ASSIGNMENT NO 2 SOLUTION

Problem 14

a) The transmission delay is L/R. The total delay is

$$\frac{IL}{R(1-I)}+\frac{L}{R}=\frac{L/R}{1-I}$$

b) Let $x = L/R$.

Total delay = $\frac{x}{1-ax}$

For x=0, the total delay =0; as we increase x, total delay increases, approaching infinity as x approaches 1/a.

Problem 18

On linux you can use the command

```
traceroute www.targethost.com
```

and in the Windows command prompt you can use

```
tracert www.targethost.com
```

In either case, you will get three delay measurements. For those three measurements you can calculate the mean and standard deviation. Repeat the experiment at different times of the day and comment on any changes.

Here is an example solution:

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
 1  thunder.sdsc.edu (132.249.20.5)  2.802 ms  0.645 ms  0.484 ms
 2  dolphin.sdsc.edu (132.249.31.17)  0.227 ms  0.248 ms  0.239 ms
 3  dc-sdg-agg1--sdsc-1.cenic.net (137.164.23.129)  0.360 ms  0.260 ms  0.240 ms
 4  dc-riv-core1--sdg-agg1-10ge-2.cenic.net (137.164.47.14)  8.847 ms  8.497 ms  8.230 ms
 5  dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  9.969 ms  9.920 ms  9.846 ms
 6  dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.845 ms  9.729 ms  9.724 ms
 7  hurricane--lax-px1-ge.cenic.net (198.32.251.86)  9.971 ms  16.981 ms  9.850 ms
 8  10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  72.796 ms  80.278 ms  72.346 ms
 9  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.126 ms  71.442 ms  73.623 ms
10  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  70.924 ms  70.959 ms  71.072 ms
11  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  70.870 ms  71.089 ms  70.957 ms
12  72.22.188.102 (72.22.188.102)  71.242 ms  71.228 ms  71.102 ms
```

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
 1  thunder.sdsc.edu (132.249.20.5)  0.478 ms  0.353 ms  0.308 ms
 2  dolphin.sdsc.edu (132.249.31.17)  0.212 ms  0.251 ms  0.238 ms
 3  dc-sdg-agg1--sdsc-1.cenic.net (137.164.23.129)  0.237 ms  0.246 ms  0.240 ms
 4  dc-riv-core1--sdg-agg1-10ge-2.cenic.net (137.164.47.14)  8.628 ms  8.348 ms  8.357 ms
 5  dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  9.934 ms  9.963 ms  9.852 ms
 6  dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.831 ms  9.814 ms  9.676 ms
 7  hurricane--lax-px1-ge.cenic.net (198.32.251.86)  10.194 ms  10.012 ms  16.722 ms
 8  10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  73.856 ms  73.196 ms  73.979 ms
 9  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.247 ms  71.199 ms  71.646 ms
10  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  70.987 ms  71.073 ms  70.985 ms
11  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  71.075 ms  71.042 ms  71.328 ms
12  72.22.188.102 (72.22.188.102)  71.626 ms  71.299 ms  72.236 ms
```

```
 1  thunder.sdsc.edu (132.249.20.5)  0.403 ms  0.347 ms  0.358 ms
 2  dolphin.sdsc.edu (132.249.31.17)  0.225 ms  0.244 ms  0.237 ms
 3  dc-sdg-agg1--sdsc-1.cenic.net (137.164.23.129)  0.362 ms  0.256 ms  0.239 ms
 4  dc-riv-core1--sdg-agg1-10ge-2.cenic.net (137.164.47.14)  8.850 ms  8.358 ms  8.227 ms
 5  dc-lax-core1--lax-core2-10ge-2.cenic.net (137.164.46.64)  10.096 ms  9.869 ms  10.351 ms
 6  dc-lax-px1--lax-core1-10ge-2.cenic.net (137.164.46.151)  9.721 ms  9.621 ms  9.725 ms
 7  hurricane--lax-px1-ge.cenic.net (198.32.251.86)  11.345 ms  10.048 ms  13.844 ms
 8  10gigabitethernet4-3.core1.nyc4.he.net (72.52.92.225)  71.920 ms  72.977 ms  77.264 ms
 9  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  71.273 ms  71.247 ms  71.291 ms
10  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  71.114 ms  82.516 ms  71.136 ms
11  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  71.232 ms  71.071 ms  71.039 ms
12  72.22.188.102 (72.22.188.102)  71.585 ms  71.608 ms  71.493 ms
```

