DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES
E INFORMÁTICA

MESTRADO INTEGRADO EM ENG. DE COMPUTADORES E TELEMÁTICA

ANO 2019/2020

# DESEMPENHO E DIMENSIONAMENTO DE REDES

## ASSIGNMENT GUIDE NO. 4

## PERFORMANCE OF A PACKET SWITCHING CONNECTION

## *Simulator1*

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, 22% for 1518 bytes and an equal probability for the values from 65 to 1517.

Input parameters of *Simulator1*:

$\lambda_{data}$ – 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 the of 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 (size and 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% × LOSTPACKETS / TOTALPACKETS
APD = 1000 × DELAYS / TRANSMITTEDPACKETS
MPD = 1000 × MAXDELAY
TT = $10^{-6}$ × TRANSMITTEDBYTES × 8 / total simulated time

**a)** Using *Simulator1*, develop a MATLAB script to run 10 simulations with the stopping criteria $P$ = 1000 for each of the cases defined in Table I. In the script, compute 90% confidence intervals and present the results in the form $a \pm b$.

*Table I*

| Case | $\lambda_{data}$ (pps) | $C$ (Mbps) | $f$ (Bytes) | Packet Loss (%) | Average Delay (msec) | Maximum Delay (msec) | Transm. Through. (Mbps) |
|---|---|---|---|---|---|---|---|
| A | 100 | 2 | 100000 | | | | |
| B | 200 | 2 | 100000 | | | | |
| C | 100 | 2 | 10000 | | | | |
| D | 200 | 2 | 10000 | | | | |
| E | 500 | 10 | 100000 | | | | |
| F | 1000 | 10 | 100000 | | | | |
| G | 500 | 10 | 10000 | | | | |
| H | 1000 | 10 | 10000 | | | | |

**b)** With the obtained results, take conclusions concerning the impact of the different input values of packet rate ($\lambda_{data}$), connection capacity ($C$) and queue size ($f$) on the performance parameters of the connection.

**c)** Repeat experiment **a)** again for the cases of Table I but now consider 10 simulations with the stopping criteria $P$ = 100000. Compare the confidence intervals of these results with the ones of **a)**. Describe and justify the conclusions you take from the observed differences.

**d)** Repeat experiment **a)** again for the cases of Table I but now consider 1000 simulations with the stopping criteria $P$ = 1000. Compare the confidence intervals of these results with the ones of **a)** and **c)**. Describe and justify the conclusions you take from the observed differences.

**e)** Implement 2 MATLAB function, each one to compute the theoretical values of the average packet delay for the queueing models $M/M/1$ and $M/G/1$, respectively[1]. Run the functions to compute these theoretical values for the cases of Table I. Take conclusions on the comparison between the theoretical values and the simulation results and determine which (and why) queueing model better approximates the performance of the simulated system.

**f)** Consider the connection capacity $C$ = 2 Mbps and the queue size $f$ = 10000. Compute the performance parameters for the following values of $\lambda_{data}$ = 50, 100, 150, 200, 250, 270, 290, 310, 330, 350, 400, 450 and 500 pps (for each case, run 10 simulations with the stopping criteria $P$ = 100000). Present the average values of the performance parameters in 3 plots: one with the Packet Loss results, one with the Average and the Maximum Packet Delay results and one with Transmitted Throughput results. Take conclusions from the analysis of these 3 plots.

[1] Recall the $M/M/1$ queueing model (slides 29-30) and the $M/G/1$ queueing model (slides 38-39) in the theoretical presentation of Module 2.

**g)** Repeat experiment **f)** changing the queue size to $f$ = 100000. Take conclusions from the analysis of these 3 plots and also by comparing them with the plots of **f)**.

**h)** Consider now the connection capacity $C$ = 10 Mbps and the queue size $f$ = 10000. Compute the performance parameters for the following values of $\lambda_{data}$ = 250, 500, 750, 1000, 1250, 1350, 1450, 1550, 1650, 1750, 2000, 2250 and 2500 pps (for each case, run 10 simulations with the stopping criteria $P$ = 100000). Again, present the average values of the performance parameters in 3 plots: one with the Packet Loss results, one with the Average and Maximum Packet Delay results and one with Transmitted Throughput results. Take conclusions from the analysis of these 3 plots and also by comparing them with the plots of **f)** and **g)**.

**i)** Repeat experiment **h)** changing the queue size to $f$ = 100000. Take conclusions from the analysis of these 3 plots and also by comparing them with the plots of **f)**, **g)** and **h)**.

## *Simulator2*

Develop *Simulator2*, by changing the previous *Simulator1* in order to consider $n$ additional VoIP (Voice over IP) packet flows. In *Simulator2*, consider that each VoIP flow generates packets with size uniformly distributed between 110 Bytes and 130 Bytes, and the time between packet arrivals is uniformly distributed between 16 milliseconds and 24 milliseconds[2]. Consider also that packets of all flows (data and VoIP) are queued on a single queue served with a FIFO (First-In-First Out)-discipline.

