DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES
E INFORMÁTICA

MESTRADO EM ENGENHARIA DE COMPUTADORES E TELEMÁTICA

ANO 2021/2022

MODELAÇÃO E DESEMPENHO DE REDES E SERVIÇOS

PRACTICAL GUIDE

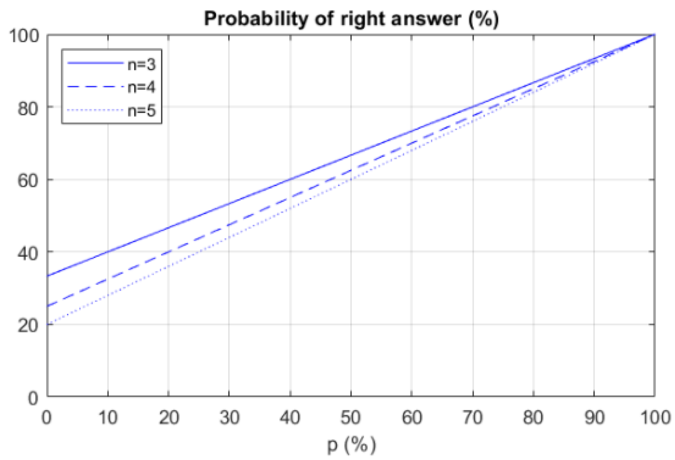
Task 1

Consider a multiple choice test such that each question has n possible 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.

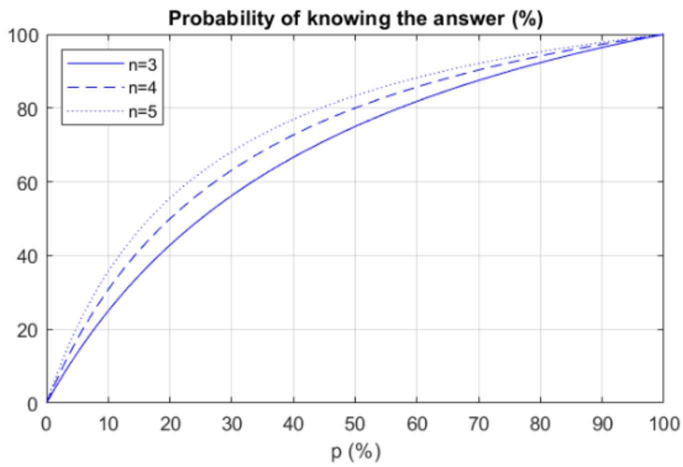
1.a. When $p = 60\%$ and $n = 4$, determine the probability of the student to select the right answer. Answer: 70%

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 $n = 3, 4$ 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

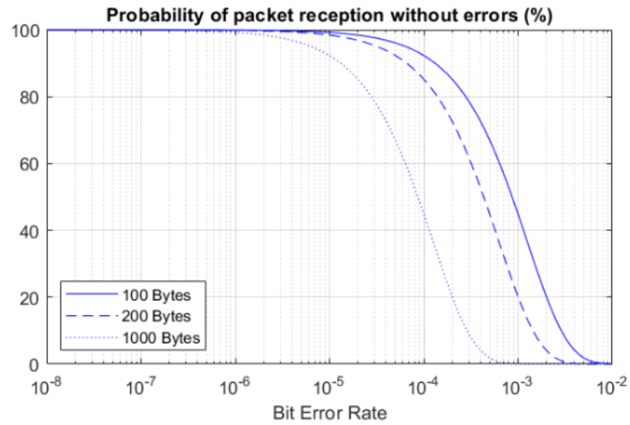
Consider a wireless link between multiple stations for data communications with a bit error rate (*ber*) of p. Assume that errors in the different bits of a data packet are statistically independent (i.e., the number of errors of a data packet is a binomial random variable).

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

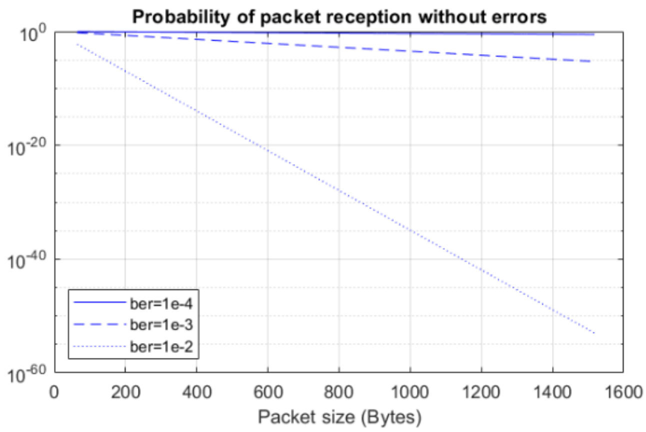
2.b. Determine the probability of a data packet of 1000 Bytes to be received with exactly one error when $p = 10^{-3}$. Answer: 0.2676%