Traceroutes between San Diego Super Computer Center and www.poly.edu

a) The average (mean) of the round-trip delays at each of the three hours is 71.18 ms, 71.38 ms and 71.55 ms, respectively. The standard deviations are 0.075 ms, 0.21 ms, 0.05 ms, respectively.

b) In this example, the traceroutes have 12 routers in the path at each of the three hours. No, the paths didn't change during any of the hours.

c) Traceroute packets passed through four ISP networks from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.

```
traceroute to www.poly.edu (128.238.24.40), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.500 ms  0.415 ms  0.440 ms
 2  62.193.33.29 (62.193.33.29)  0.910 ms  1.065 ms  1.026 ms
 3  bg1.stella-net.net (62.193.32.254)  0.972 ms  1.026 ms  1.078 ms
 4  62.193.32.66 (62.193.32.66)  1.021 ms  0.988 ms  0.947 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.537 ms  1.752 ms  1.714 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  80.273 ms  80.103 ms  79.971 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  86.494 ms  85.872 ms  86.223 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  85.248 ms  85.424 ms  85.388 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  86.194 ms  85.864 ms  86.116 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  85.796 ms  85.823 ms  85.766 ms
11  72.22.188.102 (72.22.188.102)  87.717 ms  86.817 ms  86.774 ms

traceroute to www.poly.edu (128.238.24.40), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.375 ms  0.397 ms  0.355 ms
 2  62.193.33.29 (62.193.33.29)  0.810 ms  0.877 ms  0.836 ms
 3  bg1.stella-net.net (62.193.32.254)  1.098 ms  0.991 ms  1.055 ms
 4  62.193.32.66 (62.193.32.66)  0.994 ms  0.960 ms  1.157 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.679 ms  1.816 ms  1.768 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  80.416 ms  90.573 ms  90.659 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  85.933 ms  95.987 ms  96.087 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  90.268 ms  90.229 ms  90.030 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  85.833 ms  85.448 ms  85.418 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  87.067 ms  86.025 ms  85.962 ms
11  72.22.188.102 (72.22.188.102)  86.542 ms  86.369 ms  86.170 ms
```

```
traceroute to 128.238.24.40 (128.238.24.40), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.396 ms  0.284 ms  0.239 ms
 2  62.193.33.29 (62.193.33.29)  0.817 ms  0.786 ms  0.848 ms
 3  bg1.stella-net.net (62.193.32.254)  1.150 ms  1.216 ms  1.265 ms
 4  62.193.32.66 (62.193.32.66)  1.002 ms  0.963 ms  0.923 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.573 ms  1.534 ms  1.643 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  88.738 ms  82.866 ms  82.783 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  94.888 ms  90.936 ms  90.877 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  90.498 ms  90.543 ms  90.482 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  85.716 ms  85.408 ms  85.637 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  85.779 ms  85.290 ms  85.252 ms
11  72.22.188.102 (72.22.188.102)  86.217 ms  86.652 ms  86.588 ms
```

Traceroutes from www.stella-net.net (France) to www.poly.edu (USA).

d) The average round-trip delays at each of the three hours are 87.09 ms, 86.35 ms and 86.48 ms, respectively. The standard deviations are 0.53 ms, 0.18 ms, 0.23 ms, respectively. In this example, there are 11 routers in the path at each of the three hours. No, the paths didn't change during any of the hours. Traceroute packets passed three ISP networks from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.

Problem 19

An example solution:

```
traceroute to www.poly.edu (128.238.24.30), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.426 ms  0.329 ms  0.284 ms
 2  62.193.33.25 (62.193.33.25)  0.810 ms  0.771 ms  0.878 ms
 3  62.193.32.66 (62.193.32.66)  0.815 ms  0.840 ms  0.801 ms
 4  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.387 ms  1.506 ms  1.467 ms
 5  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  85.402 ms  85.553 ms  85.353 ms
 6  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  94.360 ms  96.220 ms  96.355 ms
 7  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  90.279 ms  87.459 ms  87.709 ms
 8  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  85.474 ms  85.450 ms  85.983 ms
 9  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  86.160 ms  85.768 ms  86.016 ms
10  72.22.188.102 (72.22.188.102)  124.111 ms  89.340 ms  89.556 ms
```

```
 1  vl200.hs01.mar01.jaguar-network.net (85.31.192.253)  0.552 ms  0.414 ms
 2  ae1.cr01.mar01.jaguar-network.net (85.31.194.9)  0.340 ms  0.213 ms
 3  xe2-0-0.cr01.par02.jaguar-network.net (78.153.231.201)  9.933 ms  9.841 ms
 4  te1-3.er01.par02.jaguar-network.net (85.31.194.14)  9.828 ms  9.962 ms
 5  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  10.456 ms  10.332 ms
 6  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  88.793 ms  96.781 ms
 7  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  94.651 ms  99.654 ms
 8  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  94.786 ms  94.755 ms
 9  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  91.935 ms  91.776 ms
10  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  91.909 ms  91.784 ms
11  72.22.188.102 (72.22.188.102)  93.791 ms  93.515 ms
```

