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DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES E INFORMÁTICA

MESTRADO EM ENGENHARIA DE COMPUTADORES E TELEMÁTICA

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# MODELAÇÃO E DESEMPENHO DE REDES E SERVIÇOS

# PRACTICAL GUIDE

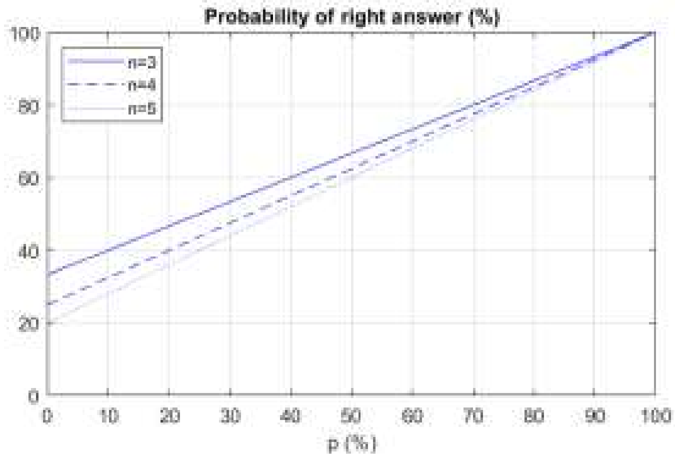
## Task 1

Consider a multiple choice test such that each question has $n$ multiple answers and only one is correct. Assume that the student has studied a percentage $p$ (with $0\% \leq p \leq 100\%$) of the test content. When a question addresses the content the student has studied, he selects the right answer with 100% of probability. Otherwise, the student always selects randomly one of the $n$ answers with a uniform distribution.

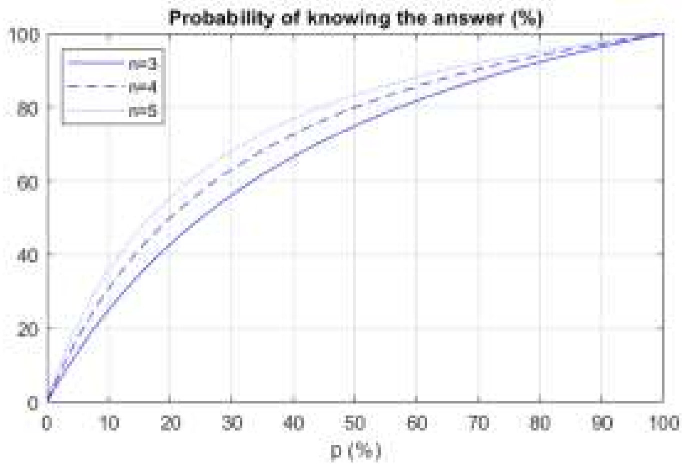
**1.a.** When $p = 60\%$ and $n = 4$, determine the probability of the student to select the right answer. Answer: 70%

**1.b.** When $p = 70\%$ and $n = 5$, determine the probability of the student to known the answer when he selects the right answer. Answer: 92.1%

**1.c.** Draw a plot with the same look as the plot below with the probability of the student to select the right answer as a function of the probability $p$ (consider the number of multiple answers $n = 3, 4$ and 5). What do you conclude from these results? Answer:




**1.d.** Draw a plot with the same look as the plot below with the probability of the student to know the answer when he selects the right answer as a function of the probability $p$ (consider $n = 3, 4$ and 5). What do you conclude from these results? Answer:



## Task 2

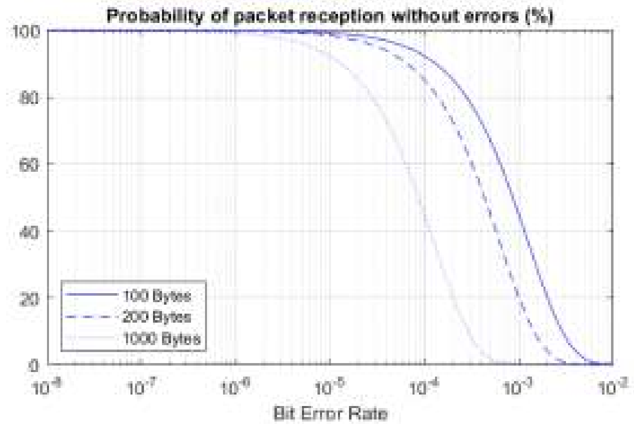
Consider a wireless link between multiple stations for data communications with a bit error rate (*ber*) of $p$. Assume that transmission errors in the different bits of a data frame are statistically independent (i.e., the number of errors of a data packet is a binomial random variable).

