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**DEPARTAMENTO DE ELETRÓNICA, TELECOMUNICAÇÕES E INFORMÁTICA**

MESTRADO EM ENGENHARIA DE COMPUTADORES E TELEMÁTICA

ANO 2021/2022

**MODELAÇÃO E DESEMPENHO DE REDES E SERVIÇOS**

**MINI-PROJECT 1**

**PERFORMANCE EVALUATION OF POINT-TO-POINT LINKS**

**SUPPORTING PACKET SERVICES**

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| **TASK 1** |

Consider the event driven simulator *Simulator1* used in Task 5 of the Practical Guide.

**1.a.** Consider the case of *C* = 10 Mbps and *f* = 1.000.000 Bytes. Run *Simulator1* 50 times with a stopping criterion of *P* = 10000 each run and compute the estimated values and the 90% confidence intervals of the average delay performance parameter when ʎ = 400, 800, 1200, 1600 and 2000 pps. Present the average packet delay results in bar charts with the confidence intervals in error bars1. Justify the results and take conclusions concerning the impact of the packet rate in the obtained average packet delay.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30 | lambda = [400, 800, 1200, 1600, 2000];  C = 10;  f = 1000000;  P = 10000;  N = 50;  alfa = 0.1;  PL = zeros(1,5);  APD = zeros(1,5);  MPD = zeros(1,5);  TT = zeros(1,5);  mediaAPD = zeros(1,5);  termAPD = zeros(1,5);  for i= 1:length(lambda)  for it= 1:N  [PL(it), APD(it), MPD(it), TT(it)] = Simulator1(lambda(i),C,f,P);  end  mediaAPD(i) = mean(APD);  termAPD(i) = norminv(1-alfa/2)\*sqrt(var(APD)/N);  end  figure(1);  h = bar(lambda,mediaAPD);  hold on  er = errorbar(lambda,mediaAPD,termAPD);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Packet Delay');  xlabel('Lambda (pps)');  ylabel('Average packet delay (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 6). De seguida, foram inicializados quatro vetores a zeros (linhas 7 a 10), que irão conter os valores de retorno do *simulator1* e mais dois vetores a zeros (linhas 11 e 12) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *lambdas* (linhas 13 a 19), executou-se o simulador N vezes (linhas 14 a 16) e, com os valores lidos do simulador, calculou-se a média do atraso médio de pacotes e a respetiva taxa de ocupação (linhas 17 e 18).  Por fim, desenhou-se o gráfico correspondente ao atraso médio de pacotes (linhas 20 a 30). | |
| **Result** | |
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| **Conclusions** | |
| Pode-se verificar que o atraso médio de pacotes é exponencialmente positivo e que para valores de, pelo menos 2000 pedidos por segundo, existe uma acentuação significativa, uma vez que o número de pacotes que estão na fila é substancialmente maior ao longo da simulação.  Como a fila de espera é do tipo FIFO, o tempo que leva a transmitir um pacote que entrou por último vai ser exponencialmente maior comparado com valores de lambda mais pequenos, logo o aumento será igualmente exponencial.  É importante salientar que os resultados obtidos podem não ser completamente fiáveis, dado que os intervalos de confiança são muito altos em comparação com os valores e suas variações. | |

**1.b.** Consider the case of ʎ = 1800 pps and C = 10 Mbps. Run *Simulator1* 50 times with a stopping criterion of P = 10000 each run and compute the estimated values and the 90% confidence intervals of the average delay and packet loss performance parameters when f = 100.000, 20.000, 10.000 and 2.000 Bytes. Present the average packet delay results in one figure and the average packet loss results in another figure (in both cases, in bar charts with the confidence intervals in error bars). Justify the results and take conclusions concerning the impact of the queue size in the obtained average packet delay and average packet loss.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45 | lambda = 1800;  C = 10;  f = [100000, 20000, 10000, 2000];  P = 10000;  N = 50;  alfa = 0.1;  PL = zeros(1,4);  APD = zeros(1,4);  MPD = zeros(1,4);  TT = zeros(1,4);  mediaPL = zeros(1,4);  termPL = zeros(1,4);  mediaAPD = zeros(1,4);  termAPD = zeros(1,4);  for i= 1:length(f)  for it= 1:N  [PL(it), APD(it), MPD(it), TT(it)] = Simulator1(lambda,C,f(i),P);  end  mediaPL(i) = mean(PL);  termPL(i) = norminv(1-alfa/2)\*sqrt(var(PL)/N);  mediaAPD(i) = mean(APD);  termAPD(i) = norminv(1-alfa/2)\*sqrt(var(APD)/N);  end  figure(1);  h = bar(f,mediaPL);  hold on  er = errorbar(f,mediaPL,termPL);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Packet Loss');  xlabel('Queue size (bytes)');  ylabel('Average packet loss (%)');  hold off  figure(2);  h = bar(f,mediaAPD);  hold on  er = errorbar(f,mediaAPD,termAPD);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Packet Delay');  xlabel('Queue size (bytes)');  ylabel('Average packet delay (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 6). De seguida, foram inicializados quatro vetores a zeros (linhas 7 a 10), que irão conter os valores de retorno do *simulator1* e mais quatro vetores a zeros (linhas 11 a 14) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *f* (linhas 15 a 23), executou-se o simulador N vezes (linhas 16 a 18) e, com os valores lidos do simulador, calculou-se a média de pacotes perdidos e a respetiva taxa de ocupação (linhas 19 e 20) e calculou-se a média do atraso médio de pacotes e a respetiva taxa de ocupação (linhas 21 e 22).  Por fim, desenharam-se os gráficos correspondentes à perda de pacotes (linhas 24 a 34) e ao atraso médio do pacote (linhas 35 a 45). | |
| **Result** | |
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| **Conclusions** | |
| É de esperar que haja uma substancial perda de pacotes, pois os valores do tamanho da fila de espera são consideravelmente inferiores ao valor fixo a aproximadamente 10 MBytes. Quanto menor for o tamanho da fila de espera, mais incapacidade de armazenamento de pacotes antes de serem atendidos, tendo que descartar alguns. Isto é provado pela tendência decrescente exponencial do valor proporcionalmente ao tamanho da fila.  Relativamente ao atraso médio de pacotes, apresenta uma tendência crescente com o aumento do tamanho da fila de espera. Como a fila de espera suporta mais pacotes à espera de serem processados, quando um pacote é inserido no fim da fila, permanecerá à espera durante mais tempo que numa fila de tamanho mais reduzido, na qual o pacote será mais rapidamente descartado, o que não possibilita que fique à espera tanto tempo. | |

