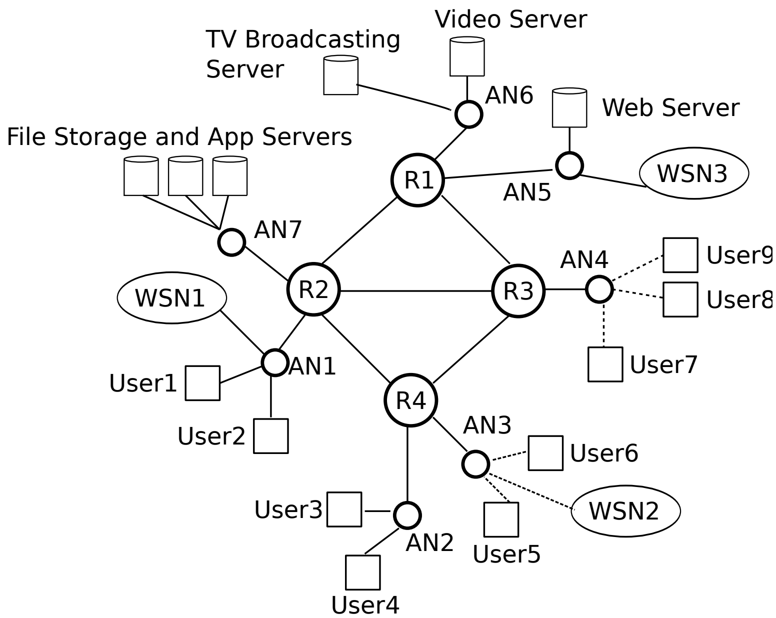

Figure 1: Basic Network

Seminar 5: Exercises

Exercise 1

An application generates a data flow with the following characteristics:

- $\lambda_1 = 1000$ packets/second, following a Poisson process.
- Average packet size of $E[L_1] = 8500$ bits.
- The packet size distribution is characterized by a $\text{CV}[L_1] = 3.2$.

This data flows is send through a network interface that is connected to a wireless link of capacity $R = 10$ Mbps. We can consider the buffer space is large enough to consider it infinite.

1. Calculate the time a packet of such an application remains in the system $E[D_1]$.
2. If the network interface is shared with another application that injects $\lambda_2 = 100$ packets/second to the network interface, where the packets are of constant size and equal to $L_2 = 8000$ bits, calculate the new value of $E[D_1]$, and the value of $E[D_2]$.

Exercise 2

Let us consider a network interface that receives $\lambda = 20000$ packets/second following a Poisson process. The probability distribution (histogram) of the packet sizes is as follows:

- Packets of $L_1 = 64$ Bytes with probability 0.3
- Packets of $L_2 = 500$ Bytes with probability 0.5
- Packets of $L_3 = 1500$ Bytes with probability 0.2

The network interface has a large buffer space which can be considered infinite and is able to transmit packets at $R = 100$ Mbps.

1. Calculate the average delay a packet remains in the buffer ($E[D_q]$) and in the system ($E[D]$) if we make the assumption that packets are exponentially distributed with average $E[L] = 0.3L_1 + 0.5L_2 + 0.2L_3$ bits.
2. Calculate the traffic load (a) in Erlangs, and which fraction corresponds to packets of size L_1, L_2 and L_3 respectively (i.e., a_1, a_2, and a_3).

3. Considering the actual packet size distribution, calculate the average residual time ($E[D_r]$). Compare this value with the residual time in case the packet sizes follow an exponential distribution.

4. Considering the actual packet size distribution, calculate the $E[D_q]$ and $E[D]$, $E[D_1]$, $E[D_2]$ and $E[D_3]$ delays, where $E[D_i]$ is the time a packet of size i remains inside the network interface. Compare the results with the values obtained assuming the packet sizes where exponentially distributed.

Hint: $E[D_s^2] = 2E^2[D_s]$ in the case of M/M/1.

Exercise 3

Let us consider an AP transmitting a data flow of $B = 4$ Mbps to a station placed at a distance of $d = 25$ meters. All the packets of the flow have the same fixed size of $L = 1100$ bits (deterministic), and packets arrive to the buffer following a Poisson process. The network interface at the AP has an infinite buffer size. The propagation delay is negligible, as well as any packet processing delay. The transmission delay is $E[D_s] = 0.195$ ms.

