Lecture 1 Problems

1. The equation
$$d_{end-to-end} = N\frac{L}{R}$$
Where L is the length of each packet, N is the number of links, and R is the transmission speed of each link can be generalized for P packets as
$$d_{end-to-end} = (N + P - 1)\frac{L}{R}$$
Here, $\frac{L}{R}$ is the transmission delay of each link. Links transport 1 packet at a time, and there are $N - 1$ switches between each link.

2.
   a. The network can support 16 simultaneous connections: 4 connections between each of the 4 hosts.
   b. There can be 8 simultaneous connections between host A and C: 4 routing through B and another 4 routing through D.
   c. Yes, we can route 4 connections between A and C as well as B and D:

3.
   a. $d_{prop} = \frac{m}{s}$
   b. $d_{trans} = \frac{L}{R}$
   c. $d_{end-to-end} = d_{prop} + d_{trans}$
   d. $x_{last} = (t - d_{trans})s$, so at time $t = d_{trans}$, $x_{last} = 0$. In other words, the last bit of the packet is still just about to leave A.
   e. $x_{first} = ts$. At time $t = d_{trans}$, $x_{first} = d_{trans}s$. If $d_{prop} > d_{trans}$, then it follows that $x_{first} < m$ (because $s = \frac{m}{d_{prop}}$, so $x_{first} = d_{trans}\frac{m}{d_{prop}}$), meaning the first bit of the packet has yet to reach B.
   f. If instead $d_{prop} < d_{trans}$, then it follows that $x_{first} > m$, meaning the first bit of the packet has reached B.
   g. If $s = 2.5 \cdot 10^8\,\mathrm{m/s}$, $L = 120\,\mathrm{bits}$, $R = 56\,\mathrm{kbps}$, and $d_{prop} = d_{trans}$ then
$$\begin{aligned} \frac{m}{s} &= \frac{L}{R} \\ &\Downarrow \\ m &= s\frac{L}{R} \\ &= (2.5 \cdot 10^8\,\mathrm{m/s})\frac{120\,\mathrm{bits}}{56\,\mathrm{kbps}} \\ &\approx 535\,\mathrm{m} \end{aligned}$$

4. If N = number of packets, L = length of each packet in bits, and R = transmission rate in bps, then

   a.

$$
\begin{aligned}
d_{avg\,queue} &= \frac{\sum_{i=0}^{N-1} i\frac{L}{R}}{N} \\
&= \frac{(N-1)L}{2R}
\end{aligned}
$$

   b. If N packets arrive to the link every $\frac{LN}{R}$ seconds, then the average queuing delay is still $\frac{(N-1)L}{2R}$, since the next burst of packets arrives right as the previous burst is done.

5. If $m = 20\,000\,\text{km}$, $R = 2\,\text{Mbps}$, and $s = 2.5 \cdot 10^8\,\text{m/s}$, then

   a. The bandwidth-delay product

$$
\begin{aligned}
R \cdot d_{prop} &= R\frac{m}{s} \\
&= 2\,\text{Mbps} \cdot \frac{20\,000\,\text{km}}{2.5 \cdot 10^8\,\text{m/s}} \\
&= 160\,\text{kb}
\end{aligned}
$$

   b. The maximum number of bits in the link at any given must be 160 kb (the number of bits the link can transmit in d_{prop} seconds).

   c. The **bandwidth-delay product** must be the maximum number of bits that can fit in a given link at any given time.

   d. $w = \frac{m}{160\,\text{kb}} = \frac{20\,000\,\text{km}}{160\,\text{kb}} = 125$ meters per bit. This would make each bit longer than a football field.

   e. $w = \frac{m}{R\frac{m}{s}} = \frac{s}{R}$

6. If $R = 10\,\text{Mbps}$, $s = 2.4{\cdot}10^8\,\text{m/s}$, and m = distance from geostationary satellite to surface = $35\,786\,\text{km}$, then

   a. $d_{prop} = \frac{m}{s} = \frac{35\,786\,\text{km}}{2.4{\cdot}10^8\,\text{m/s}} \approx 0.15\,\text{s}$

   b. The bandwidth-delay product $R \cdot d_{prop} = 10\,\text{Mbps} \cdot 0.15\,\text{s} = 150\,\text{Mb}$.

   c.

$$
\begin{aligned}
d_{end-to-end} &= d_{trans} + d_{prop} \\
&= \frac{x}{R} + d_{prop} \\
x &= R(d_{end-to-end} - d_{prop}) \\
&= 10\,\text{Mbps} \cdot (60\,\text{s} - 0.15\,\text{s}) \\
&= 450\,\text{Mb}
\end{aligned}
$$