Answers to the mid-term exam of Introduction to Networking

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1. Consider the queuing delay in a router buffer. Suppose all the packets are L bits long, the transmission rate is R bit/sec and that N packets arrive simultaneously at the buffer every LN/R seconds.

   Question. Find the **average** queuing delay of a packet.

   Hint. The queuing delay for the first packet is 0; for the second packet it is L/R; for the third packet it is $2L/R$ etc. The last packet (number N) has already been transmitted when the second batch (i.e., group) of packets arrives.

   Answer. It takes NL/R seconds to transmit the N packets. Thus, the buffer is empty when a batch of N packets arrive.

   The first of the N packets has no queuing delay. The second packet has a queuing delay of L/R seconds. The n-th packet has a delay of $(n-1)L/R$.

   Therefore the average delay is

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

2. **Questions.** Consider the queuing delay in a router buffer. Let I denote the traffic intensity, that is: $I = aL/R$. Suppose that the queuing delay takes the form $IL/R(1-I)$ for $I < 1$.

   (a) Provide a formula for the total delay, that is, the queuing delay plus the transmission delay.

   (b) Express the total delay as a function d of L/R, that is to say, define $d(x) = \ldots$

   Answers.

   (a) The total delay is

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

(b) Let us call $d(L/R)$ the total delay in function of L/R. We have

$$\frac{L}{R}\frac{1}{1-I} = \frac{L}{R}\frac{1}{1-\dfrac{aL}{R}} = \frac{x}{1-ax} = d(x)$$

where $x = L/R$.

3. We consider sending voice from host A to host B over a packet-switched network (for example, Internet phone). Host A converts analog voice to a digital **64 Kbps** bit stream on the fly. Host A then groups the bits into a **48-byte** packets. There is one link between host A and B; its transmission rate is **1 Mbps** and its propagation delay is **2 msec**.

   As soon as host A gathers a packet, it sends it to host B. As soon as host B receives an *entire* packet, it converts the packet's bits into an analog signal.

   Question. How much time elapses from the time a bit is created (from the original analog signal at host A) until the bit is decoded (as part of the analog signal at host B)?

   Answer. Before any bit can be transmitted, all the bits in the same packet must be gathered first. This requires

$$\frac{48 \times 8}{64 \times 10^3} \text{ sec} = 6 \text{ msec}$$

   The time required to transmit the packet is

$$\frac{48 \times 8}{1 \times 10^6} \text{ sec} = 0.384 \text{ msec}$$

   The propagation delay is 2 msec.

   Therefore the delay between coding and decoding is

$$6 \text{ msec} + 0.384 \text{ msec} + 2 \text{ msec} = 8.384 \text{ msec}$$