Traceroutes from two different cities in France to New York City in United States

a) In these traceroutes from two different cities in France to the same destination host in United States, seven links are in common including the transatlantic link.

traceroute to www.poly.edu (128.238.24.30), 30 hops max, 60 byte packets

1				*	*	*
2	hos-tr3.juniper2.rz10.hetzner.de hos-tr2.juniper1.rz10.hetzner.de	213.239.224.65 213.239.224.33	de de	**0.224** ms **0.174** ms	**0.176** ms	
3	hos-bb1.juniper1.ffm.hetzner.de hos-bb1.juniper4.ffm.hetzner.de	213.239.240.224 213.239.240.230	de de	**4.746** ms **4.823** ms	**4.780** ms	
4	20gigabitethernet4-3.core1.fra1.he.net	80.81.192.172	de	**5.462** ms	**5.461** ms	**5.456** ms
5	10gigabitethernet1-4.core1.ams1.he.net 10gigabitethernet5-3.core1.ams1.he.net 10gigabitethernet5-3.core1.lon1.he.net	72.52.92.94 72.52.92.77 184.105.213.145	us us us	**12.899** ms **13.197** ms **26.110** ms		
6	10gigabitethernet1-4.core1.lon1.he.net	72.52.92.81	us	**18.720** ms	**18.871** ms	**18.862** ms
7	10gigabitethernet7-4.core1.nyc4.he.net	72.52.92.241	us	**86.677** ms	**85.580** ms	**86.560** ms
8	lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net 10gigabitethernet3-4.core1.nyc5.he.net lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net	216.66.50.106 184.105.213.218 216.66.50.106	us us us	**118.500** ms **90.346** ms **118.500** ms		
9	ae0.nycmnyzrj91.lightower.net	72.22.160.156	us	**85.289** ms	**85.552** ms	**85.283** ms

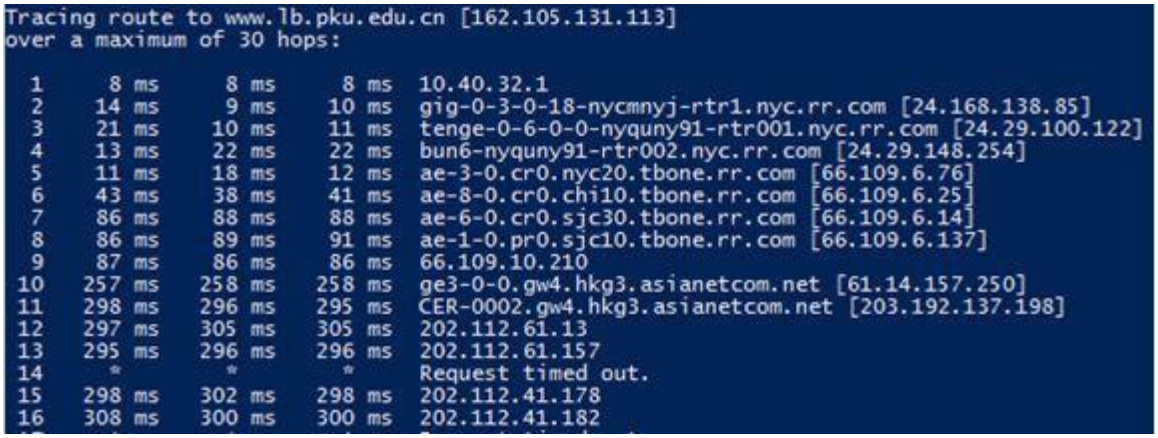
```
traceroute to www.poly.edu (128.238.24.30), 30 hops max, 60 byte packets
 1  62-193-36-1.stella-net.net (62.193.36.1)  0.426 ms  0.329 ms  0.284 ms
 2  62.193.33.25 (62.193.33.25)  0.810 ms  0.771 ms  0.878 ms
 3  62.193.32.66 (62.193.32.66)  0.815 ms  0.840 ms  0.801 ms
 4  10gigabitethernet-2-2.par2.he.net (195.42.144.104)  1.387 ms  1.506 ms  1.467 ms
 5  10gigabitethernet7-1.core1.ash1.he.net (184.105.213.93)  85.402 ms  85.553 ms  85.353 ms
 6  10gigabitethernet1-2.core1.nyc4.he.net (72.52.92.85)  94.360 ms  96.220 ms  96.355 ms
 7  10gigabitethernet3-4.core1.nyc5.he.net (184.105.213.218)  90.279 ms  87.459 ms  87.709 ms
 8  lightower-fiber-networks.10gigabitethernet3-2.core1.nyc5.he.net (216.66.50.106)  85.474 ms  85.450 ms  85.983 ms
 9  ae0.nycmnyzrj91.lightower.net (72.22.160.156)  86.160 ms  85.768 ms  86.016 ms
10  72.22.188.102 (72.22.188.102)  124.111 ms  89.340 ms  89.556 ms
```

