University of Waterloo
ECE 358, Spring 2017
Pencil-n-Paper Assignment 1

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Problem 1

(a)

If the network is not store-n-forward, $d_{\text{end-to-end}} = \frac{L}{R}$, as incoming bits can immediately flow to the next router and there is no propagation delay.

(b)

Given $N - 1$ routers between two hosts, a bit from the source must travel across N links. Each link introduces a $d_{\text{end-to-end}}$ of $\frac{L}{R}$ in order for all L bits to be stored in the next router before it is forwarde again. Since there is no propagation, queuing, or processing delay, this accounts for the entire delay, given N routers there is a total delay of $d_{end-to-end} = N\frac{L}{R}$.

(c)

The delay is $N\frac{L}{R} + (P - 1)\frac{L}{R}$, since once one router has forwarded one packet it may immediately receive another without waiting for the first packet to reach the destination. The first packet arrives at time $N\frac{L}{R}$, the next packet arrives at time $N\frac{L}{R} + \frac{L}{R}$, and each successive packet arrives $\frac{L}{R}$ after the previous one.

(d)

Since every packet but the first must now wait an extra $\frac{L}{R}$ for the last bit of the previous packet to be sent from the next router, the delay is now $N\frac{L}{R} + (2P - 2)\frac{L}{R}$.

Problem 2

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Construct e where e(u,v) = G.c(u,v) - G.a(u,v)
Construct G' = <V, e>
Use a standard shortest path algorithm such as Dijkstra's algorithm or
Floyd-Warshall on G' and return the path if it exists

return 'none'
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Problem 3

(a)

$$d_{\text{prop}} = \frac{m}{s}$$

(b)

$$d_{\text{trans}} = \frac{L}{R}$$

(c)

$$d_{\text{end-to-end}} = \frac{L}{R} + \frac{m}{s}$$

(d)

The first bit of the packet left A at time 0, therefore at time $t = d_{\text{trans}}$ it will have travelled $d_{\text{trans}} \cdot s$ meters along the link.

Problem 4

Each packet takes $\frac{L}{R}$ to completely exit through the link, therefore the first packet in the queue will have a queueing delay of 0, the second will have a delay of $\frac{L}{R}$, the third will have $2\frac{L}{R}$, and so on until the Nth packet which has a queueing delay of $(N-1)\frac{L}{R}$. This means the average queuenig delay is

$$\frac{\sum_{x=0}^{N-1} x \cdot \frac{L}{R}}{N} = \frac{L}{2NR}(N-1)(N) = \frac{L(N-1)}{2R}$$

Problem 5

If $a \leq \mu$, then there will be no queueing delay, and $d_{\text{total}} = d_{\text{trans}} = \frac{n}{\mu}$. If $a > \mu$, then the last packet will arrive at time $\frac{n-1}{a}$, and will depart at time $\frac{n-1}{\mu}$, therefore there will be a queueing delay of $\frac{n-1}{\mu} - \frac{n-1}{a}$. That puts the total delay when $a > \mu$ at $\frac{2n-1}{\mu} - \frac{n-1}{a}$.

Problem 6

40 terabytes is 320,000,000,000,000 bits, therefore it will take $\frac{320 \times 10^{12}}{100 \times 10^{6}} = 3.2 \times 10^{6}$ seconds $=$ 53333.33 minutes $=$ 888.89 hours $=$ 37.04 days to transfer the complete file. Overnight delivery is definitely the superior option.

Problem 7

From 1c we determined that for P packets, $d_{\text{end-to-end}} = (N + P - 1)\frac{L}{R}$. In this problem, $N = 3$, $P = \frac{F}{S}$, and $L = S + 80$. This gives us

$$\begin{aligned}
d_{\text{end-to-end}} &= \left(\frac{F}{S} + 2\right)\frac{S + 80}{R} \\
&= \frac{(S + 80)(F + 2S)}{RS} \\
\frac{\partial d_{\text{end-to-end}}}{\partial S} &= \frac{2(-40F + S^2)}{RS^2} \\
\frac{2(-40F + S^2)}{RS^2} &= 0 \Rightarrow S = \sqrt{40F}
\end{aligned}$$

Therefore to minimize the delay from A to B we should use packets of size $S = \sqrt{40F}$