1. In this problem, we consider sending real-time voice from Host A to Host B over a packet-switched network (VoIP). Host A converts analog voice to a digital 128 kbps bit stream on the fly. Host A then groups the bits into 64-byte packets. There is one link between Host A and B; its transmission rate is 4 Mbps and its propagation delay is 8 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 to an analog signal. 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)? (note: 128 kbps = $128*10^3$ bps, 4Mbps = $4*10^6$ bps)

A) 2.08 msec
B) 6.08 msec
C) 9.128 msec
D) 12.128 msec

2. a) Consider a packet of length L which begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i, s_i, and R_i denote the length, propagation speed, and the transmission rate of link i, for i = 1, 2, 3. The packet switch delays each packet by d_{proc}. Assuming no queuing delays, in terms of d_i, s_i, and R_i, (i = 1,2,3), and L, what is the total end-to-end delay for the packet?

A) $L/(R_1 + R_2 + R_3) + d_1/s_1 + d_2/s_2 + d_3/s_3 + 2d_{proc}$
B) $L/R_1 + L/R_2 + L/R_3 + d_1/s_1 + d_2/s_2 + d_3/s_3 + 2d_{proc}$
C) $LR_1 + LR_2 + LR_3 + d_1s_1 + d_2s_2 + d_3s_3 + 2d_{proc}$
D) $LR_1 + LR_2 + LR_3 + d_1s_1 + d_2s_2 + d_3s_3$

b) Suppose now packet is 1,500 bytes, the propagation speed on all three links is $2.5*10^8$ m/s, the transmission rates of all three links are 2 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay? (Note that M = 10^6, k = 10^3)

A) 24 msec
B) 64 msec
C) 86 msec
D) 96 msec

3. In the above problem, suppose $R_1 = R_2 = R_3 = R$ and $d_{proc} = 0$. Further suppose the packet switch does not store-and-forward packets but instead immediately transmits each bit it receives before waiting for the entire packet to arrive. What is the end-to-end delay?

A) 16 msec
B) 26 msec
C) 36 msec
D) 46 msec

4. A packet switch receives a packet and determines the outbound link to which the packet should be forwarded. When the packet arrives, one other packet is halfway done being transmitted on this outbound link and four other packets are waiting to be transmitted. Packets are transmitted in order of arrival. Suppose all packets are 1,500 bytes and the link rate is 2 Mbps. What is the queuing delay for the packet? (Note that M = 10^6.)

A) 27 msec
B) 37 msec
C) 47 msec
D) 57 msec

More generally, what is the queuing delay when all packets have length L, the transmission rate is R, x bits of the currently-being-transmitted packet have been transmitted, and n packets are already in the queue?

5. The `tracert` command (in Windows) or `traceroute` command (in Mac/Unix/Linux) is one of the key diagnostic tools for TCP/IP. It displays a list of all the routers that a packet must go through to get from the computer where tracert is run to any other computer on the Internet. To use the command, type the tracert (or traceroute) command followed by the host name of the computer to which you want to trace the route in the command prompt. E.g., `tracert cityu.edu.hk` OR `traceroute cityu.edu.hk`. Answer the following questions:

a. What is the meaning of each column in the traceroute output?

b. Why do we see "*" sometimes?

c. Why is the round-trip delay of router N sometimes longer than the round-trip delay of router N+1 (e.g., the delays to Router 3 are larger than the delays to Router 4)?