**1.c.** Consider the case of ʎ = 1800 pps and f = 1.000.000 Bytes. Run *Simulator1* 50 times with a stopping criterion of P = 10000 at each run and compute the estimated values and the 90% confidence intervals of the average delay performance parameter when C = 10, 20, 30 and 40 Mbps. Present the average packet delay results in bar charts with the confidence intervals in error bars. Justify the results and take conclusions concerning the impact of the link capacity in the obtained average packet delay.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30 | lambda = 1800;  C = [10, 20, 30, 40];  f = 1000000;  P = 10000;  N = 50;  alfa = 0.1;  PL = zeros(1,4);  APD = zeros(1,4);  MPD = zeros(1,4);  TT = zeros(1,4);  mediaAPD = zeros(1,4);  termAPD = zeros(1,4);  for i= 1:length(C)  for it= 1:N  [PL(it), APD(it), MPD(it), TT(it)] = Simulator1(lambda,C(i),f,P);  end  mediaAPD(i) = mean(APD);  termAPD(i) = norminv(1-alfa/2)\*sqrt(var(APD)/N);  end  figure(4);  h = bar(C,mediaAPD);  hold on  er = errorbar(C,mediaAPD,termAPD);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Packet Delay');  xlabel('Link bandwidth (Mbps)');  ylabel('Average packet delay (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 6). De seguida, foram inicializados quatro vetores a zeros (linhas 7 a 10), que irão conter os valores de retorno do *simulator1* e mais dois vetores a zeros (linhas 11 e 12) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *f* (linhas 13 a 19), executou-se o simulador N vezes (linhas 14 a 16) e, com os valores lidos do simulador, calculou-se a média de pacotes perdidos e a respetiva taxa de ocupação (linhas 17 e 18).  Por fim, desenhou-se o gráfico correspondente ao atraso médio do pacote (linhas 20 a 30). | |
| **Result** | |
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| **Conclusions** | |
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**1.d.** Consider that the system is modelled by a M/G/1 queueing model. Determine the theoretical values of the average packet delay using the M/G/1 model for all cases of 1.c. Compare the theoretical values with the simulation results of experiments 1.c and take conclusions.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31 | lambda = 1800;  C = [10, 20, 30, 40];  f = 1000000;  P = 10000;  N = 50;  alfa = 0.1;  PL = zeros(1,4);  APD = zeros(1,4);  MPD = zeros(1,4);  TT = zeros(1,4);  size = MeanPacketSize();  sim\_APD = zeros(1,4);  the\_APD = zeros(1,4);  the\_APD\_2 = zeros(1,4);  for i = 1:length(C)  for it= 1:N  [PL(it), APD(it), MPD(it), TT(it)] = Simulator1(lambda,C(i),f,P);  the\_APD\_2 = TheoAvgDelayMG1(lambda,C(i),size)\*1000;  end  sim\_APD(i) = mean(APD);  the\_APD(i) = mean(the\_APD\_2);  end  figure(5);  h = bar(C,[sim\_APD; the\_APD]);  hold on  grid on  title("Average Packet Deplay (MG1 queueing model)");  legend('Simulation','Theoretical', 'location', 'northeast')  xlabel('Link bandwidth (Mbps)');  ylabel('Average packet delay (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 6). De seguida, foram inicializados quatro vetores a zeros (linhas 7 a 10), que irão conter os valores de retorno do *simulator1*. Na linha 11 foi definido o tamanho dos pacotes, com auxílio da função *MeanPacketSize.* Nas linhas 12 a 14 foram inicializados os vetores necessários para armazenar os valores que se pretendem reter da simulação.  Depois, para cada valor do vetor C(linhas 15 a 22), executou-se o simulador N vezes (linhas 16 a 19) e, com os valores lidos do simulador, calculou-se os valores teóricos para o APD no modelo M/G/1 com o auxílio da função *TheoAvgDelayMG1* e os valores de simulação para o APD no modelo M/G/1.  Por fim, desenhou-se o gráfico correspondente ao atraso médio do pacote, apresentando os valores de simulação e teóricos (linhas 23 a 31). | |
| **Result** | |
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| **Conclusions** | |
| No modelo M/G/1, os valores teóricos de atraso médio de pacotes mantêm-se semelhantes aos valores simulados para valores de C elevados. No entanto, tanto os valores teóricos como os simulados, têm um decréscimo exponencial muito acentuado para larguras de banda menores ou iguais a 10 Mbps. | |

**1.e.** Develop a new version of *Simulator1* to estimate 3 additional performance parameters: the average packet delay of the packets of size 64, 110 and 1518 Bytes, respectively. Consider the case of ʎ = 1800 pps and f = 1.000.000. Run the new version of Simulator1 50 times with a stopping criterion of P = 10000 at each run and compute the estimated values and the 90% confidence intervals of the 3 new average delay performance parameters when C = 10, 20, 50 and 100 Mbps. Present the average packet delay results in bar charts with the confidence intervals in error bars. Justify these results and the differences between them and the results of 1.c. Take conclusions concerning the impact of the link capacity in the obtained average packet delay of packets with different sizes.

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| **Matlab code** | |
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| **Code analysis** | |
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| **Result** | |
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| **Conclusions** | |
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| **TASK 2** |

Consider the event driven simulators *Simulator3* and *Simulator4* developed in Task 7 of the Practical Guide.

**2.a.** Consider the case of ʎ = 1500 pps, C = 10 Mbps and f = 1.000.000 Bytes. Run *Simulator3* 50 times with a stopping criterion of P = 10000 each run and compute the estimated values and the 90% confidence intervals of the average delay performance parameter of data packets and VoIP packets when n = 10, 20, 30 and 40 VoIP flows. Present the average data packet delay results in one figure and the average VoIP packet delay results in another figure (in both cases, in bar charts with the confidence intervals in error bars). Justify the results and take conclusions concerning the impact of the number of VoIP flows in the obtained average packet delay of each service when both services (data and VoIP) are statistically multiplexed in a single FIFO queue.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50 | lambda = 1500;  C = 10;  f = 1000000;  P = 10000;  N = 50;  n = [10, 20, 30, 40];  alfa = 0.1;  PLdata = zeros(1,4);  APDdata = zeros(1,4);  MPDdata = zeros(1,4);  PLvoip = zeros(1,4);  APDvoip = zeros(1,4);  MPDvoip = zeros(1,4);  TT = zeros(1,4);  mediaAPDdata = zeros(1,4);  termAPDdata = zeros(1,4);  mediaAPDvoip = zeros(1,4);  termAPDvoip = zeros(1,4);  for i= 1:length(n)  for it= 1:N  [PLdata(it), APDdata(it), MPDdata(it), TT(it), PLvoip(it), APDvoip(it), MPDvoip(it)] = Simulator3(lambda,C,f,P,n(i));  end  mediaAPDdata(i) = mean(APDdata);  termAPDdata(i) = norminv(1-alfa/2)\*sqrt(var(APDdata)/N);  mediaAPDvoip(i) = mean(APDvoip);  termAPDvoip(i) = norminv(1-alfa/2)\*sqrt(var(APDvoip)/N);  end  figure(1);  h = bar(n,mediaAPDdata);  hold on  er = errorbar(n,mediaAPDdata,termAPDdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Data Packet Delay');  xlabel('n (sec)');  ylabel('APDdata (ms)');  hold off  figure(2);  h = bar(n,mediaAPDvoip);  hold on  er = errorbar(n,mediaAPDvoip,termAPDvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average VoIP Packet Delay');  xlabel('n (sec)');  ylabel('APDvoip (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 7). De seguida, foram inicializados sete vetores a zeros (linhas 8 a 14), que irão conter os valores de retorno do *simulator3* e mais quatro vetores a zeros (linhas 15 a 18) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *n* (linhas 19 a 28), executou-se o simulador N vezes (linhas 20 a 23) e, com os valores lidos do simulador, calculou-se a média do atraso médio de pacotes e a respetiva taxa de ocupação (linhas 24 e 27), para dados e para VoIP.  Por fim, desenharam-se os gráficos correspondentes ao atraso médio de pacotes de dados (linhas 29 a 39) e ao atraso médio de pacotes de VoIP (linhas 40 a 50). | |
| **Result** | |
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| **Conclusions** | |
| **FALTAAAAAAAAA** | |