Input parameters of *Simulator2*:

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

Performance parameters estimated by *Simulator1*:

- $\text{PL}_{data}$ – Packet Loss of data packets (%)
- $\text{PL}_{VoIP}$ – Packet Loss of VoIP packets (%)
- $\text{APD}_{data}$ – Average Delay of data packets (milliseconds)
- $\text{APD}_{VoIP}$ – Average Delay of VoIP packets (milliseconds)
- $\text{MPD}_{data}$ – Maximum Delay of data packets (milliseconds)
- $\text{MPD}_{VoIP}$ – Maximum Delay of VoIP packets (milliseconds)
- TT – Transmitted Throughput (data + VoIP) (Mbps)

In the implementation of *Simulator2*, the time instant of the first packet arrival of each VoIP flow must be randomly generated with a uniform distribution between 0 and 20 milliseconds.

**j)** Using *Simulator2*, run 10 simulations with the stopping criteria $P$ = 100000 for each of the cases defined in Table II (again, compute 90% confidence intervals and present the results in the form $a \pm b$).

[2] These values are based on G.726 standard, at 32 kbps, assumming a packet size of ± 10 Bytes with a uniform distribution around its average size and considering also a jitter of ± 4 milliseconds with a uniform distribution around an inter arrival time of 20 milliseconds.

| *Table II* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Case | $\lambda_{data}$ (pps) | $C$ (Mbps) | $f$ (Bytes) | $n$ | Packet Loss data / VoIP (%) | Avg. Delay data / VoIP (msec) | Max. Delay data / VoIP (msec) | Transm. Through. (Mbps) |
| A | 200 | 2 | 100000 | 5 | / | / | / | |
| B | 200 | 2 | 100000 | 10 | / | / | / | |
| C | 200 | 2 | 100000 | 15 | / | / | / | |
| D | 200 | 2 | 10000 | 5 | / | / | / | |
| E | 200 | 2 | 10000 | 10 | / | / | / | |
| F | 200 | 2 | 10000 | 15 | / | / | / | |
| G | 1000 | 10 | 100000 | 25 | / | / | / | |
| H | 1000 | 10 | 100000 | 50 | / | / | / | |
| I | 1000 | 10 | 100000 | 75 | / | / | / | |
| J | 1000 | 10 | 10000 | 25 | / | / | / | |
| K | 1000 | 10 | 10000 | 50 | / | / | / | |
| L | 1000 | 10 | 10000 | 75 | / | / | / | |

**k)** Based on the results of Table II, take conclusions concerning the impact of the different input values of packet rate ($\lambda_{data}$), connection capacity ($C$), queue size ($f$) and number of VoIP flows ($n$) on the performance parameters of the connection for the two types of flows (data and VoIP) with the FIFO discipline.

## *Simulator3*

Develop *Simulator3*, by changing the previous *Simulator2* in order to consider that VoIP packets are sent by the router with higher priority than data packets. The input parameters, the performance parameters to be estimated and the stopping criteria are the same as *Simulator2*.

**l)** Repeat experiment **j)** but now using *Simulator3* instead of *Simulator2*. Present the obtained results.

**m)** Based on the results of experiment **j)** and **l)**, take conclusions concerning the impact of the different input values on the performance parameters of the connection for the two types of flows (data and VoIP) with the priority discipline. Justify the differences between the FIFO and the priority disciplines.

**n)** Implement a MATLAB function to compute the theoretical values of the average packet delay for the M/G/1 queueing model with 2 priorities[3].

**o)** Based on the simulation results obtained with *Simulator3* in **l)**, which are the cases of Table II that can be modelled by the M/G/1 model with 2 priorities and why? For such cases, use the MATLAB function developed in **n)** to determine the theoretical average packet delay values of each of the two types of flows (data and VoIP). Compare the

[3] Recall the *M*/*G*/1 queueing model with priorities (slides 22-23) in the theoretical presentation of Module 4.

theoretical values with the simulation values and determine if this model is adequate to model the behavior of the simulated system.

### ***Simulator4***

Develop *Simulator4*, by changing the previous *Simulator3* in order to consider that upon arrival, VoIP packets are always accepted in the queue (if there is enough space) but data packets are accepted only if the total queue occupation is not higher than $r$, in percentage (a simplified version of WRED – Weighted Random Early Discard – discipline). The input parameters are the same as *Simulator3* plus the additional parameter $r$ (in percentage). The performance parameters to be estimated and the stopping criteria are the same as *Simulator3*.

**p)** Consider only the cases of Table II with $f$ = 10000 Bytes. Using *Simulator4*, run 10 simulations with the stopping criteria $P$ = 100000 for these cases with $r$ = 25%, 50% and 75% (again, compute 90% confidence intervals and present the results in the form $a \pm b$). Present the obtained results.

**q)** Based on the results of experiment **l)** and **p)**, take conclusions concerning the impact of the different input values on the performance parameters of the connection for the two types of flows (data and VoIP) with the RED discipline. Justify the differences between using and not using the RED discipline.