the theoretical values with the results of the simulation and justify the differences.

h) Using simulator 2, repeat **f)** but now considering that the queue size of link 1 is 7500 Bytes (the queue size of link 2 remains 150000 Bytes). Compare these results with the ones obtained in **f)** and justify the observed differences.

i) Consider the following network of a given company, composed by 3 routers connecting 3 networks (LAN A, LAN B and Datacenter LAN) with point-to-point links of 100 Mbps. The network has also a connection to the ISP Gateway of capacity X Mbps. The queues of all links are of size f = 150000 Bytes. The figure proposes the link ID values that you must consider for each unidirectional link.



The estimated maximum data throughput (in Mbps) of each packet flow is:

		To:			
		Internet	Datacenter	A	B
From:	Internet	-	2.0	6.0	10.0
	Datacenter	16.0	-	50.0	10.0
	A	2.0	50.0	-	20.0
	B	2.0	10.0	20.0	-

The subscription with the ISP requires the capacity X to be a multiple of 10 Mbps. Using Simulator 2, estimate the performance parameters of all packet flows for X = 10, 20, … Mbps and stop when the average packet loss of all flows is zero and the average packet delay of all flows is below 1 millisecond. In all cases, run the simulator 10 times with a stopping criteria of S = 200 seconds and present the obtained confidence intervals. Analyze the impact of the different values of X on the performance parameters of each flow.

APPENDIX A – SIMULATOR 1 FUNCTION

The input and output parameters of the MATLAB function implementing Simulator 1 must follow the following example:

```
par.r= 6000000; %bps
par.f= 150000;  %Bytes
par.S= 1000;    %seconds

out = simulator1(par);

fprintf("Average Packet Loss (%%)= %f\n",out.AvgPacketLoss);
fprintf("Average Packet Delay (ms)= %f\n",out.AvgPacketDelay);
fprintf("Transmitted Throughput (Mbps)= %f\n",out.TransThroughput);
```

APPENDIX B – SIMULATOR 2 FUNCTION

The input and output parameters of the MATLAB function implementing Simulator 2 must follow the following example:

```
par.r= [1e6 3e6 6e6]; %bps
par.J{1}= [1];        %routing path of flow 1
par.J{2}= [1 2];      %routing path of flow 2
par.J{3}= [2];        %routing path of flow 3
par.C= [5e6 10e6];    %bps
par.f= [150e3 150e3]; %Bytes
par.S= 1000;          %seconds

out = simulator2(par);

for a= 1:length(par.r)
    fprintf("Average Packet Loss (%%)= %f\n",out.AvgPacketLoss(a));
    fprintf("Average Packet Delay (ms)= %f\n",out.AvgPacketDelay(a));
end
```

APPENDIX C – SIMULATOR 1 PROPOSED DIAGRAM