**2.b.** Repeat experiment 2.a but now with *Simulator4*. Justify these results and the differences between them and the results of 2.a. Take conclusions concerning the impact of the number of VoIP flows in the obtained average packet delay of each service when VoIP service is supported with a priority which is higher than the data service.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50 | lambda = 1500;  C = 10;  f = 1000000;  P = 10000;  N = 50;  n = [10, 20, 30, 40];  alfa = 0.1;  PLdata = zeros(1,4);  APDdata = zeros(1,4);  MPDdata = zeros(1,4);  PLvoip = zeros(1,4);  APDvoip = zeros(1,4);  MPDvoip = zeros(1,4);  TT = zeros(1,4);  mediaAPDdata = zeros(1,4);  termAPDdata = zeros(1,4);  mediaAPDvoip = zeros(1,4);  termAPDvoip = zeros(1,4);  for i= 1:length(n)  for it= 1:N  [PLdata(it), APDdata(it), MPDdata(it), TT(it), PLvoip(it), APDvoip(it), MPDvoip(it)] = Simulator4(lambda,C,f,P,n(i));  end  mediaAPDdata(i) = mean(APDdata);  termAPDdata(i) = norminv(1-alfa/2)\*sqrt(var(APDdata)/N);  mediaAPDvoip(i) = mean(APDvoip);  termAPDvoip(i) = norminv(1-alfa/2)\*sqrt(var(APDvoip)/N);  end  figure(3);  h = bar(n,mediaAPDdata);  hold on  er = errorbar(n,mediaAPDdata,termAPDdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Data Packet Delay');  xlabel('n (sec)');  ylabel('APDdata (ms)');  hold off  figure(4);  h = bar(n,mediaAPDvoip);  hold on  er = errorbar(n,mediaAPDvoip,termAPDvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average VoIP Packet Delay');  xlabel('n (sec)');  ylabel('APDvoip (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 7). De seguida, foram inicializados sete vetores a zeros (linhas 8 a 14), que irão conter os valores de retorno do *simulator4* e mais quatro vetores a zeros (linhas 15 a 18) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *n* (linhas 19 a 28), executou-se o simulador N vezes (linhas 20 a 23) e, com os valores lidos do simulador, calculou-se a média do atraso médio de pacotes e a respetiva taxa de ocupação (linhas 24 e 27), para dados e para VoIP.  Por fim, desenharam-se os gráficos correspondentes ao atraso médio de pacotes de dados (linhas 29 a 39) e ao atraso médio de pacotes de VoIP (linhas 40 a 50). | |
| **Result** | |
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| **Conclusions** | |
| **FALTAAAAAAAAA** | |

**2.c.** Consider that the system is modelled by a M/G/1 queueing model with priorities. Determine the theoretical values of the average data packet delay and average VoIP packet delay using the M/G/1 model for all cases of 2.b. Compare the theoretical values with the simulation results of experiments 2.b and take conclusions.

