4. In a few sentences, please compare the following terms and explain the relationship between them: link bandwidth (in Hertz), baud rate (in sample-per-second), symbol rate (in symbol-per-second), and data rate (in bit-per-second).

   Link bandwidth: the range of frequencies that the channel can reliably transfer (without strong attenuation).

   Baud rate: number of samples per second

   Symbol rate: number of symbols per second, one sample is considered to represent one symbol.

   Data rate: number of bits per second, one symbol can represent $\log_2 V$ bits of information, where V is the number of discrete levels of signal)

5. In traditional telephone systems, local loop (i.e., between a telephone set and its nearest telephone switch) link bandwidth is about 3KHz.

   a) If using 16-QAM, what is the maximum achievable baud rate and data rate (assume noiseless channel)? [Hint: Nyquist limit]

   According to Nyquist limit, $2H \log_2 V = 6000 \log_2 16 = 24$ Kbps.

   b) If the signal-to-noise ratio imposed by the system between two remote telephone sets is about 30dB, what is the maximum achievable data rate? [Hint: Shannon's Limit]

   $30dB = 10^{30/10} = 1000$.

   According to Shannon's limit, $H \log_2(1 + S/N) = 3000 \log_2 1000 \approx 30$ Kbps.

2. Consider the queueing delay in a router buffer. Suppose all packets are L bits, and the transmission rate is R bps.

   (a) Suppose that N packets simultaneously arrive at the buffer every LN/R seconds. Find the average queueing delay of a packet. (*Hint:* The queueing delay for the first packet is zero; for the second packet L/R; for the third packet $2L/R$. The Nth packet has already been transmitted when the second batch of packets arrives.)
   Ans : Total queuing delay $=L/R \times [0 + 1 + 2 + ... + (N-1)] = (L/R) \times [N(N-1)/2]$ second
   Average queuing dalay=total queuing delay/$N = (L/(2R)) \times (N-1)$ second

   (b) Suppose that N packets arrive at the buffer every LN/R seconds, and the inter-arrival time of two adjacent packets is $L/(2R)$ (that is, if the first packet arrives at t_0, the 2nd packet arrives at $t_0 + L/(2R)$, the 3rd packet arrives at $t_0 + 2L/(2R)$, ..., and the Nth packet arrives at $t_0 + NL/2R$). Find the average queueing delay of a packet.
   Ans : Total queuing delay $=(L/(2R)) \times [0+1+2+....+(N-1)] = (L/(2R)) \times [N(N-1)/2]$ second
   Average queuing dalay=total queuing delay/$N = (L/(4R)) \times (N-1)$ second

3. Suppose there is a $R = 10$ Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of 2.4×10^8 meters/sec.

   (a) What is the propagation delay of the link?
   Ans : The geostationary satellites are 36,000 km above earth.
   $t_{prop} = 36 \times 10^6 / 2.4 \times 10^8 = 150ms$

   (b) What is the bandwidth-delay product, $R \times t_{prop}$?
   Ans : $R \times t_{prop} = 10 \times 10^6 \times 150 \times 10^{-3} = 1.5 \times 10^6 bits$

   (c) Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?
   Ans : $x_{min} = 1(minute) \times 10 \times 10^6 (bps) = 60(sec) \times 10 \times 10^6 (bps) = 600 \times 10^6 bits$

1. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

   (a) Express the propagation delay, d_{prop}, in terms of m and s.
   Ans : $d_{prop} = m/s$

   (b) Determine the transmission time of the packet, d_{trans}, in terms of L and R.
   Ans : $d_{trans} = L/R$

   (c) Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
   Ans : end-to-end delay= $d_{prop} + d_{trans} = m/s + L/R$

   (d) Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{trans}$, where is the last bit of the packet?
   Ans : The last bit will be on the link (just being transmitted from the transmitter and put to the wire).

   (e) Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?
   Ans : The first bit will be in the link (have not reached the receiver yet).

   (f) Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?
   Ans : The first bit will be at the receiver.

   (g) Suppose $s = 2.5 \times 10^8$ meters/sec, $L = 100$ bits, and $R = 28$ kbps. Find the distance m so that $d_{prop} = d_{trans}$.
   Ans : $m = sL/R = 0.89 \times 10^6 meter$