ECE363 Assignment 1

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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.

   Propagation Delay, dprop $= \left[\frac{\text{distance}}{\text{propagation speed}} \right] = \left[\frac{m}{s} \right]$

   Answer: m / s

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

   Transmission delay, $d_{trans} = \frac{1}{R} \times L = \frac{L}{R}$

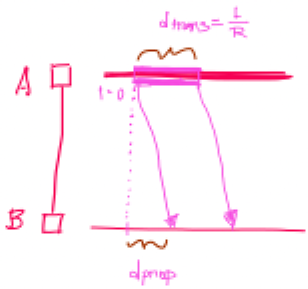
   Answer: L / R

   (c) Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

   An expression for the end-to-end delay without including processing and queuing delays:

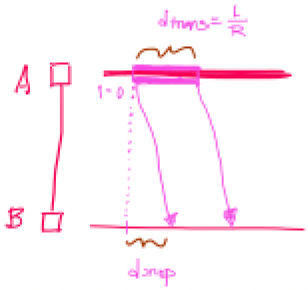
   $\left.\begin{matrix}\text{Transmission Delay} \\ + \\ \text{Propagation Delay}\end{matrix}\right\} = \frac{m}{s} + \frac{L}{R}$

(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?



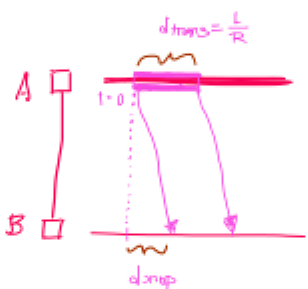
The last bit of the package is still at A, since at time T= d_{trans} the first bit packet just left A, but the last bit is still be at A.

(e) Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?



The last bit of the package is in the middle of the link. When $d_{prop} > d_{trans}$ at time T= d_{trans} the last bit packet just left A, and the first bit is in the link and in the middle.

(f) Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?



The last bit of the package has already arrived at B. When $d_{prop} < d_{trans}$ at time T= d_{trans} the last bit packet just left A, but since the propagation delay is smaller, the first bit should have already arrived at B.

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

$$d_{prop} = d_{trans}$$
$$\Rightarrow \frac{m}{s} = \frac{L}{R}$$
$$\Rightarrow m = s\frac{L}{R} = (2.5 \times 10^8)\left(\frac{100}{28000}\right) = 892857.1428571$$
$$\therefore m = 892857.14\ meters$$

3. Suppose there is a $R = 10$ Mbps microwave link between a geostationary satellite and its base station on Earth. The distance between the satellite and the base station is $36,000$ km. 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?

Given $R = 10$ Mbps $= 10000000$
$m = 36000$ km $= 36000000$
$s = 2.4 \times 10^8$ m/s

$\therefore d_{prop} = \frac{m}{s} = 0.15$ seconds

(b) What is the bandwidth-delay product, $R \times d_{prop}$?

Given $R = 10$ Mbps $= 10000000$
$m = 36000$ km $= 36000000$
$s = 2.4 \times 10^8$ m/s
$\therefore d_{prop} = \frac{m}{s} = 0.15$ seconds

Bandwidth delay Product, $R \times d_{prop}$
$= 10000000 \times 0.15$
$= 1500000$ bytes $= 1.5$ MB

(c) Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

Ignoring processing and queuing delays, the time it takes for the satellite to take a picture and send it to base is 60 seconds. Keeping that in mind, we have:

$$d_{prop} + d_{trans} = 60\ seconds$$
$$\Rightarrow 0.15\ seconds + \frac{x}{10000000\ bps} = 60\ seconds$$
$$\therefore x = 598500000\ bits = 598.5\ Megabits$$

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 refers to the range of frequencies available for data transmission and is measured in Hertz. **Baud rate** (in samples per second) represents the number of signal changes per second and is often used interchangeably with symbol rate. **Symbol rate** (in symbols per second) signifies the rate at which symbols are transmitted. **Data rate** (in bits per second) is the amount of information transmitted per unit of time and is influenced by the modulation scheme and the number of bits represented by each symbol.