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| **Matlab code** | |
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| **Code analysis** | |
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| **Result** | |
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| **Conclusions** | |
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**2.d.** Consider the case of ʎ = 1500 pps, C = 10 Mbps and f = 10.000 Bytes. Run *Simulator3* 50 times with a stopping criterion of P = 10000 each run and compute the estimated values and the 90% confidence intervals of the average delay and packet loss performance parameters of data packets and VoIP packets when n = 10, 20, 30 and 40 VoIP flows. Present the results of each of the 4 performance parameters (average data packet delay, average VoIP packet delay, data packet loss and VoIP packet loss) in different figures (in all cases, in bar charts with the confidence intervals in error bars). Justify the results and take conclusions concerning the impact of the number of VoIP flows in the obtained average packet delay and packet loss of each service when both services (data and VoIP) are statistically multiplexed in a single FIFO queue of small size.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80 | lambda = 1500;  C = 10;  f = 10000;  P = 10000;  N = 50;  n = [10, 20, 30, 40];  alfa = 0.1;  PLdata = zeros(1,4);  APDdata = zeros(1,4);  MPDdata = zeros(1,4);  PLvoip = zeros(1,4);  APDvoip = zeros(1,4);  MPDvoip = zeros(1,4);  TT = zeros(1,4);  mediaAPDdata = zeros(1,4);  termAPDdata = zeros(1,4);  mediaAPDvoip = zeros(1,4);  termAPDvoip = zeros(1,4);  mediaPLdata = zeros(1,4);  termPLdata = zeros(1,4);  mediaPLvoip = zeros(1,4);  termPLvoip = zeros(1,4);  for i= 1:length(n)  for it= 1:N  [PLdata(it), APDdata(it), MPDdata(it), TT(it), PLvoip(it), APDvoip(it), MPDvoip(it)] = Simulator3(lambda,C,f,P,n(i));  end  mediaPLdata(i) = mean(PLdata);  termPLdata(i) = norminv(1-alfa/2)\*sqrt(var(PLdata)/N);  mediaPLvoip(i) = mean(PLvoip);  termPLvoip(i) = norminv(1-alfa/2)\*sqrt(var(PLvoip)/N);  mediaAPDdata(i) = mean(APDdata);  termAPDdata(i) = norminv(1-alfa/2)\*sqrt(var(APDdata)/N);  mediaAPDvoip(i) = mean(APDvoip);  termAPDvoip(i) = norminv(1-alfa/2)\*sqrt(var(APDvoip)/N);  end  figure(5);  h = bar(n,mediaPLdata);  hold on  er = errorbar(n,mediaPLdata,termPLdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Data Packet Loss');  xlabel('n (sec)');  ylabel('PLdata (%)');  hold off  figure(6);  h = bar(n,mediaPLvoip);  hold on  er = errorbar(n,mediaPLvoip,termPLvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('VoIP Packet Loss');  xlabel('n (sec)');  ylabel('PLvoip (%)');  hold off  figure(7);  h = bar(n,mediaAPDdata);  hold on  er = errorbar(n,mediaAPDdata,termAPDdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Data Packet Delay');  xlabel('n (sec)');  ylabel('APDdata (ms)');  hold off  figure(8);  h = bar(n,mediaAPDvoip);  hold on  er = errorbar(n,mediaAPDvoip,termAPDvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average VoIP Packet Delay');  xlabel('n (sec)');  ylabel('APDvoip (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 7). De seguida, foram inicializados sete vetores a zeros (linhas 8 a 14), que irão conter os valores de retorno do *simulator3* e mais oito vetores a zeros (linhas 15 a 22) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *n* (linhas 23 a 36), executou-se o simulador N vezes (linhas 24 a 27) e, com os valores lidos do simulador, calculou-se os pacotes de dados perdidos e de VoIP e as respetivas taxas de ocupação (linhas 28 a 31) e a média do atraso médio de pacotes de dados e de VoIP e a respetiva taxa de ocupação (linhas 32 a 35).  Por fim, desenharam-se os gráficos correspondentes aos pacotes de dados perdidos (linhas 37 a 47), aos pacotes de VoIP perdidos (linhas 48 a 58), ao atraso médio de pacotes de dados (linhas 59 a 69) e ao atraso médio de pacotes de VoIP (linhas 70 a 80). | |
| **Result** | |
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| **Conclusions** | |
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**2.e.** Repeat experiment 2.d but now with *Simulator4*. Justify these results and the differences between them and the results of 2.d. Take conclusions concerning the impact of the number of VoIP flows in the obtained average packet delay and packet loss of each service when VoIP service is supported with a priority which is higher than the data service and the queue is of small size.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  78  79  80  81 | lambda = 1500;  C = 10;  f = 10000;  P = 10000;  N = 50;  n = [10, 20, 30, 40];  alfa = 0.1;  PLdata = zeros(1,4);  APDdata = zeros(1,4);  MPDdata = zeros(1,4);  PLvoip = zeros(1,4);  APDvoip = zeros(1,4);  MPDvoip = zeros(1,4);  TT = zeros(1,4);  mediaAPDdata = zeros(1,4);  termAPDdata = zeros(1,4);  mediaAPDvoip = zeros(1,4);  termAPDvoip = zeros(1,4);  mediaPLdata = zeros(1,4);  termPLdata = zeros(1,4);  mediaPLvoip = zeros(1,4);  termPLvoip = zeros(1,4);  for i= 1:length(n)  for it= 1:N  [PLdata(it), APDdata(it), MPDdata(it), TT(it), PLvoip(it), APDvoip(it), MPDvoip(it)] = Simulator4(lambda,C,f,P,n(i));  end  mediaPLdata(i) = mean(PLdata);  termPLdata(i) = norminv(1-alfa/2)\*sqrt(var(PLdata)/N);  mediaPLvoip(i) = mean(PLvoip);  termPLvoip(i) = norminv(1-alfa/2)\*sqrt(var(PLvoip)/N);  mediaAPDdata(i) = mean(APDdata);  termAPDdata(i) = norminv(1-alfa/2)\*sqrt(var(APDdata)/N);  mediaAPDvoip(i) = mean(APDvoip);  termAPDvoip(i) = norminv(1-alfa/2)\*sqrt(var(APDvoip)/N);  end  figure(9);  h = bar(n,mediaPLdata);  hold on  er = errorbar(n,mediaPLdata,termPLdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Data Packet Loss');  xlabel('n (sec)');  ylabel('Data packet loss (%)');  hold off  figure(10);  h = bar(n,mediaPLvoip);  hold on  er = errorbar(n,mediaPLvoip,termPLvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('VoIP Packet Loss');  xlabel('n (sec)');  ylabel('VoIP packet loss (%)');  hold off  figure(11);  h = bar(n,mediaAPDdata);  hold on  er = errorbar(n,mediaAPDdata,termAPDdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Data Packet Delay');  xlabel('n (sec)');  ylabel('Average data packet delay (ms)');  hold off  figure(12);  h = bar(n,mediaAPDvoip);  hold on  er = errorbar(n,mediaAPDvoip,termAPDvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average VoIP Packet Delay');  xlabel('n (sec)');  ylabel('Average voIP packet delay (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 7). De seguida, foram inicializados sete vetores a zeros (linhas 8 a 14), que irão conter os valores de retorno do *simulator4* e mais oito vetores a zeros (linhas 15 a 22) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *n* (linhas 23 a 36), executou-se o simulador N vezes (linhas 24 a 27) e, com os valores lidos do simulador, calculou-se os pacotes de dados perdidos e de VoIP e as respetivas taxas de ocupação (linhas 28 a 31) e a média do atraso médio de pacotes de dados e de VoIP e a respetiva taxa de ocupação (linhas 32 a 35).  Por fim, desenharam-se os gráficos correspondentes aos pacotes de dados perdidos (linhas 37 a 47), aos pacotes de VoIP perdidos (linhas 48 a 58), ao atraso médio de pacotes de dados (linhas 59 a 69) e ao atraso médio de pacotes de VoIP (linhas 70 a 81). | |
| **Result** | |
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| **Conclusions** | |
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**2.f.** Develop a new version of *Simulator4* to consider that VoIP packets are always accepted in the queue (if there is enough space) but data packets are accepted in the queue only if the total queue occupation does not become higher than 90% (a simplified version of WRED – Weighted Random Early Discard). Repeat experiment 2.e but now with the new version of Simulator4. Justify these results and the differences between them and the results of 2.e. Take conclusions concerning the impact of the number of VoIP flows in the obtained average packet delay and packet loss of each service when (i) VoIP service is supported with a priority which is higher than the data service and (ii) the packet acceptance in the queue is differentiated.

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  78  79  80  81 | lambda = 1500;  C = 10;  f = 10000;  P = 10000;  N = 50;  n = [10, 20, 30, 40];  alfa = 0.1;  PLdata = zeros(1,4);  APDdata = zeros(1,4);  MPDdata = zeros(1,4);  PLvoip = zeros(1,4);  APDvoip = zeros(1,4);  MPDvoip = zeros(1,4);  TT = zeros(1,4);  mediaAPDdata = zeros(1,4);  termAPDdata = zeros(1,4);  mediaAPDvoip = zeros(1,4);  termAPDvoip = zeros(1,4);  mediaPLdata = zeros(1,4);  termPLdata = zeros(1,4);  mediaPLvoip = zeros(1,4);  termPLvoip = zeros(1,4);  for i= 1:length(n)  for it= 1:N  [PLdata(it), APDdata(it), MPDdata(it), TT(it), PLvoip(it), APDvoip(it), MPDvoip(it)] = Simulator4New(lambda,C,f,P,n(i));  end  mediaPLdata(i) = mean(PLdata);  termPLdata(i) = norminv(1-alfa/2)\*sqrt(var(PLdata)/N);  mediaPLvoip(i) = mean(PLvoip);  termPLvoip(i) = norminv(1-alfa/2)\*sqrt(var(PLvoip)/N);  mediaAPDdata(i) = mean(APDdata);  termAPDdata(i) = norminv(1-alfa/2)\*sqrt(var(APDdata)/N);  mediaAPDvoip(i) = mean(APDvoip);  termAPDvoip(i) = norminv(1-alfa/2)\*sqrt(var(APDvoip)/N);  end  figure(9);  h = bar(n,mediaPLdata);  hold on  er = errorbar(n,mediaPLdata,termPLdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Data Packet Loss');  xlabel('n (sec)');  ylabel('Data packet loss (%)');  hold off  figure(10);  h = bar(n,mediaPLvoip);  hold on  er = errorbar(n,mediaPLvoip,termPLvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('VoIP Packet Loss');  xlabel('n (sec)');  ylabel('VoIP packet loss (%)');  hold off  figure(11);  h = bar(n,mediaAPDdata);  hold on  er = errorbar(n,mediaAPDdata,termAPDdata);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average Data Packet Delay');  xlabel('n (sec)');  ylabel('Average data packet delay (ms)');  hold off  figure(12);  h = bar(n,mediaAPDvoip);  hold on  er = errorbar(n,mediaAPDvoip,termAPDvoip);  er.Color = [0 0 0];  er.LineStyle = 'none';  grid on  title('Average VoIP Packet Delay');  xlabel('n (sec)');  ylabel('Average voIP packet delay (ms)');  hold off |
| **Code analysis** | |
| Primeiramente, foram atribuídos os valores às constantes do problema, de acordo com o pedido no enunciado (linhas 1 a 7). De seguida, foram inicializados sete vetores a zeros (linhas 8 a 14), que irão conter os valores de retorno do *simulator4New* e mais oito vetores a zeros (linhas 15 a 22) que irão conter os valores finais para a média e a taxa de ocupação das variáveis pretendidas.  Depois, para cada valor do vetor *n* (linhas 23 a 36), executou-se o simulador N vezes (linhas 24 a 27) e, com os valores lidos do simulador, calculou-se os pacotes de dados perdidos e de VoIP e as respetivas taxas de ocupação (linhas 28 a 31) e a média do atraso médio de pacotes de dados e de VoIP e a respetiva taxa de ocupação (linhas 32 a 35).  Por fim, desenharam-se os gráficos correspondentes aos pacotes de dados perdidos (linhas 37 a 47), aos pacotes de VoIP perdidos (linhas 48 a 58), ao atraso médio de pacotes de dados (linhas 59 a 69) e ao atraso médio de pacotes de VoIP (linhas 70 a 81). | |
| **Result** | |
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| **Conclusions** | |
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| **SIMULATOR 1** |