**2.a.** Determine the probability of a data frame of 100 Bytes to be received without errors when $p = 10^{-2}$. Answer: 0.0322%

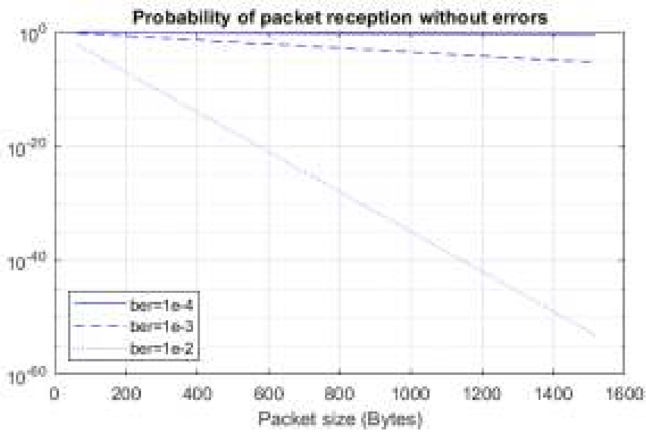
**2.b.** Determine the probability of a data frame of 1000 Bytes to be received with exactly one error when $p = 10^{-3}$. Answer: 0.2676%

**2.c.** Determine the probability of a data frame of 200 Bytes to be received with one or more errors when $p = 10^{-4}$. Answer: 14.7863%

**2.d.** Draw a plot using a logarithmic scale for the X-axis (use the MATLAB function `semilogx`) with the same look as the plot below with the probability of a data frame (of size 100 Bytes, 200 Bytes or 1000 Bytes) being received without errors as a function of the *ber* (from $p = 10^{-8}$ up to $p = 10^{-2}$). What do you conclude from these results? Answer:

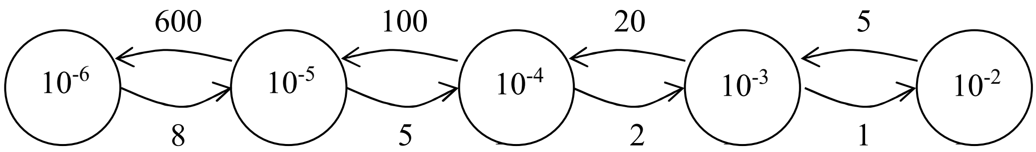



**2.e.** Draw a plot using a logarithmic scale for the Y-axis (use the MATLAB function `semilogy`) with the same look as the plot below with the probability of a data frame being received without errors (for $p = 10^{-4}$, $10^{-3}$ and $10^{-2}$) as a function of the packet size (all integer values from 64 Bytes up to 1518 Bytes). What do you conclude from these results? Answer:



## Task 3

Consider a wireless link between multiple stations for data communications. The bit error rate (*ber*) introduced by the wireless link (due to the variation of the propagation and interference factors along with time) is approximately given by the following Markov chain:




where the state transition rates are in number of transitions per hour. Consider that the link is in an interference state when its *ber* is at least $10^{-3}$ and in a normal state, otherwise. Assume that all stations detect with a probability of 100% when the data frames sent by the other stations are received with errors. Determine:

**3.a.** the probability of the link being in each of the five states; answer: $9.86\times10^{-1}$ ($10^{-6}$), $1.31\times10^{-2}$ ($10^{-5}$), $6.57\times10^{-4}$ ($10^{-4}$), $6.57\times10^{-5}$ ($10^{-3}$), $1.31\times10^{-5}$ ($10^{-2}$)

**3.b.** the average percentage of time the link is in each of the five states; answer: $9.86\times10^{-1}$ ($10^{-6}$), $1.31\times10^{-2}$ ($10^{-5}$), $6.57\times10^{-4}$ ($10^{-4}$), $6.57\times10^{-5}$ ($10^{-3}$), $1.31\times10^{-5}$ ($10^{-2}$)

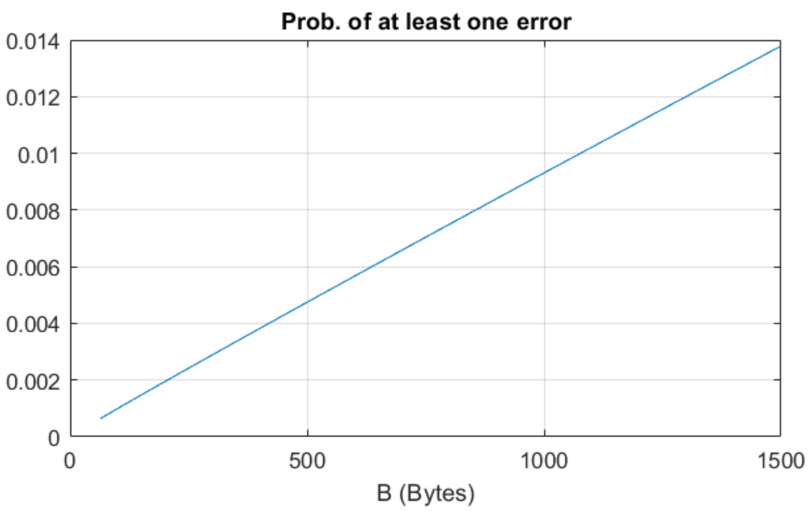
**3.c.** the average *ber* of the link; answer: $1.38\times10^{-6}$

