Q.2

At time **N*(L/R)** the first packet has reached the destination, the second packet is stored in the last router, the third packet is stored in the next-to-last router, etc. At time **N*(L/R) + L/R**, the second packet has reached the destination, the third packet is stored in the last router, etc. Continuing with this logic, we see that at time **N*(L/R) + (P-1)*(L/R) = (N+P-1)*(L/R)** all packets have reached the destination.

Q.4

a) Between the switch in the upper left and the switch in the upper right we can have 4 connections. Similarly we can have four connections between each of the 3 other pairs of adjacent switches. Thus, this network can support up to 16 connections.

b) We can 4 connections passing through the switch in the upper-right-hand corner and another 4 connections passing through the switch in the lower-left-hand corner, giving a total of 8 connections.

c) Yes. For the connections between A and C, we route two connections through B and two connections through D. For the connections between B and D, we route two connections through A and two connections through C. In this manner, there are at most 4 connections passing through any link.

Q.6

a) $d = \frac{m}{s}\ seconds$

b) $d = \frac{L}{R}\ seconds$

c) $d = \left(\frac{m}{s} + \frac{L}{R}\right) seconds$

d) The bit is just leaving Host A.

e) The first bit is in the link and has not reached Host B.

f) The first bit has reached Host B.

g) $m = \frac{L}{R}s = \frac{120}{56*10^3}(2.5 * 10^8) = 536km$

Q.8

a) 20 users

b) p = 0.1

c) $\binom{120}{n} p^n (1-p)^{120-n}$

d) $1 - \sum_{n=0}^{20} \binom{120}{n} p^n (1-p)^{120-n}$

For 21 users or more:

P(Xj=1)=p

P(Xj > 20) = P(Z <= 9 / 3.286) = P(Z <= 2.74) = 0.997

P(Xj > 20) = 0.003

Q.12

The arriving packet must first wait for the link to transmit 4.5 *1,500 bytes = 6,750 bytes or 54,000 bits. Since these bits are transmitted at 2 Mbps, the queuing delay is 27 msec. Generally, the queuing delay is **(nL + (L - x))/R**.

Q.14

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

b) Let x = L/R, total delay = x / (1-ax), for x = 0, total delay is 0 and for x equal to infinity, total delay ia 1/a

Q.18

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.

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.

Q.20

Throughput = **min{Rs, Rc, R/M}**

Q.22

Probability of successfully receiving a packet is: **ps= (1-p)N**.

The number of transmissions needed to be performed until the packet is successfully received by the client is a geometric random variable with success probability ps. Thus, the average number of transmissions needed is given by: 1/ps . Then, the average number of re-transmissions needed is given by: 1/ps -1.

Q.24

40 terabytes = 40 * 1012 * 8 bits. So, if using the dedicated link, it will take 40 * 1012 * 8 / (100 *106) =3200000 seconds = 37 days. But with FedEx overnight delivery, you can guarantee the data arrives in one day, and it should cost less than $100.