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86  87  88  89  90  91  92 | function [PL , APD , MPD , TT] = Simulator1(lambda,C,f,P)  % INPUT PARAMETERS:  % lambda - packet rate (packets/sec)  % C - link bandwidth (Mbps)  % f - queue size (Bytes)  % P - number of packets (stopping criterium)  % OUTPUT PARAMETERS:  % PL - packet loss (%)  % APD - average packet delay (milliseconds)  % MPD - maximum packet delay (milliseconds)  % TT - transmitted throughput (Mbps)  % EVENTS:  ARRIVAL= 0; % Arrival of a packet  DEPARTURE= 1; % Departure of a packet  % STATE VARIABLES:  STATE = 0; % 0 - connection free; 1 - connection bysy  QUEUEOCCUPATION= 0; % Occupation of the queue (in Bytes)  QUEUE= []; % Size and arriving time instant of each packet in the queue  % STATISTICAL COUNTERS:  TOTALPACKETS= 0; % No. of packets arrived to the system  LOSTPACKETS= 0; % No. of packets dropped due to buffer overflow  TRANSMITTEDPACKETS= 0; % No. of transmitted packets  TRANSMITTEDBYTES= 0; % Sum of the Bytes of transmitted packets  DELAYS= 0; % Sum of the delays of transmitted packets  MAXDELAY= 0; % Maximum delay among all transmitted packets  % INITIALIZING THE SIMULATION CLOCK:  Clock= 0;  % INITIALIZING THE LIST OF EVENTS WITH THE FIRST ARRIVAL:  tmp= Clock + exprnd(1/lambda);  EventList = [ARRIVAL, tmp, GeneratePacketSize(), tmp];  % SIMILATION LOOP:  while TRANSMITTEDPACKETS<P % Stopping criterium  EventList= sortrows(EventList,2); % Order EventList by time  Event= EventList(1,1); % Get first event and  Clock= EventList(1,2); % and  PacketSize= EventList(1,3); % associated  ArrivalInstant= EventList(1,4); % parameters.  EventList(1,:)= []; % Eliminate first event  switch Event  case ARRIVAL % If first event is an ARRIVAL  TOTALPACKETS= TOTALPACKETS+1;  tmp= Clock + exprnd(1/lambda);  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSize(), tmp];  if STATE==0  STATE= 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock];  else  if QUEUEOCCUPATION + PacketSize <= f  QUEUE= [QUEUE;PacketSize , Clock];  QUEUEOCCUPATION= QUEUEOCCUPATION + PacketSize;  else  LOSTPACKETS= LOSTPACKETS + 1;  end  end  case DEPARTURE % If first event is a DEPARTURE  TRANSMITTEDBYTES= TRANSMITTEDBYTES + PacketSize;  DELAYS= DELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXDELAY  MAXDELAY= Clock - ArrivalInstant;  end  TRANSMITTEDPACKETS= TRANSMITTEDPACKETS + 1;  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUE(1,1)/(C\*10^6), QUEUE(1,1), QUEUE(1,2)];  QUEUEOCCUPATION= QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:)= [];  else  STATE= 0;  end  end  end  % PERFORMANCE PARAMETERS DETERMINATION:  PL= 100\*LOSTPACKETS/TOTALPACKETS; % in %  APD= 1000\*DELAYS/TRANSMITTEDPACKETS; % in milliseconds  MPD= 1000\*MAXDELAY; % in milliseconds  TT= 10^(-6)\*TRANSMITTEDBYTES\*8/Clock; % in Mbps  end  function out= GeneratePacketSize()  aux= rand();  aux2= [65:109 111:1517];  if aux <= 0.19  out= 64;  elseif aux <= 0.19 + 0.23  out= 110;  elseif aux <= 0.19 + 0.23 + 0.17  out= 1518;  else  out = aux2(randi(length(aux2)));  end  end |

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| **SIMULATOR 1 (NEW VERSION – 1.e)** |

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| **Matlab code** | |
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| **SIMULATOR 3** |

