Network Engineering - Mid-Term exam - 2019/2020

Problem 1 - 6 points

We monitor the amount of traffic generated by an application every second. The obtained sequence is: $X(t) = \{1, 2, 2, 1, 2, 3, 3, 3, 2, 2, 1, 2, 1, 2, 1, 1, 2, 3, 2, 1, 2, 1, x, x, x, x, x, x, x\}$ Mbps.

1. (0.5 points) Determine the state space of X(t) using the values of X(t) except the ones labelled with 'x'.
2. (0.5 points) Assign a value to the 'x' as you consider.
3. (1 point) Represent the stochastic process X(t) using a Markov chain. Indicate the value of the transitions.
4. (1 point) Calculate the stationary distribution of X(t) by solving the Markov chain.
5. (1 point) What is the average traffic generation rate of such an application?
6. (1 point) Considering that such application feeds a M/M/2/4 network interface, using the average traffic generation rate from previous point, calculate the packet blocking probability, and the average packet delay in it. Assume that packets arrive to the network interface following a Poisson process, and packet sizes are exponentially distributed with average value $E[L] = 4000$ bits. The capacity of the link is $C = 1.5$ Mbps.
7. (1 point) Is X(t) stationary? Are the results from previous point valid?

Problem 2 - 4 points

Three stations are associated to a dual-band Access Point (AP), i.e., the AP is able to transmit data in both 2.4 and 5 GHz bands. While station A and station C are single band (2.4 and 5 GHz, respectively), station B is also dual band, and so it can receive data simultaneously in both bands.

The AP receives three traffic flows, respectively directed to station A, B and C. The load of each flow in bps is $B_A = 1$ Mbps, $B_B = 2$ Mbps and $B_C = 0.5$ Mbps. Packets in each flow arrive to the AP following a Poisson process. Also, the packets of all flows are exponentially distributed, with average size $E[L]$ bits. The aggregate packet arrival rate is $\lambda = \lambda_A + \lambda_B + \lambda_C$ packets / second, with λ_i the packet arrival rate of flow i.

The transmission time of a packet between the AP and any station using the 2.4 GHz band is $E[D_{s,2.4}] = E[L]/4.5E6$ ms, and using the 5 GHz band is $E[D_{s,5}] = E[L]/3E6$ ms.

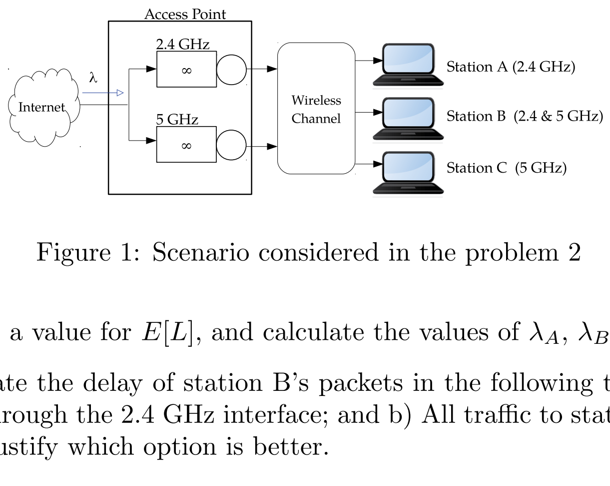

Figure 1: Scenario considered in the problem 2

1. (0.5 points) Choose a value for $E[L]$, and calculate the values of λ_A, λ_B and λ_C.
2. (1.5 points) Calculate the delay of station B's packets in the following two cases: a) All traffic to station B is send through the 2.4 GHz interface; and b) All traffic to station B is send through the 5 GHZ interface. Justify which option is better.
3. (2 points) Given that the traffic to station B can be split between the two network interfaces, find the share of traffic that goes to each network interface that equalizes the average delay of the two network interfaces. Justify the obtained results.

