Network Engineering - Mid-Term exam - Group 1 - 2020/2021

Recently, the use of 'extenders' to improve the performance of WiFi networks has been popularized. In the scenario shown in Figure 1, the traffic directed to the station can be transmitted directly from the Access Point, or relayed through the extender. In the first case (route A), the transmission rate of the AP is low. In the second case (route B), the transmission rate of the AP and extender is high, but there is a two-hop path to reach the destination. Note that we assume the AP, the extender and the station are multiband, supporting three interfaces (2.4, 5 and 6 GHz).

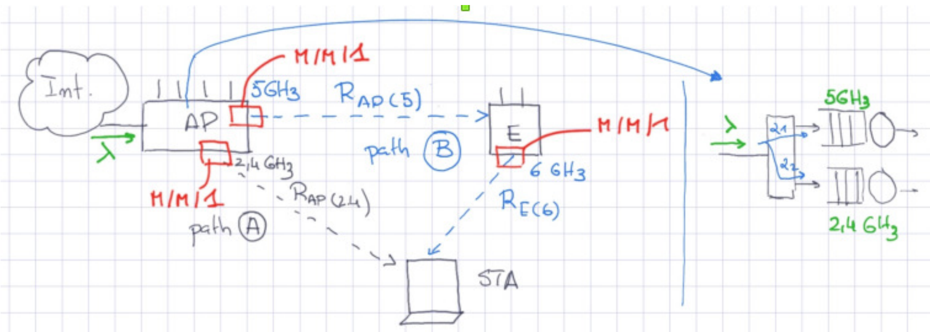

Figure 1: Network

Problem 1 (25 mins) - 5 points

In this first problem, we will examine which 'route', A or B, is better. To do so consider that a traffic flow of $10 \cdot x_3$ Mbps directed to the station arrives to the AP from Internet, with x_3 the third number of your NIA. Packets of this flow arrive at the AP following a Poisson process, and the packets have a size exponentially distributed, with average value $\mathbb{E}[L] = 1000 \cdot x_2$ bits, with x_2 the 2rd number of your NIA. If the x_i number of your NIA is zero, use 1.

1. (0.5 points) Write your NIA, and the values of $R_{\text{AP}(2.4)} = 11 \cdot x_3$ Mbps, $R_{\text{AP}(5)} = 20 \cdot x_3$ Mbps, $R_{\text{E}(6)} = 20 \cdot x_3$ Mbps, and $\mathbb{E}[L]$.
2. (1.25 points) Calculate the average packet delay, $\mathbb{E}[D_A]$, in the case the AP transmits packets directly to the STA (route 'A').
3. (1.25 points) Calculate the average packet delay, $\mathbb{E}[D_B]$, in the case the AP transmits packets to the STA through the extender (route 'B').
4. (2.0 points) Calculate the average packet delay, $\mathbb{E}[D']$ in the case the AP transmits half of the packets through the extender and half of the packets directly to the station. Note that the average packet delay now is computed by averaging the delay of the two paths, this is: $\mathbb{E}[D'] = 0.5\,\mathbb{E}[D_A] + 0.5\,\mathbb{E}[D_B]$. Explain and compare the results obtained in this and previous questions.

Problem 2 (35 mins) - 5 points

In order to improve the last case considered in Problem 1, where the traffic is distributed between the two links, the AP decides to use a single shared buffer for the two interfaces. In this case, the buffer size is $Q = \min(4, 2 \cdot x_4)$, with x_4 the 4th number of your NIA. Also, in this case, the two interfaces use the same transmission rate, set-up as the mean value of the transmission rates considered in previous exercise: $R_{\text{AP}} = 0.5(R_{\text{AP}(5)} + R_{\text{AP}(2.4)})$.

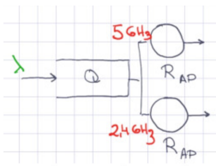

Figure 2: Multi-Link Operation - Shared buffer

1. (1.25 points) Draw the Markov chain that represents the M/M/2/K system, write its local balance equations, and find its equilibrium distribution.
2. (1.25 points) Obtain the blocking probability, and the probability that the two interfaces are transmitting packets.
3. (1.25 points) Calculate the end to end average packet delay in this case. Note that in this case, the probability that packets are transmitted over each interface is the same as before, 1/2, since the two 'servers' (i.e., interfaces) are used with the same probability.