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99  100  101  102  103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118  119  120  121  122  123  124  125  126  127  128  129  130  131  132  133  134  135  136  137  138  139  140  141  142  143  144  145  146  147  148  149  150  151  152  153 | function [PLdata , APDdata, MPDdata , TT , PLvoip, APDvoip, MPDvoip ] = Simulator3(lambda,C,f,P,n)  % INPUT PARAMETERS:  % lambda - packet rate (packets/sec)  % C - link bandwidth (Mbps)  % f - queue size (Bytes)  % P - number of packets (stopping criterium)  % n - additional VoIP packet flows (sec)  % OUTPUT PARAMETERS:  % PLdata - packet loss of data packets (%)  % APDdata - average delay of data packets (milliseconds)  % MPDdata - maximum delay of data packets (milliseconds)  % PLvoip - packet loss of voip packets (%)  % APDvoip - average delay of voip packets (milliseconds)  % MPDvoip - maximum delay of voip packets (milliseconds)  % TT - transmitted throughput (Mbps)  % EVENTS:  ARRIVAL = 0; % Arrival of a packet  DEPARTURE = 1; % Departure of a packet  DATA = 2;  VOIP = 3;  % STATE VARIABLES:  STATE = 0; % 0 - connection free; 1 - connection bysy  QUEUEOCCUPATION = 0; % Occupation of the queue (in Bytes)  QUEUE = []; % Size and arriving time instant of each packet in the queue  % STATISTICAL COUNTERS:  TOTALPACKETS = 0; % No. of packets arrived to the system  TOTALVOIPPACKETS = 0; % No. of voip packets arrived to the systeM  LOSTPACKETS = 0; % No. of packets dropped due to buffer overflow  LOSTVOIPPACKETS = 0; % No. of voip packets dropped due to buffer overflow  TRANSMITTEDPACKETS = 0; % No. of transmitted packets  TRANSMITTEDVOIPPACKETS = 0; % No. of voip transmitted packets  TRANSMITTEDBYTES = 0; % Sum of the Bytes of transmitted packets  DELAYS = 0; % Sum of the delays of transmitted packets  VOIPDELAYS = 0; % Sum of the delays of transmitted voip packets  MAXDELAY = 0; % Maximum delay among all transmitted packets  MAXVOIPDELAY = 0; % Maximum delay among all transmitted voip packets  % INITIALIZING THE SIMULATION CLOCK:  Clock = 0;  % INITIALIZING THE LIST OF EVENTS WITH THE FIRST ARRIVAL:  tmp = Clock + exprnd(1/lambda);  EventList = [ARRIVAL, tmp, GeneratePacketSize(), tmp, DATA];  for i=1:n  tmp = Clock + 0.02\*rand();  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSizeVoip(), tmp, VOIP];  end  % SIMILATION LOOP:  while (TRANSMITTEDPACKETS + TRANSMITTEDVOIPPACKETS) < P % Stopping criterium  EventList = sortrows(EventList,2); % Order EventList by time  Event = EventList(1,1); % Get first event  Clock = EventList(1,2);  PacketSize = EventList(1,3);  ArrivalInstant = EventList(1,4);  PacketType = EventList(1,5);  EventList(1,:)= []; % Eliminate first event  switch Event  case ARRIVAL % If first event is an ARRIVAL  if PacketType == DATA  TOTALPACKETS = TOTALPACKETS+1;  tmp = Clock + exprnd(1/lambda);  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSize(), tmp, PacketType];  if STATE == 0  STATE = 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock, PacketType];  else  if QUEUEOCCUPATION + PacketSize <= f  QUEUE = [QUEUE;PacketSize , Clock, PacketType];  QUEUEOCCUPATION = QUEUEOCCUPATION + PacketSize;  else  LOSTPACKETS = LOSTPACKETS + 1;  end  end  else  TOTALVOIPPACKETS = TOTALVOIPPACKETS+1;  tmp = Clock + 0.008\*rand() + 0.016;  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSizeVoip(), tmp, PacketType];  if STATE == 0  STATE = 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock, PacketType];  else  if QUEUEOCCUPATION + PacketSize <= f  QUEUE = [QUEUE;PacketSize , Clock, PacketType];  QUEUEOCCUPATION = QUEUEOCCUPATION + PacketSize;  else  LOSTVOIPPACKETS = LOSTVOIPPACKETS + 1;  end  end  end  case DEPARTURE % If first event is a DEPARTURE  if PacketType == DATA  TRANSMITTEDBYTES = TRANSMITTEDBYTES + PacketSize;  DELAYS = DELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXDELAY  MAXDELAY = Clock - ArrivalInstant;  end  TRANSMITTEDPACKETS = TRANSMITTEDPACKETS + 1;  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUE(1,1)/(C\*10^6), QUEUE(1,1), QUEUE(1,2), QUEUE(1,3)];  QUEUEOCCUPATION = QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:) = [];  else  STATE = 0;  end  end  if PacketType == VOIP  TRANSMITTEDBYTES = TRANSMITTEDBYTES + PacketSize;  VOIPDELAYS = VOIPDELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXVOIPDELAY  MAXVOIPDELAY = Clock - ArrivalInstant;  end  TRANSMITTEDVOIPPACKETS = TRANSMITTEDVOIPPACKETS + 1;  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUE(1,1)/(C\*10^6), QUEUE(1,1), QUEUE(1,2), QUEUE(1,3)];  QUEUEOCCUPATION = QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:) = [];  else  STATE= 0;  end  end  end  end  % PERFORMANCE PARAMETERS DETERMINATION:  PLdata = 100\*LOSTPACKETS/TOTALPACKETS; % in %  APDdata = 1000\*DELAYS/TRANSMITTEDPACKETS; % in milliseconds  MPDdata = 1000\*MAXDELAY; % in milliseconds  PLvoip = 100\*LOSTVOIPPACKETS/TOTALVOIPPACKETS; % packet loss VOIP  APDvoip = 1000\*VOIPDELAYS/TRANSMITTEDVOIPPACKETS; % average packet delay VOIP  MPDvoip = 1000\*MAXVOIPDELAY; % maximum packet delay VOIP  TT = 10^(-6)\*TRANSMITTEDBYTES\*8/Clock; % in Mbps  end  function out = GeneratePacketSize()  aux = rand();  aux2 = [65:109 111:1517];  if aux <= 0.19  out= 64;  elseif aux <= 0.19 + 0.23  out = 110;  elseif aux <= 0.19 + 0.23 + 0.17  out = 1518;  else  out = aux2(randi(length(aux2)));  end  end  function out = GeneratePacketSizeVoip()  out = randi([110 130]);  end |

