Typical solution for Project No. 5

ECE 642
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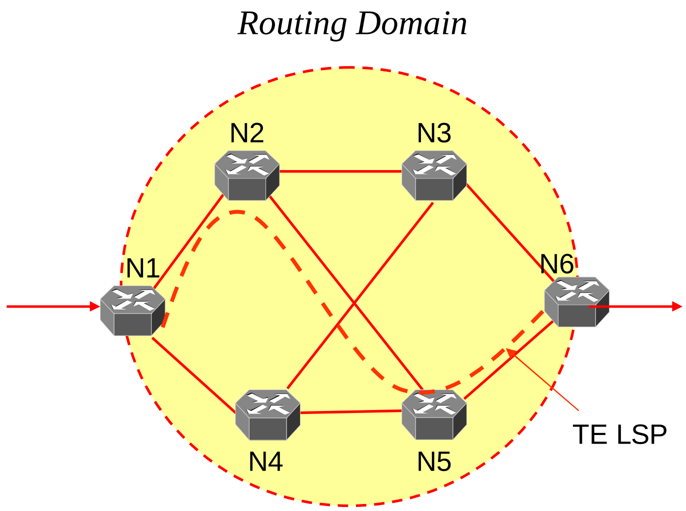
I Project description: Simulating MPLS traffic engineering in backbone networks

In this project we simulate an open queueing network model with multiple hops between source and destination. Each queue can be considered as an M/M/1 with infinite buffer and each link has a bandwidth of 1 Gbps. The traffic arrival is Poisson and the average packet length is 1200 bytes. We need to simulate the E2E delay for utilization of 0.1 to 0.8 in three different case: the independent service time, the consistent service time and simulating for one single link then multiplying the results with 3. At the end, compare the simulated results in different cases with the analysis result.



II Analysis

Based on this M/M/1 assumption for each queue, and according to the Little's formula applied over the entire LSP, the average end-to-end delay through an LSP consisting of N hops is

$$E[T] = \frac{1}{\gamma}\sum_{i=1}^{N}\frac{\lambda_i}{\mu_i - \lambda_i} \tag{1}$$

where γ is the throughput entering the LSP. In this particular open queueing network problem, γ is also the poisson arrival rate to each individual queue, in other words:

$$\gamma = \lambda_i \qquad i = 1, 2, \cdots N$$

By considering the above fact, (1) reduces to:

$$E[T] = \sum_{i=1}^{N}\frac{1}{\mu_i - \lambda_i} \tag{2}$$

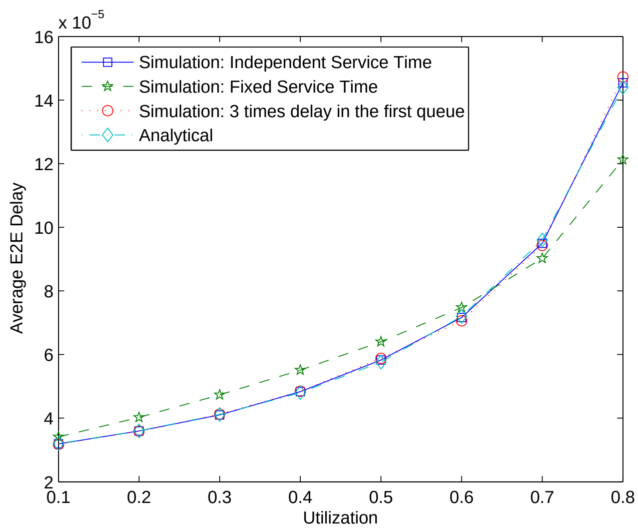
In this project, it is assumed that each link in the LSP has a fixed capacity (i.e. $\mu_i = \mu_1$ for $i = 1, 2, \cdots N$). Also, as noted earlier, the arrival rates in each link is fixed (i.e. $\lambda_i = \lambda_1$ for $i = 1, 2, \cdots N$). Therefore, considering (2),the analytical value for expected delay is:

$$E[T] = \frac{N}{\mu_1 - \lambda_1} = \frac{3}{\mu_1 - \lambda_1} \tag{3}$$

III Simulation results and graph

The simulation results and analysis results are listed below. The first column is the value of utilization, the second column is the simulation result of average delay for independent service time case, the third column is the simulation result of average delay for consistent service time case, the fourth column is the simulation result of 3∗(average delay of a single queue), and the last column is the analysis result.

ρ	independent case (msec)	consistent case (msec)	$3 * avg\_delay$ (msec)	analysis (msec)
0.1	0.0319	0.0341	0.0318	0.032
0.2	0.0360	0.0402	0.0359	0.036
0.3	0.0410	0.0473	0.0412	0.0411
0.4	0.0483	0.0551	0.0485	0.0480
0.5	0.0583	0.0640	0.0588	0.0576
0.6	0.0716	0.0748	0.0706	0.0720
0.7	0.0950	0.0902	0.0943	0.0960
0.8	0.1454	0.1213	0.1473	0.1440



IV Program List

```
clear all; PacketsNumber=50000;
NumberOfHops=3;md=[];mdf=[];md3=[];mdt=[];
for rho=0.1:0.1:0.8
    uniform=rand(NumberOfHops+1,PacketsNumber);
    mu=(1200*8/(1e9))^-1;
```

```
    lambda=rho*mu;
    tau=-1/lambda*log(uniform(1,:));
    x=-1/mu*log(uniform(2,:));
    t(1)=tau(1);
    for i=2:PacketsNumber
        t(i)=t(i-1)+tau(i);
    end
    s(1)=t(1)+x(1);
    for i=2:PacketsNumber
        s(i)=max([t(i) s(i-1)])+x(i);
    end
    t1=t;s1=s; xf=x;tf=t;sf=s;
    for i=2:NumberOfHops
        x=-1/mu*log(uniform(i+1,:));
        t=s;tf=sf;
        s(1)=t(1)+x(1);
        sf(1)=tf(1)+xf(1);
        for j=2:PacketsNumber
            s(j)=max([t(j) s(j-1)])+x(j);
            sf(j)=max([tf(j) sf(j-1)])+xf(j);
        end
    end
    md=[md mean(s-t1)]
    mdf=[mdf mean(sf-t1)]
    md3=[md3 NumberOfHops*mean(s1-t1)]
    mdt=[mdt NumberOfHops/(mu-lambda)]
end rho=[.1:.1:.8];
plot(rho,md,'-s',rho,mdf,'--p',rho,md3,':o',rho,mdt,'-.d')
legend('Simulation: Independent Service Time','Simulation: Fixed
Service Time','Simulation: 3 times delay in the first
queue','Analytical',4) xlabel('Utilization');
 ylabel('Average E2E Delay');
```