4. (1.25 points) Compare the results with the obtained in the last case of the first problem. Note that the set-up is not exactly the same, and so the numerical values are not directly comparable. Therefore, keep the discussion at the qualitative level.

```
function MidTerm_Group1_20202021()

Problem1();
Problem2();

end

function Problem1()

disp('#### Problem 1 ####');

x3=2;

R_AP24 = 11E6*x3;
R_AP5 = 20E6*x3;
R_E6 = 20E6*x3;

x2=4;

EL=1000*x2;

lambda = 10E6*x3/EL;

% b) AP--> STA

mu_AP24 = R_AP24/EL;

ED_A = 1 / (mu_AP24-lambda);

% c) AP-->E-->STA

mu_AP5 = R_AP5/EL;
mu_E6 = R_E6/EL;


ED_B1 = 1 / (mu_AP5-lambda);
ED_B2 = 1 / (mu_E6-lambda);
ED_B = ED_B1 + ED_B2;


disp('End-to-end delay: options A and B');
disp([ED_A ED_B]);

% d) half & half (the point now is to consider lambda / 2!!!!)

lambda_A = 0.5*lambda;
lambda_B = 0.5*lambda;

% path A
ED_A_ = 1 / (mu_AP24-lambda_A);

% path B
ED_B1_ = 1 / (mu_AP5-lambda_B);
ED_B2_ = 1 / (mu_E6-lambda_B);
ED_B_ = ED_B1_ + ED_B2_;

% Average
ED_ = 0.5*ED_A_+0.5*ED_B_;

disp('End-to-end delay: options A and B | mixed (average)');
disp([ED_A_ ED_B_ ED_]);

% We can see it works much better!
```

```
end


function Problem2()

disp('#### Problem 2 ####');

x3=2;

R_AP24 = 11E6*x3;
R_AP5 = 20E6*x3;
R_E6 = 20E6*x3;

R_AP=0.5*(R_AP24+R_AP5);

x2=4;

EL=1000*x2;

lambda = 10E6*x3/EL;

% a) M/M/2/K

x4=5;

K=6; % Q=4

mu_AP = R_AP/EL;

a=lambda/mu_AP;

pi0=1/(1 + a + a^2/2 + a^3/4 + a^4/8 + a^5/16 + a^6/32);
pi1=a*pi0;
pi2=a^2/2*pi0;
pi3=a^3/4*pi0;
pi4=a^4/8*pi0;
pi5=a^5/16*pi0;
pi6=a^6/32*pi0;

disp('Equilibrium distribution - sum (validation)');
disp([pi0 pi1 pi2 pi3 pi4 pi5 pi6 pi0+pi1+pi2+pi3+pi4+pi5+pi6 ]);


% b)
Pb = pi6;
P2tx = 1-pi0-pi1;

disp('Pb Prob 2 tx');
disp([Pb P2tx]);

% c)

EN=pi1*1 + pi2*2 + pi3*3 + pi4*4 + pi5*5 + pi6*6;
ED = EN/(lambda*(1-pi6));

disp('Delay at the AP (the same regardless for which interface is tx)');
disp([ED]);

mu_AP5 = R_AP5/EL;
mu_E6 = R_E6/EL;
lambda_B = 0.5*lambda;
ED_B2_ = 1 / (mu_E6-lambda_B); % only half of the packets!!

EDe2e = 0.5*ED + 0.5*(ED + ED_B2_);
```

```
disp('End to end delay');
disp([EDe2e]);

%d) It goes better, since we transmit through different paths. The use of a
% shared buffer makes the use of the two interfaces more efficient, since
% both are working in case there are packets waiting for transmission.
% Compared to the case of the two buffers, it could be the case that one
% interface has plenty of packets waiting for transmission while the other
% is idle.

end
```