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| **SIMULATOR 4** |

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99  100  101  102  103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118  119  120  121  122  123  124  125  126  127  128  129  130  131  132  133  134  135  136  137  138  139  140  141  142  143  144  145  146  147  148  149  150  151  152  153  154  155  156  157  158  159  160  161  162  163  164  165  166  167  168  169 | function [PLdata , APDdata, MPDdata , TT , PLvoip, APDvoip, MPDvoip ] = Simulator4(lambda,C,f,P,n)  % INPUT PARAMETERS:  % lambda - packet rate (packets/sec)  % C - link bandwidth (Mbps)  % f - queue size (Bytes)  % P - number of packets (stopping criterium)  % n - additional VoIP packet flows (sec)  % OUTPUT PARAMETERS:  % PLdata - packet loss of data packets (%)  % APDdata - average delay of data packets (milliseconds)  % MPDdata - maximum delay of data packets (milliseconds)  % PLvoip - packet loss of voip packets (%)  % APDvoip - average delay of voip packets (milliseconds)  % MPDvoip - maximum delay of voip packets (milliseconds)  % TT - transmitted throughput (Mbps)  % EVENTS:  ARRIVAL = 0; % Arrival of a packet  DEPARTURE = 1; % Departure of a packet  DATA = 2;  VOIP = 3;  % STATE VARIABLES:  STATE = 0; % 0 - connection free; 1 - connection bysy  QUEUEOCCUPATION = 0; % Occupation of the queue (in Bytes)  QUEUEVOIPOCCUPATION = 0;% Occupation of the voip queue (in Bytes)  QUEUE = []; % Size and arriving time instant of each packet in the queue  QUEUEVOIP = [];  % STATISTICAL COUNTERS:  TOTALPACKETS = 0; % No. of packets arrived to the system  TOTALVOIPPACKETS = 0; % No. of voip packets arrived to the systeM  LOSTPACKETS = 0; % No. of packets dropped due to buffer overflow  LOSTVOIPPACKETS = 0; % No. of voip packets dropped due to buffer overflow  TRANSMITTEDPACKETS = 0; % No. of transmitted packets  TRANSMITTEDVOIPPACKETS = 0; % No. of voip transmitted packets  TRANSMITTEDBYTES = 0; % Sum of the Bytes of transmitted packets  DELAYS = 0; % Sum of the delays of transmitted packets  VOIPDELAYS = 0; % Sum of the delays of transmitted voip packets  MAXDELAY = 0; % Maximum delay among all transmitted packets  MAXVOIPDELAY = 0; % Maximum delay among all transmitted voip packets  % INITIALIZING THE SIMULATION CLOCK:  Clock = 0;  % INITIALIZING THE LIST OF EVENTS WITH THE FIRST ARRIVAL:  tmp = Clock + exprnd(1/lambda);  EventList = [ARRIVAL, tmp, GeneratePacketSize(), tmp, DATA];  for i=1:n  tmp = Clock + 0.02\*rand();  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSizeVoip(), tmp, VOIP];  end  % SIMILATION LOOP:  while (TRANSMITTEDPACKETS + TRANSMITTEDVOIPPACKETS) < P % Stopping criterium  EventList = sortrows(EventList,2); % Order EventList by time  Event = EventList(1,1); % Get first event  Clock = EventList(1,2);  PacketSize = EventList(1,3);  ArrivalInstant = EventList(1,4);  PacketType = EventList(1,5);  EventList(1,:)= []; % Eliminate first event  switch Event  case ARRIVAL % If first event is an ARRIVAL  if PacketType == DATA  TOTALPACKETS = TOTALPACKETS+1;  tmp = Clock + exprnd(1/lambda);  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSize(), tmp, PacketType];  if STATE == 0  STATE = 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock, PacketType];  else  if QUEUEOCCUPATION + QUEUEVOIPOCCUPATION + PacketSize <= f  QUEUE = [QUEUE; PacketSize , Clock, PacketType];  QUEUEOCCUPATION = QUEUEOCCUPATION + PacketSize;  else  LOSTPACKETS = LOSTPACKETS + 1;  end  end  else  TOTALVOIPPACKETS = TOTALVOIPPACKETS + 1;  tmp = Clock + 0.008\*rand() + 0.016;  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSizeVoip(), tmp, PacketType];  if STATE == 0  STATE = 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock, PacketType];  else  if QUEUEOCCUPATION + PacketSize <= f  QUEUEVOIP = [QUEUEVOIP; PacketSize , Clock, PacketType];  QUEUEVOIPOCCUPATION = QUEUEVOIPOCCUPATION + PacketSize;  else  LOSTVOIPPACKETS = LOSTVOIPPACKETS + 1;  end  end  end  case DEPARTURE % If first event is a DEPARTURE  if PacketType == DATA  TRANSMITTEDBYTES = TRANSMITTEDBYTES + PacketSize;  DELAYS = DELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXDELAY  MAXDELAY = Clock - ArrivalInstant;  end  TRANSMITTEDPACKETS = TRANSMITTEDPACKETS + 1;  if QUEUEVOIPOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUEVOIP(1,1)/(C\*10^6), QUEUEVOIP(1,1), QUEUEVOIP(1,2), QUEUEVOIP(1,3)];  QUEUEVOIPOCCUPATION = QUEUEVOIPOCCUPATION - QUEUEVOIP(1,1);  QUEUEVOIP(1,:) = [];  else  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE , Clock + 8\*QUEUE(1,1)/(C\*10^6) , QUEUE(1,1) , QUEUE(1,2), QUEUE(1,3)];  QUEUEOCCUPATION = QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:) = [];  else  STATE = 0;  end  end  end  if PacketType == VOIP  TRANSMITTEDBYTES = TRANSMITTEDBYTES + PacketSize;  VOIPDELAYS = VOIPDELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXVOIPDELAY  MAXVOIPDELAY = Clock - ArrivalInstant;  end  TRANSMITTEDVOIPPACKETS = TRANSMITTEDVOIPPACKETS + 1;  if QUEUEVOIPOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUEVOIP(1,1)/(C\*10^6), QUEUEVOIP(1,1), QUEUEVOIP(1,2), QUEUEVOIP(1,3)];  QUEUEVOIPOCCUPATION = QUEUEVOIPOCCUPATION - QUEUEVOIP(1,1);  QUEUEVOIP(1,:) = [];  else  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE , Clock + 8\*QUEUE(1,1)/(C\*10^6) , QUEUE(1,1) , QUEUE(1,2), QUEUE(1,3)];  QUEUEOCCUPATION = QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:) = [];  else  STATE = 0;  end  end  end  end  end  % PERFORMANCE PARAMETERS DETERMINATION:  PLdata = 100\*LOSTPACKETS/TOTALPACKETS; % in %  PLvoip = 100\*LOSTVOIPPACKETS/TOTALVOIPPACKETS; % in %  APDdata = 1000\*DELAYS/TRANSMITTEDPACKETS; % in milliseconds  APDvoip = 1000\*VOIPDELAYS/TRANSMITTEDVOIPPACKETS; % in milliseconds  MPDdata = 1000\*MAXDELAY; % in milliseconds  MPDvoip = 1000\*MAXVOIPDELAY; % in milliseconds  TT = 10^(-6)\*TRANSMITTEDBYTES\*8/Clock; % in Mbps  end  function out = GeneratePacketSize()  aux = rand();  aux2 = [65:109 111:1517];  if aux <= 0.19  out= 64;  elseif aux <= 0.19 + 0.23  out = 110;  elseif aux <= 0.19 + 0.23 + 0.17  out = 1518;  else  out = aux2(randi(length(aux2)));  end  end  function out = GeneratePacketSizeVoip()  out = randi([110 130]);  end |

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| **SIMULATOR 4 (NEW VERSION – 2.f)** |