Solution 1

```
function Exercise1()

X = [1,2,2,1,2,3,3,3,2,2,1,2,1,2,1,1,2,3,2,1,2,1,1,1,1,1,2,3,3];

% State space = {1,2,3}

% Markov chain: (1)-(2)-(3)

p11=5/12;
p12=7/12;

p21=6/11;
p22=2/11;
p23=3/11;

p32=2/5;
p33=3/5;

% To count the cases of x->y
%c=0;
%for i=1:28
%   if(X(i)==3)
%      if(X(i+1)==3)
%        c=c+1;
%      end
%   end
%end
%disp(c);

% Balance equations
% pi1*p12 = pi2 * p22
% pi2*p23 = pi3 * p32
% pi2 = p12/p22 * pi1;
% pi3 = p23/p32 * pi2 = p23/p32 * p12/p22 * pi1;

pi1 = 1 / (1 + p12/p22 + p23/p32 * p12/p22);
pi2 = p12/p22 * pi1;
pi3 = p23/p32 * p12/p22 * pi1;

disp('Stationary Distribution');
disp([pi1 pi2 pi3]);

disp('Average Traffic Generation Rate')
lambda = pi1*1E6 + pi2*2E6 + pi3*3E6;
disp(lambda);

% M/M/2/4 (0-1-2-3-4)

C=1.5E6;
EL=4000;

lambda=lambda/EL;
mu = C/EL;
a = lambda/mu;
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```
% pi0 * lambda = mu * pi1;
% pi1 * lambda = 2 * mu * pi2;
% pi2 * lambda = 2 * mu * pi3;
% pi3 * lambda = 2 * mu * pi4;

pi0 = 1 / (1 + a + a^2/2 + a^3/4 + a^4/8);
pi1 = a*pi0;
pi2 = a^2/2*pi0;
pi3 = a^3/4*pi0;
pi4 = a^4/8*pi0;

disp('Stationary Distribution');
disp([pi0 pi1 pi2 pi3 pi4]);

disp('Blocking Probability');
disp(pi4);

disp('Number of packets');
EN = pi1*1+pi2*2+pi3*3+pi4*4;
disp([EN]);

disp('Expected Delay');
ED=EN/(lambda*(1-pi4));
disp(ED);

% The process is stationary if we look it at large temporal intervals.
% However, at analyzing the behavior of each 1s interval, it is not, and so
% the analysis of the blocking prob and delay must be done considering the
% 3 intervals indep. and then averaging the results.


end
```

Solution 2

```
function Exercise2()

Ba=1E6;
Bb=2E6;
Bc=0.5E6;

lambdaa=Ba/9000;
lambdab=Bb/9000;
lambdac=Bc/9000;

mu24=1/2E-3;
mu5 = 1/3E-3;

% a)All traffic to B --> 2.4 GHz

a24 = (lambdaa+lambdab)/mu24;
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```
ED_24 = 1/(mu24-lambdaa-lambdab);

disp('a) ED_{2.4}');
disp(ED_24);

% b) All traffic to B --> 5 GHz

a24 = (lambdaa)/mu24;

ED_5 = 1/(mu5-lambdac-lambdab);

disp('b) ED_{5}');
disp(ED_5);


% Share of traffic

% (mu24 - la - alfa * lb) = (mu5 - lc - (1-alfa)*lb)
% mu24-mu5-la+lc = alfa * lb - (1-alfa)*lb
% mu24-mu5-la+lc = alfa * lb - lb + alfa*lb
% mu24-mu5-la+lc+lb = 2 * alfa * lb
% alfa = (mu24-mu5-la+lc+lb) / (2*lb)

alfa = (mu24-mu5-lambdaa+lambdac+lambdab) / (2*lambdab);
ED_24 = 1/(mu24-lambdaa-alfa*lambdab);
ED_5 = 1/(mu5-lambdac-(1-alfa)*lambdab);

disp('Share 2.4 & 5');
disp(alfa);
disp('c) Delays 2.4 and 5');
disp([ED_24 ED_5]);

end
```