2.c. Determine the probability of a data packet 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 packet (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:

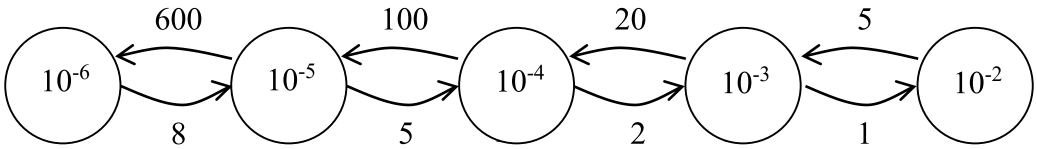


2.e. Draw a plot using a logarithmic scale for the Y-axis (use the MATLAB function `semilogy`) with the same look as the plot below with the probability of a data packet being received without errors (for $p = 10^{-4}$, 10^{-3} and 10^{-2}) as a function of the packet size (all integer values from 64 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: 9.86×10^{-1} (10^{-6}), 1.31×10^{-2} (10^{-5}), 6.57×10^{-4} (10^{-4}), 6.57×10^{-5} (10^{-3}), 1.31×10^{-5} (10^{-2})

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

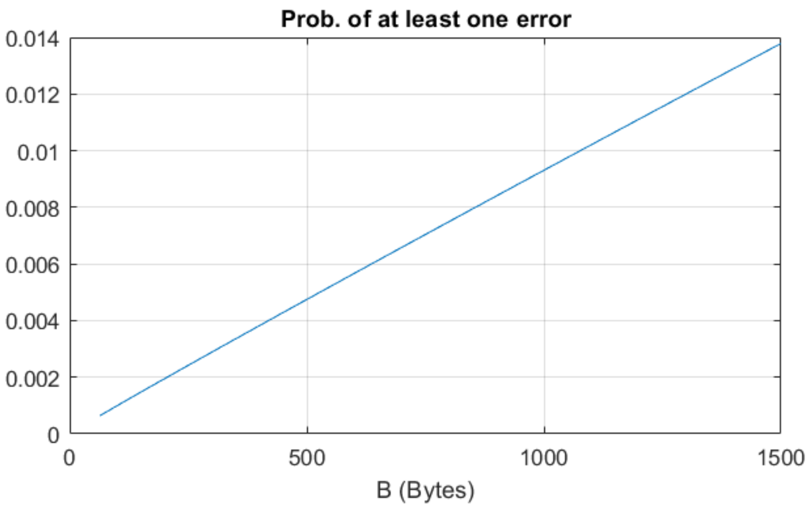
3.c. the average *ber* of the link; answer: 1.38×10^{-6}

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

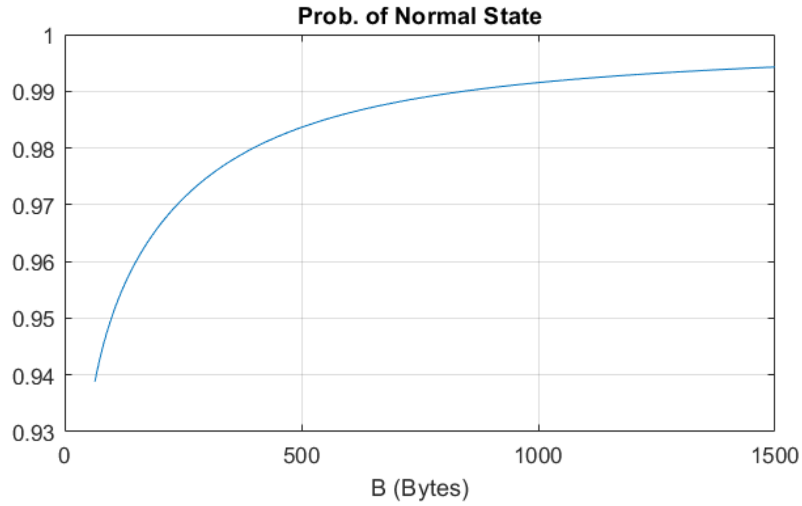
3.e. the probability of the link being in the normal state and in interference state; answer: 0.999921 (normal), 7.89×10^{-5} (interference)

3.f. the average *ber* of the link when it is in the normal state and when it is in the interference state; answer: 1.18×10^{-6} (normal), 2.50×10^{-3} (interference)