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99  100  101  102  103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118  119  120  121  122  123  124  125  126  127  128  129  130  131  132  133  134  135  136  137  138  139  140  141  142  143  144  145  146  147  148  149  150  151  152  153  154  155  156  157  158  159  160  161  162  163  164  165  166  167  168  169  170 | function [PLdata , APDdata, MPDdata , TT , PLvoip, APDvoip, MPDvoip ] = Simulator4(lambda,C,f,P,n)  % INPUT PARAMETERS:  % lambda - packet rate (packets/sec)  % C - link bandwidth (Mbps)  % f - queue size (Bytes)  % P - number of packets (stopping criterium)  % n - additional VoIP packet flows (sec)  % OUTPUT PARAMETERS:  % PLdata - packet loss of data packets (%)  % APDdata - average delay of data packets (milliseconds)  % MPDdata - maximum delay of data packets (milliseconds)  % PLvoip - packet loss of voip packets (%)  % APDvoip - average delay of voip packets (milliseconds)  % MPDvoip - maximum delay of voip packets (milliseconds)  % TT - transmitted throughput (Mbps)  % EVENTS:  ARRIVAL = 0; % Arrival of a packet  DEPARTURE = 1; % Departure of a packet  DATA = 2;  VOIP = 3;  % STATE VARIABLES:  STATE = 0; % 0 - connection free; 1 - connection bysy  QUEUEOCCUPATION = 0; % Occupation of the queue (in Bytes)  QUEUEVOIPOCCUPATION = 0;% Occupation of the voip queue (in Bytes)  QUEUE = []; % Size and arriving time instant of each packet in the queue  QUEUEVOIP = [];  % STATISTICAL COUNTERS:  TOTALPACKETS = 0; % No. of packets arrived to the system  TOTALVOIPPACKETS = 0; % No. of voip packets arrived to the systeM  LOSTPACKETS = 0; % No. of packets dropped due to buffer overflow  LOSTVOIPPACKETS = 0; % No. of voip packets dropped due to buffer overflow  TRANSMITTEDPACKETS = 0; % No. of transmitted packets  TRANSMITTEDVOIPPACKETS = 0; % No. of voip transmitted packets  TRANSMITTEDBYTES = 0; % Sum of the Bytes of transmitted packets  DELAYS = 0; % Sum of the delays of transmitted packets  VOIPDELAYS = 0; % Sum of the delays of transmitted voip packets  MAXDELAY = 0; % Maximum delay among all transmitted packets  MAXVOIPDELAY = 0; % Maximum delay among all transmitted voip packets  % INITIALIZING THE SIMULATION CLOCK:  Clock = 0;  % INITIALIZING THE LIST OF EVENTS WITH THE FIRST ARRIVAL:  tmp = Clock + exprnd(1/lambda);  EventList = [ARRIVAL, tmp, GeneratePacketSize(), tmp, DATA];  for i=1:n  tmp = Clock + 0.02\*rand();  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSizeVoip(), tmp, VOIP];  end  % SIMILATION LOOP:  while (TRANSMITTEDPACKETS + TRANSMITTEDVOIPPACKETS) < P % Stopping criterium  EventList = sortrows(EventList,2); % Order EventList by time  Event = EventList(1,1); % Get first event  Clock = EventList(1,2);  PacketSize = EventList(1,3);  ArrivalInstant = EventList(1,4);  PacketType = EventList(1,5);  EventList(1,:)= []; % Eliminate first event  switch Event  case ARRIVAL % If first event is an ARRIVAL  if PacketType == DATA  TOTALPACKETS = TOTALPACKETS+1;  tmp = Clock + exprnd(1/lambda);  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSize(), tmp, PacketType];  if STATE == 0  STATE = 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock, PacketType];  else  if QUEUEOCCUPATION + QUEUEVOIPOCCUPATION <= f\*0.9 && QUEUEOCCUPATION + QUEUEVOIPOCCUPATION + PacketSize  QUEUE = [QUEUE; PacketSize , Clock, PacketType];  QUEUEOCCUPATION = QUEUEOCCUPATION + PacketSize;  else  LOSTPACKETS = LOSTPACKETS + 1;  end  end  else  TOTALVOIPPACKETS = TOTALVOIPPACKETS + 1;  tmp = Clock + 0.008\*rand() + 0.016;  EventList = [EventList; ARRIVAL, tmp, GeneratePacketSizeVoip(), tmp, PacketType];  if STATE == 0  STATE = 1;  EventList = [EventList; DEPARTURE, Clock + 8\*PacketSize/(C\*10^6), PacketSize, Clock, PacketType];  else  if QUEUEOCCUPATION + PacketSize <= f  QUEUEVOIP = [QUEUEVOIP; PacketSize , Clock, PacketType];  QUEUEVOIPOCCUPATION = QUEUEVOIPOCCUPATION + PacketSize;  else  LOSTVOIPPACKETS = LOSTVOIPPACKETS + 1;  end  end  end  case DEPARTURE % If first event is a DEPARTURE  if PacketType == DATA  TRANSMITTEDBYTES = TRANSMITTEDBYTES + PacketSize;  DELAYS = DELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXDELAY  MAXDELAY = Clock - ArrivalInstant;  end  TRANSMITTEDPACKETS = TRANSMITTEDPACKETS + 1;  if QUEUEVOIPOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUEVOIP(1,1)/(C\*10^6), QUEUEVOIP(1,1), QUEUEVOIP(1,2), QUEUEVOIP(1,3)];  QUEUEVOIPOCCUPATION = QUEUEVOIPOCCUPATION - QUEUEVOIP(1,1);  QUEUEVOIP(1,:) = [];  else  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE , Clock + 8\*QUEUE(1,1)/(C\*10^6) , QUEUE(1,1) , QUEUE(1,2), QUEUE(1,3)];  QUEUEOCCUPATION = QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:) = [];  else  STATE = 0;  end  end  end  if PacketType == VOIP  TRANSMITTEDBYTES = TRANSMITTEDBYTES + PacketSize;  VOIPDELAYS = VOIPDELAYS + (Clock - ArrivalInstant);  if Clock - ArrivalInstant > MAXVOIPDELAY  MAXVOIPDELAY = Clock - ArrivalInstant;  end  TRANSMITTEDVOIPPACKETS = TRANSMITTEDVOIPPACKETS + 1;  if QUEUEVOIPOCCUPATION > 0  EventList = [EventList; DEPARTURE, Clock + 8\*QUEUEVOIP(1,1)/(C\*10^6), QUEUEVOIP(1,1), QUEUEVOIP(1,2), QUEUEVOIP(1,3)];  QUEUEVOIPOCCUPATION = QUEUEVOIPOCCUPATION - QUEUEVOIP(1,1);  QUEUEVOIP(1,:) = [];  else  if QUEUEOCCUPATION > 0  EventList = [EventList; DEPARTURE , Clock + 8\*QUEUE(1,1)/(C\*10^6) , QUEUE(1,1) , QUEUE(1,2), QUEUE(1,3)];  QUEUEOCCUPATION = QUEUEOCCUPATION - QUEUE(1,1);  QUEUE(1,:) = [];  else  STATE = 0;  end  end  end  end  end  % PERFORMANCE PARAMETERS DETERMINATION:  PLdata = 100\*LOSTPACKETS/TOTALPACKETS; % in %  PLvoip = 100\*LOSTVOIPPACKETS/TOTALVOIPPACKETS; % in %  APDdata = 1000\*DELAYS/TRANSMITTEDPACKETS; % in milliseconds  APDvoip = 1000\*VOIPDELAYS/TRANSMITTEDVOIPPACKETS; % in milliseconds  MPDdata = 1000\*MAXDELAY; % in milliseconds  MPDvoip = 1000\*MAXVOIPDELAY; % in milliseconds  TT = 10^(-6)\*TRANSMITTEDBYTES\*8/Clock; % in Mbps  end  function out = GeneratePacketSize()  aux = rand();  aux2 = [65:109 111:1517];  if aux <= 0.19  out= 64;  elseif aux <= 0.19 + 0.23  out = 110;  elseif aux <= 0.19 + 0.23 + 0.17  out = 1518;  else  out = aux2(randi(length(aux2)));  end  end  function out = GeneratePacketSizeVoip()  out = randi([110 130]);  end |

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| **AUXILIAR FUNCTIONS** |

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| **Matlab code** | |
| 1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34 | function miu = Miu(C,size)  miu=(C\*10^6)/size;  end  function avgMG1 = TheoAvgDelayMG1(lambda,C,size)  es = ES(C);  es2 = ES2(C);  avgMG1 = ((lambda \* es2 ) / (2 \* (1 - lambda \* es))) + es;  end  function es2 = ES2(C)  k = (0.41/((109 - 65 + 1)+(1517 - 111 + 1)));  es2 = 0.19 \* ((64\*8)/(C\*10^6))^2 + 0.23 \* ((110\*8)/(C\*10^6))^2 + 0.17 \* ((1518\*8)/(C\*10^6))^2;  for n = 65:109  es2 = es2 + k \* ((n \* 8)/(C\*10^6))^2;  end  for n = 111:1517  es2 = es2 + k \* ((n \* 8)/(C\*10^6))^2;  end  end  function es = ES(C)  k = (0.41/((109 - 65 + 1)+(1517 - 111 + 1)));  es = 0.19 \* ((64\*8)/(C\*10^6)) + 0.23 \* ((110\*8)/(C\*10^6)) + 0.17 \* ((1518\*8)/(C\*10^6));  for n = 65:109  es = es + k \* ((n\*8)/(C\*10^6));  end  for n = 111:1517  es = es + k \* ((n\*8)/(C\*10^6));  end  end  function mean = MeanPacketSize()  mean = 0.19 \* (64\*8) + 0.23 \* (110\*8) + 0.17 \* (1518\*8);  for n = 65:109  mean = mean + ((0.41/((109 - 65 + 1)+(1517 - 111 + 1))) \* (n\*8));  end  for j = 111:1517  mean = mean + ((0.41/((109 - 65 + 1)+(1517 - 111 + 1))) \* (j\*8));  end  end |