In essence, link bandwidth sets the upper limit for symbol rate, which further impacts data rate through the chosen modulation scheme. Baud rate acts as an intermediate step, not always directly linked to data rate. The relationship between these terms is complex, with data rate being dependent on the modulation and encoding techniques used, while baud rate and symbol rate can be equal in simpler modulation schemes but differ in more advanced ones.

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 data rate (assume noiseless channel)? [Hint: Nyquist limit]

   $$2H\log_2 V \text{ bps} = 2 \cdot \underbrace{3 \cdot 10^3}_{Hz} \cdot \log_2(16) \text{ bps} = 24000 \text{ bps}$$

   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]

   $$H\log_2\left(1+\frac{S}{N}\right) \text{ bps} = 3\times10^3 \text{ Hz} \times \log_2\left(1+10^{(30/10)}\right)$$

   c) In a few sentences, please explain how telecommunication companys can achieve a data rate higher than the one calculated above.

Telecommunication companies can enhance data rates by expanding the link bandwidth and adopting advanced modulation schemes. By increasing the bandwidth, more frequency space becomes available for signal transmission, allowing for higher data rates according to the Nyquist limit. Additionally, employing higher-order modulation schemes, like 64-QAM instead of 16-QAM, enables the transmission of more bits per symbol. This improvement in spectral efficiency contributes to an overall increase in the achievable data rate.

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.)

The average queueing delay for a packet in a router buffer can be calculated using the formula for *Average Queuing Delay,* $\mathbf{D_q} = \frac{(N-1)L}{2R}$ where, *N is the number of packets arriving simultaneously at the buffer every* $\frac{NL}{R}$ *seconds, L is the size of each packet in bits and R is the transmission rate in bps (bits per second).*

The **first packet** experiences zero queueing delay because it starts transmitting immediately. The **second packet** experiences a delay of $\frac{L}{R}$ (transmission time) before it starts transmitting. The **third packet** experiences a delay of $\frac{2L}{R}$ before it starts transmitting. Similarly, its average waiting time is $\frac{2L}{R}$. This pattern continues, and for the N^{th} packet, its average waiting time is $\frac{(N-1)L}{2R}$.

Since it's an arithmetic series math, we can express it like this:

$$D_q = \frac{0 + \frac{L}{R} + \frac{2L}{R} + \frac{(N-1)L}{R}}{N} = \frac{\frac{N(N-1)L}{2R}}{N} = \frac{(N-1)L}{2R}$$

(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 $t_0 + (N-1)L/2R$). Find the average queueing delay of a packet.

The average queueing delay for a packet in a router buffer can be calculated using the formula for *Average Queuing Delay,* $\frac{(N-1)L}{R} - \frac{(N-1)L}{2R}$. where, *$N$ is the number of packets arriving simultaneously at the buffer every $\frac{NL}{R}$ seconds, L is the size of each packet in bits and R is the transmission rate in bps (bits per second).*

The **first packet** experiences 0 queueing delay because it starts transmitting immediately. The **second packet** experiences a delay of $\frac{L}{R} - \frac{L}{2R}$ (transmission time) before it starts transmitting. The **third packet** experiences a delay of $\frac{2L}{R} - \frac{2L}{2R}$ before it starts transmitting. This pattern continues, and for the N^{th} packet, its average waiting time is $\frac{(N-1)L}{R} - \frac{(N-1)L}{2R}$.

Since it's an arithmetic series math, we can express it like this:

$$D_q = \frac{0 + \left(\frac{L}{R} - \frac{2L}{R}\right) + \left(2\left(\frac{L}{R}\right) - 2\left(\frac{2L}{R}\right)\right) + \cdots + \left(\frac{(N-1)L}{R} - \frac{(N-1)L}{2R}\right)}{N}$$

$$= \frac{\frac{N(N-1)L}{2R} - \frac{N(N-1)(N-2)L}{4R}}{N} = \frac{(N-1)(N+2)L}{4RN}$$