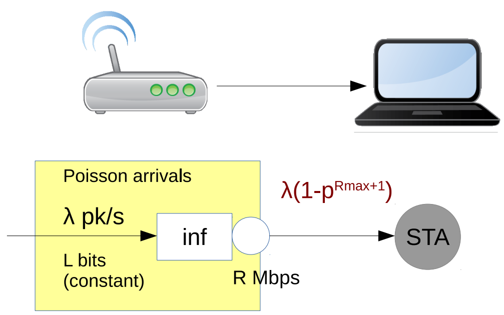

Figure 2: An AP transmitting a data flow to an STA

1. Calculate the delay $E[D]$ of the packets in the AP if the packet error probability is $p = 0$.

2. Calculate the delay $E[D]$ of the packets in the AP if the packet error probability is $p = 0.2$ and $R_{\max} = 1$.

3. Calculate the delay $E[D]$ of the packets in the AP if the packet error probability is $p = 0.2$ and $R_{\max} = 3$.

4. Calculate the throughput in bits / second for all 3 previous cases ($\lambda L(1 - p^{R_{\max}+1})$).

5. Explain the effects of p and $R_{\max}$ in the delay and throughput.

Solution Exercise 1

```
lambda1 = 1000;
EL1 = 8500;
CVL1 = 3.2;
R=10E6;


% a)

EDs1 = EL1 / R;
ED2s1 = EDs1^2*(1+CVL1^2);



a1 = lambda1*EDs1;

disp('Only flow1')
EDr = lambda1*ED2s1/2;
ED1 = EDr/((1-a1)) + EDs1

% b)

lambda2 = 100;
CVL2 = 0;
EL2 = 8000;

lambda = lambda1+lambda2;

p1 = lambda1/lambda;
p2 = lambda2/lambda;


EDs2 = EL2/R;
a2 = lambda2 * EDs2;

ED2s2 = EDs2^2*(1+0);

EDr1 = lambda1*ED2s1/2;
EDr2 = lambda2*ED2s2/2;

% EDr = lambda/2 * (p1*D2s1 + p2*D2s2)

disp('With traffic 2')

EDr = lambda *(p1*ED2s1 + p2*ED2s2)/2
```

```
a=a1+a2


EDq = EDr/(1-a)
ED1 = EDs1 + EDq
ED2 = EDs2 + EDq
ED2
```

Solution Exercise 2

```
%% EX2
% 1)

L1=64*8;
L2=500*8;
L3=1500*8;

lambda=20E3;

R=100E6;

EL = 0.3*L1 + 0.5*L2 + 0.2*L3;

mu =  R/EL;

disp('ED M/M/1');
ED = 1 /(mu-lambda)
EDq = ED - 1/mu

%2

EDs = EL/R;

a = lambda*EDs;

a1 = 0.3*lambda*L1/R;
a2 = 0.5*lambda*L2/R;
a3 = 0.2*lambda*L3/R;

%3

disp('Residual Times');
```

```
EDs1 = L1/R;
EDs2 = L2/R;
EDs3 = L3/R;

ED2s = 0.2*EDs1^2 + 0.5*EDs2^2 + 0.2*EDs3^2;

EDr = lambda * ED2s/2

%ED2s_expo = 2*EDs^2;
%EDr_expo = lambda*ED2s_expo/2

% 4 --------

disp('ED M/G/1');

EDq = EDr / (1-a)
ED = EDq + EDs
ED1 = EDq + EDs1
ED2 = EDq + EDs2
ED3 = EDq + EDs3
```

Solution Exercise 3

```
function Exercise3()

 L = 1100;
 R = 26E6;
 T = 40E-6 + (240+L)/R + 16E-6 + 40E-6+112/R + 34E-6+9E-6

B=4E6;
lambda = B/L;

% ----------- p = 0

EDs = T
ED2s = EDs^2*(1+0^2)
a = lambda * EDs

EDq = lambda * ED2s / (2*(1-a))
ED = EDs + EDq

S = lambda*L
```

```
%EDs =    1.9485e-04
%ED2s =    3.7965e-08
%a =  0.70853
%EDq =    2.3683e-04
%ED =    4.3167e-04

% --------------- p = 0.2, Rmax = 1

p=0.2

p1 = (1-p);
p2 = p;

EDs = p1*T + p2*2*T
ED2s = p1*T^2 + p2*(2*T)^2

a = lambda * EDs

EDq = lambda * ED2s / (2*(1-a))
ED = EDs + EDq

S = lambda*L*(1-p^2)

%p =  0.20000
%EDs =    2.3382e-04
%ED2s =    6.0744e-08
%a =  0.85024
%EDq =    7.3746e-04
%ED =    9.7128e-04

% --------------- p = 0.2, Rmax = 3


p1 = (1-p);
p2 = p*(1-p);
p3 = p*p*(1-p);
p4 = p*p*p;

EDs = p1*T + p2*2*T + p3*3*T + p4*4*T
ED2s = p1*T^2 + p2*(2*T)^2 + p3*(3*T)^2 + p4*(4*T)^2

a = lambda * EDs

EDq = lambda * ED2s / (2*(1-a))
```

```
ED = EDs + EDq

S = lambda*L*(1-p^4)

%EDs =    2.4317e-04
%ED2s =    7.0463e-08
%a =  0.8842
%EDq =  0.0011
%ED =  0.0013

% Throughput

%p= 0; S =  4000000
%p= 0.2; Rmax = 1; S =  3840000
%p= 0.2; Rmax = 3; S =  3993600


end
```