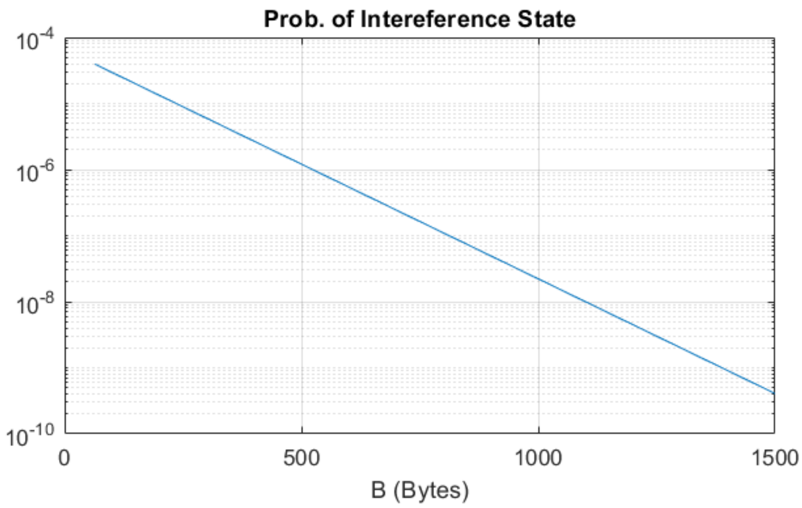
3.g. considering a data frame of size *B* (in Bytes) sent by one source station to a destination station, draw a plot with the same look as the plot below of the probability of the packet being received by the destination station with at least one error as a function of the packet size (from 64 Bytes 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 λ 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 λ = 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, 4.96×10^{-4} seconds

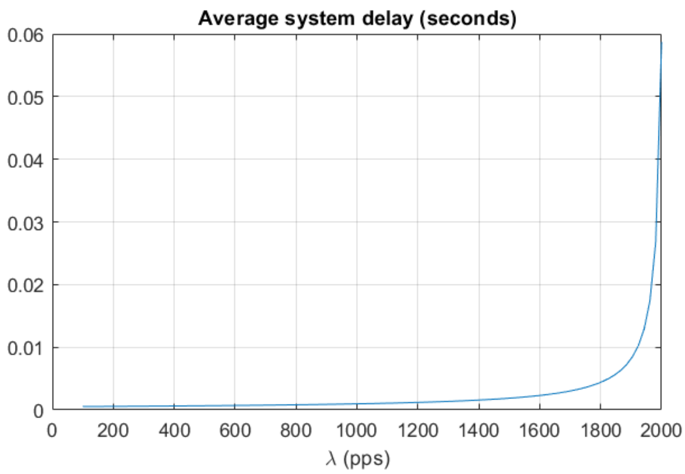
4.b. the average throughput (in Mbps) of the IP flow; answer: 4.96 Mbps

4.c. the capacity of the link, in pps; answer: 2016.06 pps

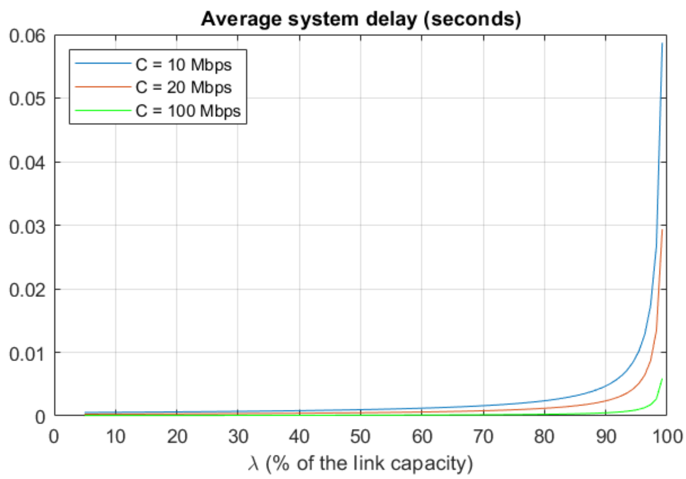
4.d. the average packet queuing delay and system packet delay of the IP flow (the system delay is the queuing delay + transmission time + propagation delays); answer: queuing – 4.60×10^{-4} seconds, system – 9.66×10^{-4} seconds

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 λ (from λ = 100 pps up to λ = 2000 pps); analyze and justify the results;

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 λ (from λ = 100 pps up to λ = 2000 pps when *C* = 10, from λ = 200 pps up to λ = 4000 pps when *C* = 20 and from λ = 1000 pps up to λ = 20000 pps when *C* = 100); the x-axis should indicate the value of λ as a percentage of the capacity of the link, in pps (determined in **4.c.**); analyze and justify the results.



Answer to **4.e.**



Answer to **4.f.**