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MESTRADO INTEGRADO EM ENG. DE COMPUTADORES E TELEMÁTICA

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DESEMPENHO E DIMENSIONAMENTO DE REDES

ASSIGNMENT GUIDE No. 3

PERFORMANCE OF A PACKET SWITCHING CONNECTION

Assignment Description

Implement the following tasks using MATLAB to obtain the requested numerical solutions and conclusions. At the end, submit a report with the answers to the questions of the tasks requested for reporting including the numerical results, the MATLAB codes duly explained and the requested conclusions.

Task 1

Consider the event driven simulator, implemented in the provided MATLAB function *Simulator1*, to estimate the performance of a point-to-point IP connection between a company router and its ISP (Internet Service Provider). The simulator only considers the downstream direction, *i.e.*, from ISP to the company (usually, the direction with highest traffic load).

Simulator1 considers a connection of C (in Mbps) and a queue of size f (in Bytes) with a FIFO (First-In-First-Out) queueing discipline. The packet flow submitted to the connection is characterized by: (i) an exponentially distributed time between packet arrivals with average $1/\lambda_{data}$ and (ii) a random packet size between 64 and 1518 bytes with the probabilities: 16% for 64 bytes, 25% for 110 bytes, 20% for 1518 bytes and an equal probability for all other values (*i.e.*, from 65 to 109 and from 111 to 1517).

Input parameters of *Simulator1*:

- λ_{data} – packet rate, in packets per second (pps)
- C – connection capacity, in Mbps
- f – queue size, in Bytes
- P – total number of transmitted packets of a simulation run

Performance parameters estimated by *Simulator1*:

- PL – Packet Loss (%)
- APD – Average Packet Delay (milliseconds)
- MPD – Maximum Packet Delay (milliseconds)
- TT – Transmitted Throughput (Mbps)

Stopping criteria of *Simulator1*:

- Time instant when the connection ends the transmission of the P^{th} packet (P is one of the input parameter); in *Simulator1*, the queued packets at the end of the simulation do not count for the performance estimation.

Simulator1 is based on the following variables:

Events: ARRIVAL (the arrival of a packet) and DEPARTURE (the transmission end of a packet).

State variables: STATE (binary variable indicating if the connection is free or busy with the transmission of a packet), QUEUEOCCUPATION (occupation of the queue, in number of bytes, with the queued packets) and QUEUE (matrix with a variable number of rows and with 2 columns where each column has the size and the arriving time instant of each packet in the queue).

Statistical counters: TOTALPACKETS (number of packets arrived to the system), LOSTPACKETS (number of packets dropped due to buffer overflow), TRANSMITTEDPACKETS (number of transmitted packets), TRANSMITTEDBYTES (sum of the bytes of the transmitted packets),

DELAYS (sum of the delays of the transmitted packets), MAXDELAY (maximum delay among all transmitted packets).

Based on the statistical counters, the performance parameters are estimated at the end as:

$$PL = 100 \times \text{LOSTPACKETS} / \text{TOTALPACKETS}$$

$$APD = 1000 \times \text{DELAYS} / \text{TRANSMITTEDPACKETS}$$

$$MPD = 1000 \times \text{MAXDELAY}$$

$$TT = 10^{-6} \times \text{TRANSMITTEDBYTES} \times 8 / \text{total simulated time}$$

- 1.a.** Develop a MATLAB script to run *Simulator1* 10 times with a stopping criterion of $P = 10000$ at each run and to compute the estimated values and the 90% confidence intervals of all performance parameters when $\lambda = 1800$ pps, $C = 10$ Mbps and $f = 1.000.000$ Bytes (~1 MByte). Results (recall that these are simulation results):

```
Packet Loss (%)           = 0.00e+00 +- 0.00e+00
Av. Packet Delay (ms)    = 7.46e+00 +- 9.55e-01
Max. Packet Delay (ms)   = 3.43e+01 +- 4.80e+00
Throughput (Mbps)        = 9.33e+00 +- 5.25e-02
```

- 1.b.** Repeat the previous experiment but now consider $f = 10.000$ Bytes (~10 KBytes) Justify the differences between these results and the previous results. Results (recall that these are simulation results):

```
Packet Loss (%)           = 1.69e+00 +- 1.52e-01
Av. Packet Delay (ms)    = 3.42e+00 +- 8.40e-02
Max. Packet Delay (ms)   = 9.02e+00 +- 3.53e-02
Throughput (Mbps)        = 9.02e+00 +- 5.51e-02
```

- 1.c.** Consider that the system is modelled by a $M/M/1$ queueing model¹. Determine the theoretical values of the packet loss, average packet delay and total throughput using the $M/M/1$ model for the parameters considered in **1.a**. Compare these values with the simulation values and take conclusions. Results:

```
Packet Loss (%)           = 0.0000
Av. Packet Delay (ms)    = 8.1275
Throughput (Mbps)        = 9.3602
```

- 1.d.** Consider that the system is modelled by a $M/G/1$ queueing model². Determine the theoretical values of the packet loss, average packet delay and total throughput using the $M/G/1$ model for the parameters considered in **1.a**. Compare these values with the theoretical values of $M/M/1$ and with the simulation values, and take conclusions. Results:

```
Packet Loss (%)           = 0.0000
Av. Packet Delay (ms)    = 7.5185
Throughput (Mbps)        = 9.3602
```

¹ Check the $M/M/1$ queueing model in slides 29-30 of the theoretical presentation of Module 2 and slide 16 in the theoretical presentation of Module 4.

