Network Simulation

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1 Two Nodes

Three experiments were performed on a two node network using the simulator. Each experiment measured the delay of a single packet being sent from the first node $n1$ to the second node $n2$. In each case the packet had a size of 1,000 bytes.

1.1 Experiment 1

Listing 1 shows the network configuration for this experiment.

Listing 1: Network configuration

```
n1 n2
n2 n1

n1 n2 1Mbps 1seconds
n2 n1 1Mbps 1seconds
```

Table 1 shows the simulator output.

Table 1: Simulator output

Packet ID	Packet Created Time	Packet Received Time
1	0s	1.008s

The following calculations were used to verify the accuracy of the simulator:

$$\begin{aligned} delay_{total} &= delay_{transmission} + delay_{propagation} \\ &= \frac{8000bits}{10^6bps} + 1s \\ &= 0.008s + 1s \\ &= 1.008s \end{aligned}$$

1.2 Experiment 2

Listing 2 shows the network configuration for this experiment.

Listing 2: Network configuration

```
n1 n2
n2 n1

n1 n2 100bps 10ms
n2 n1 100bps 10ms
```

Table 2 shows the simulator output.

Table 2: Simulator output

Packet ID	Packet Created Time	Packet Received Time
1	0s	80.01s

The following calculations were used to verify the accuracy of the simulator:

$$\begin{aligned} delay_{total} &= delay_{transmission} + delay_{propagation} \\ &= \frac{8000bits}{100bps} + 0.01s \\ &= 80s + 0.01s \\ &= 80.01s \end{aligned}$$

1.3 Experiment 3

In this experiment, four packets were sent from $n1$ to $n2$ at various intervals.

Listing 3 shows the network configuration for this experiment.

Listing 3: Network configuration

```
n1 n2
n2 n1

n1 n2 1Mbps 10ms
n2 n1 1Mbps 10ms
```

Table 3 shows the simulator output.

Table 3: Simulator output

Packet ID	Packet Created Time	Packet Received Time
1	0s	0.018s
2	0s	0.026s
3	0s	0.034s
4	2s	2.018s

The following calculations were used to verify the accuracy of the simulator:

$$\begin{aligned} delay_{total} &= delay_{transmission} + delay_{propagation} \\ &= \frac{8000bits}{10^6bps} + 0.01s \\ &= 0.008s + 0.01s \\ &= 0.018s \end{aligned}$$

Packets 1, 2, and 3 were all scheduled for $t = 0$. Packet 2 must wait for packet 1 to arrive, and likewise packet 3 must wait for packet 2 to arrive. If it takes the first packet $0.018s$ to arrive, the next packet will arrive in $2 * 0.018s$ and the next in $3 * 0.018s$.

Packet 4 was scheduled for $t = 2s$ therefore it makes sense that this packet arrived at $t = 2.018s$

2 Three Nodes

Two experiments were performed on a three node network using the simulator. Each experiment measured the delay in sending 1000 packets each of size 1kb from $n1$ to $n3$.

2.1 Experiment 1: Two fast links

Listing 4 shows the network configuration for this experiment.

Listing 4: Network configuration

```
n1 n2
n2 n1 n3
n3 n2

n1 n2 1Mbps 100ms
n2 n1 1Mbps 100ms
n2 n3 1Mbps 100ms
n3 n2 1Mbps 100ms
```

Table 4 shows the simulator output.

Table 4: Simulator output

Packet ID	Packet Created Time	Packet Received Time
1	0	0.216
...	...	...
996	7.96	8.176
997	7.968	8.184
998	7.976	8.192
999	7.984	8.200
1000	7.992	8.208

The following calculations were used to verify the accuracy of the simulator:

Packets were queued as soon as the previous packet's transmission delay was up.

$$\begin{aligned} delay_{total} &= 2 * (delay_{transmission} + delay_{propagation}) \\ &= \frac{8000bits}{10^6 mbps} + 0.1s \\ &= 0.008s + 0.1s \\ &= 0.108s \end{aligned}$$

The above calculation is for the first packet. For any other packet it is necessary to add $(i-1) * transmission_{delay}$ where i is the packet number. For example packet 999 the calculation would be $998 * 0.008s + 2(0.108s) = 8.2s$

If we increase the bandwidth to 1Gbps on each link we get the following results shown in Table 5

Table 5: Simulator output

Packet ID	Packet Created Time	Packet Received Time
1	0	0.200016
...	...	...
996	0.00796	0.207976
997	0.007968	0.207984
998	0.007976	0.207992
999	0.007984	0.208000
1000	0.007992	0.208008

2.2 Experiment 2: One Fast One Slow

Listing 5 shows the network configuration for this experiment.

Listing 5: Network configuration

```
n1 n2
n2 n1 n3
n3 n2

n1 n2 1Mbps 100ms
n2 n1 1Mbps 100ms
n2 n3 256Kbps 100ms
n3 n2 256Kbps 100ms
```

Table 6 shows the simulator output.

Table 6: Simulator output

Packet ID	Packet Created Time	Packet Received Time
1	0	0.23925
...	...	...
996	7.96	31.333
997	7.968	31.36425
998	7.976	31.3955
999	7.984	31.42675
1000	7.992	31.458

The calculations for this part are similar to those in part 1 however instead of multiplying the transmission delay and propagation delay by two, it is necessary to calculate the propagation and transmission delay of each link and apply it to each packet being sent.

$$\begin{aligned} delay_{link1} &= 0.008s + 0.1s \\ delay_{link2} &= 0.03125s + 0.1s \\ delay_{total} &= 0.23925s \end{aligned}$$

Again, the above calcuation applies to the first packet. To calculate the delay for an arbitrary packet one must add $((i-1) * delay_{transmission})$ to $delay_{total}$ where i is the packet number.

3 Queueing Theory

The simulator was used to valid basic query that shows that as utilization goes up the queueing time approaches infinity.

Listing 6 shows the network configuration for this experiment.

Listing 6: Network configuration

```
n1 n2
n2 n1

n1 n2 1Mbps 1ms
n2 n1 1Mbps 1ms
```

We ran the simulator with the following utilization loads: .1, .2, .3, .4, .5, .6, .7, .8, .9, .95, .98

Table 7 shows the simulator output.

Table 7: Simulator output

Queueing Delay	Utilization
0.1	0.00039723538144099095
0.2	0.0009259551823570379
0.3	0.0015353808146987397
0.4	0.0022040796728314584
0.5	0.0040643837154374285
0.6	0.005178718239070869
0.7	0.010346967801745273
0.8	0.014725987301735601
0.9	0.02507878037089064
0.95	0.1214653059329094
0.98	0.2499052036096885

The graph below shows the simulator output in relation to the theoretical equation that shows queueing delay approach infinity. The result is two lines that match well.