b) In this example of traceroutes from one city in France and from another city in Germany to the same host in United States, three links are in common including the transatlantic link.

```
Tracing route to www.autoisp.shu.edu.cn [27.115.83.251]
over a maximum of 30 hops:

  1     9 ms     8 ms    10 ms  10.40.32.1
  2    12 ms    12 ms     9 ms  gig-3-0-4-nycmnyj-rtr1.nyc.rr.com [24.29.119.189]
  3    21 ms    20 ms    22 ms  tenge-0-6-0-0-nyquny91-rtr001.nyc.rr.com [24.29.100.122]
  4    19 ms    21 ms    22 ms  bun6-nyquny91-rtr002.nyc.rr.com [24.29.148.254]
  5    11 ms    11 ms    19 ms  ae-3-0.cr0.nyc20.tbone.rr.com [66.109.6.76]
  6    14 ms    18 ms    14 ms  ae-0-0.pr0.nyc30.tbone.rr.com [66.109.6.159]
  7    14 ms    11 ms    10 ms  xe-9-0-0.edge2.Newark1.Level3.net [4.59.20.29]
  8    12 ms    10 ms    13 ms  ae-31-51.ebr1.Newark1.Level3.net [4.69.156.30]
  9    10 ms    15 ms    13 ms  ae-2-2.ebr1.NewYork1.Level3.net [4.69.132.97]
 10    11 ms    17 ms    14 ms  ae-81-81.csw3.NewYork1.Level3.net [4.69.134.74]
 11    12 ms    14 ms    11 ms  ae-82-82.ebr2.NewYork1.Level3.net [4.69.148.41]
 12    83 ms    83 ms    88 ms  ae-2-2.ebr4.SanJose1.Level3.net [4.69.135.185]
 13    91 ms    87 ms    84 ms  ae-71-71.csw2.SanJose1.Level3.net [4.69.153.6]
 14    83 ms    83 ms    88 ms  ae-2-70.edge3.SanJose1.Level3.net [4.69.152.82]
 15   595 ms   593 ms   600 ms  CHINA-NETCO.edge3.SanJose1.Level3.net [4.79.54.6]
 16   594 ms   591 ms   592 ms  219.158.96.213
 17   539 ms   540 ms   540 ms  219.158.11.173
 18   593 ms   586 ms   585 ms  219.158.19.93
 19   585 ms   585 ms   584 ms  219.158.21.246
 20   568 ms   587 ms   569 ms  112.64.243.62
 21   570 ms   566 ms   568 ms  112.64.243.146
 22   342 ms   341 ms   347 ms  112.65.183.106
 23   574 ms   571 ms   573 ms  27.115.83.251

Trace complete.
```



Traceroutes to two different cities in China from same host in United States

c) Five links are common in the two traceroutes. The two traceroutes diverge before reaching China

Problem 20

Throughput = $min\{R_s, R_c, R/M\}$

Problem 25

a) 160,000 bits
b) 160,000 bits
c) The bandwidth-delay product of a link is the maximum number of bits that can be in the link.
d) the width of a bit = length of link / bandwidth-delay product, so 1 bit is 125 meters long, which is longer than a football field
e) s/R