² Check the $M/G/1$ queueing model in slides 38-39 of Module 2 and the resolution of Exemple 4 of Module 2.

- 1.e.** Consider that the system is modelled by a $M/M/1/m$ queueing model³. Determine the theoretical values of the packet loss, average packet delay and throughput using the $M/M/1/m$ model for the parameters considered in **1.b**. Compare these values with the simulation values and take conclusions. Results:

Packet Loss (%) = 3.2906
 Av. Packet Delay (ms) = 3.7028
 Throughput (Mbps) = 9.0522

Task 2

In the previous task, it was assumed that the connection between the company router and its ISP (Internet Service Provider) does not introduce any transmission/propagation errors (i.e., it is provided by a wired access network). In this task, we assume that the connection is provided by a wireless access (for example, through a 4G/5G mobile network).

Develop *Simulator2* by changing the previous *Simulator1* in order to consider that the connection introduces a BER (Bit Error Rate) given by b . The input parameters of *Simulator2* should be all the input parameters of *Simulator1* plus parameter b . The performance parameters estimated by *Simulator2* should be the same as the ones of the previous simulator.

- 2.a.** Run *Simulator2* 20 times with a stopping criterion of $P = 10000$ at each run and to compute the estimated values and the 90% confidence intervals of all performance parameters when $\lambda = 1800$ pps, $C = 10$ Mbps, $f = 1.000.000$ Bytes (~1 MByte) and the BER is $b = 10^{-6}$. Results (recall that these are simulation results):

Packet Loss (%) = 4.94e-01 +- 2.42e-02
 Av. Packet Delay (ms) = 7.37e+00 +- 6.20e-01
 Max. Packet Delay (ms) = 3.56e+01 +- 3.53e+00
 Throughput (Mbps) = 9.24e+00 +- 3.65e-02

- 2.b.** Repeat the previous experiment but now consider that the BER is $b = 10^{-5}$. Justify the differences between these results and the previous results. Results (recall that these are simulation results):

Packet Loss (%) = 5.07e+00 +- 1.11e-01
 Av. Packet Delay (ms) = 7.03e+00 +- 5.07e-01
 Max. Packet Delay (ms) = 3.21e+01 +- 2.72e+00
 Throughput (Mbps) = 8.49e+00 +- 3.70e-02

- 2.c.** Consider that the system is modelled by a $M/G/1$ queueing model. Determine the theoretical values of the packet loss, average packet delay and total throughput using the $M/G/1$ model for the parameters considered in **2.a** (see **Appendix A**). Compare these values with the values in **1.d** and the simulation values in **2.a**, and take conclusions. Results:

Packet Loss (%) = 0.5175
 Av. Packet Delay (ms) = 7.5163
 Throughput (Mbps) = 9.2711

³ Check the $M/M/1/m$ queueing model in slides 34-35 of the theoretical presentation of Module 2 and slide 17 of the theoretical presentation of Module 4.

2.d. Considering again the system modelled by a $M/G/1$ queueing model, determine now the theoretical values of the packet loss, average packet delay and total throughput for the parameters considered in **2.b**. Compare these values with the values in **1.d** and **2.c**, and with the simulation values in **2.c**, and take conclusions. Results:

Packet Loss (%) = 4.9601

Av. Packet Delay (ms) = 7.4961

Throughput (Mbps) = 8.5115

To be completed...

Appendix A – Performance of a connection with bit error rate and modeled as a M/G/1 queueing system

Consider a packet switching connection of capacity C (in bps) which introduces a bit error rate b and is modeled by a M/G/1 queueing system. The packet arrival rate is λ (in packets/second) and packet sizes are B_1, B_2, \dots, B_n (in Bytes), with probabilities p_1, p_2, \dots, p_n , respectively.

Packet Loss (PL):

The probability of each packet size B_i being sent without errors is:

$$P_i = (1 - b)^{8 \times B_i}$$

So, the packet loss (in %) is the weighted sum of the packet loss probability of each packet size, where the weights are the probabilities of the packet sizes:

$$PL = 100\% \times \sum_{i=1}^n p_i \times (1 - P_i)$$

Average Packet Delay (APD):

In a M/G/1 queueing system, the average queueing delay for all packets is:

$$W_Q = \frac{\lambda \times E[S^2]}{2 \times (1 - \lambda \times E[S])}$$

where $E[S]$ is the average packet transmission time and $E[S^2]$ is the average square of the packet transmission time:

$$E[S] = \sum_{i=1}^n p_i \times \frac{8 \times B_i}{C} \quad E[S^2] = \sum_{i=1}^n p_i \times \left(\frac{8 \times B_i}{C} \right)^2$$

Then, the average packet delay of each packet size B_i (if sent without errors) is the sum of its average queueing delay and its transmission time:

$$W_i = W_Q + \frac{8 \times B_i}{C}$$

So, the average packet delay is the average delay of all packets that are sent without errors:

$$APD = \frac{\sum_{i=1}^n (p_i \times P_i \times W_i)}{\sum_{i=1}^n (p_i \times P_i)}$$

Total Throughput (TT):

The total throughput is the sum of the throughput of the packets that are sent without errors for each packet size B_i :

$$TT = \sum_{i=1}^n (p_i \times P_i \times \lambda \times (8 \times B_i))$$