**3.d.** the average time duration (in minutes) that the link stays in each of the five states; answer: 7.5 min ($10^{-6}$), 0.10 min ($10^{-5}$), 0.59 min ($10^{-4}$), 2.86 min ($10^{-3}$), 12.0 min ($10^{-2}$)

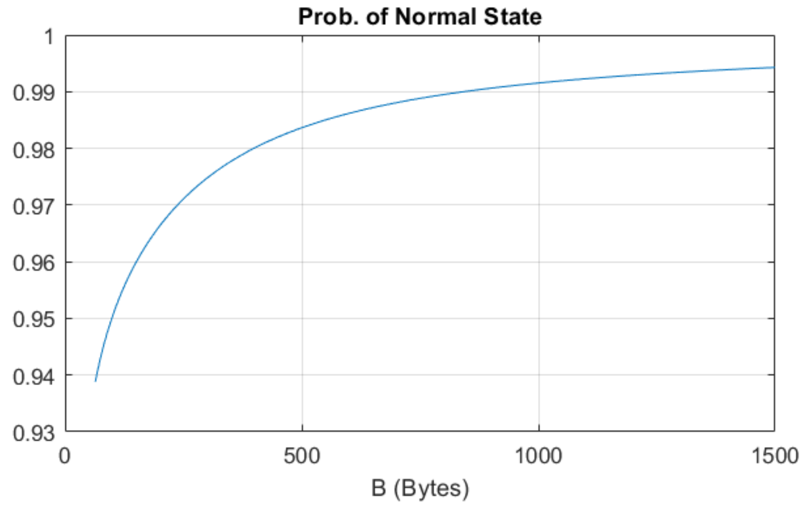
**3.e.** the probability of the link being in the normal state and in interference state; answer: 0.999921 (normal), $7.89\times10^{-5}$ (interference)

**3.f.** the average *ber* of the link when it is in the normal state and when it is in the interference state; answer: $1.18\times10^{-6}$ (normal), $2.50\times10^{-3}$ (interference)

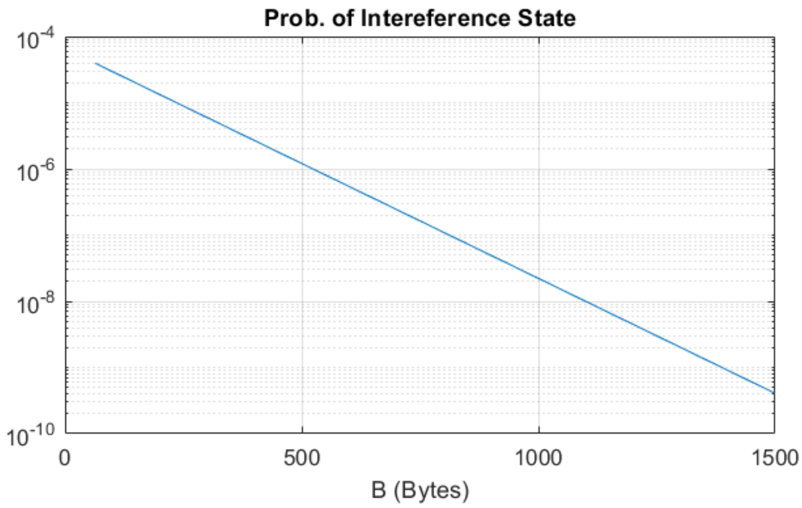
**3.g.** considering a data frame of size $B$ (in Bytes) sent by one source station to a destination station, draw a plot with the same look as the plot below of the probability of the packet being received by the destination station with at least one error as a function of the packet size (from 64 Bytes up to 1500 Bytes); analyze and justify the results; answer:



**3.h.** considering that a data frame of size *B* (in Bytes) sent by one source station is received <u>with at least one error</u> by the destination station, draw a plot with the same look as the plot below of the probability of the link being <u>in the normal state</u> as a function of the packet size (from 64 Bytes up to 1500 Bytes); analyze and justify the results; <u>answer:</u>




**3.i.** considering that a data frame of size *B* (in Bytes) sent by one source station is received <u>without errors</u> by the destination station, draw a plot with the same look as the plot below (use the MATLAB function `semilogy`) of the probability of the link being <u>in the interference state</u> as a function of the packet size (from 64 Bytes up to 1500 Bytes); analyze and justify the results; <u>answer:</u>



## Task 4

Consider an ideal link (i.e., with a *ber* = 0) from one router to another router with a capacity of $C$ Mbps (1 Mbps = $10^6$ bps) for IP communications. The link has a propagation delay of 10 μs (1 μs = $10^{-6}$ seconds). There is a very large queue at the output port of the link. The IP packet flow supported by the link is characterized by:

(i) the packet arrivals are a Poisson process with rate $\lambda$ pps (packets per second)
(ii) the size of each IP packet is between 64 and 1518 bytes (the size includes the overhead of the Layer 2 protocol) with the probabilities: 19% for 64 bytes, 23% for 110 bytes, 17% for 1518 bytes and an equal probability for all other values (i.e., from 65 to 109 and from 111 to 1517).

Consider that $\lambda = 1000$ pps and $C = 10$ Mbps. Determine:

**4.a.** the average packet size (in Bytes) and the average packet transmission time of the IP flow; answer: 620.02 Bytes, $4.96\times10^{-4}$ seconds

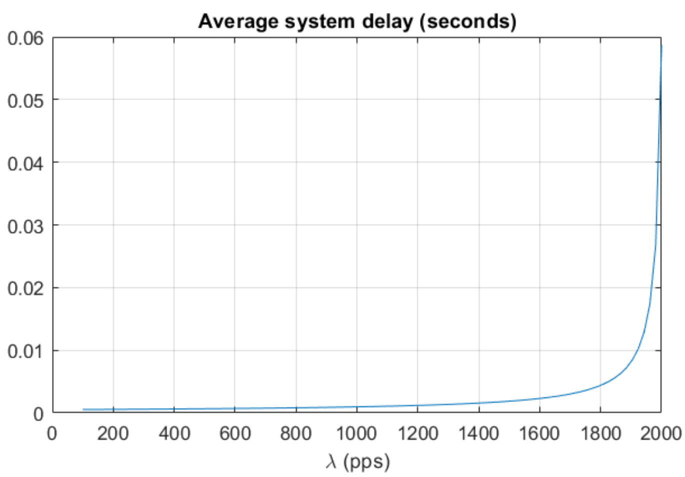
**4.b.** the average throughput (in Mbps) of the IP flow; answer: 4.96 Mbps

**4.c.** the capacity of the link, in packets/second; answer: 2016.06 pps

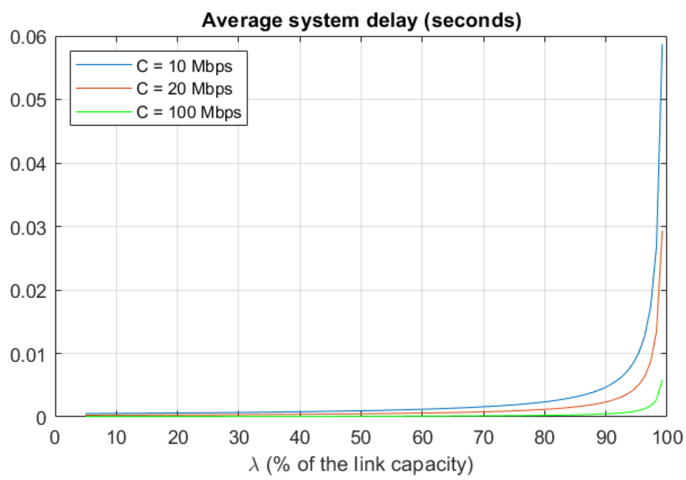
**4.d.** the average packet queuing delay and average packet system delay of the IP flow (the system delay is the queuing delay + transmission time + propagation delay) using the $M/G/1$ queuing model; answer: queuing – $4.60\times10^{-4}$ seconds, system – $9.66\times10^{-4}$ seconds

**4.e.** for $C = 10$ Mbps, draw a plot with the same look as the plot below with the average system delay as a function of the packet arrival rate $\lambda$ (from $\lambda = 100$ pps up to $\lambda = 2000$ pps); analyze the results and take conclusions;

**4.f.** for $C = 10$, 20 and 100 Mbps, draw a plot with the same look as the plot below with the average system delay as a function of the packet arrival rate $\lambda$ (from $\lambda = 100$ pps up to $\lambda = 2000$ pps when $C = 10$, from $\lambda = 200$ pps up to $\lambda = 4000$ pps when $C = 20$ and from $\lambda = 1000$ pps up to $\lambda = 20000$ pps when $C = 100$); the x-axis should indicate the value of $\lambda$ as a percentage of the capacity of the link, in pps (determined in **4.c.**); analyze the results and take conclusions.




Answer to **4.e.**




Answer to **4.f.**