Problem 1 - Packet switching versus circuit switching

(a) If circuits provide guaranteed bandwidth to users, why is packet switching preferred over networks such as the Internet? (1 point)

Circuits are preferred when one can estimate the demand for each user, and that demand is pretty constant over time. Traffic on the Internet is unpredictable and variable, and the statistical multiplexing characteristic of packet switching provides for much better utilization of the links.

(b) How do circuit and packet switched networks deal with overload? What is the user experience as the demand progressively increases on both types of networks? (1 point)

When the network is overloaded it will reject new circuits in the establishment phase, i.e., the network will return a busy signal. Packet-switched networks, on the other hand, will not necessarily reject packets, although packets will experience increasing queuing delays, and, when queues are full, packet drops.

(c) In packet-switched networks, as load increases, what component of end-to-end delay increases? Other than average delay, is any other metric affected? (2 points)

Queuing delays will increase as routers and switches become overloaded. Other than average delay, jitter will also increase as different packets will encounter queues of varying lengths. Furthermore, in the case of TCP, dropped packets can cause long delays for some bytes.

Problem 2 - Modulation and Encoding

(a) A typical analog phone line will carry frequencies between 300 Hz and 3,300 Hz and has a signal-to-noise ratio of 30 dB.

a. Will this support a 56Kbps modem? (1 point)

The answer is no. The signal-to-noise ratio in dB is given by

\[ 10 \log_{10}(S/N) = 30dB \]  
\[ \log_{10}(S/N) = 3 \]  
\[ S/N = 1000. \]
Using Shannon’s formula for the capacity of a noise channel,

\[ C = B \log_2(1 + S/N) \]
\[ = (3300 - 300) \log_2(1001) \]
\[ = 3000 \times 9.967 \]
\[ = 29901.6 \text{bps}. \]

b. What changes can you make to the channel to support such a rate? \( (1 \text{ point}) \)

You can increase the signal power to \( S' \), such that

\[ \log_2\left(1 + \frac{S'}{N}\right) = 9.967 \times \frac{56000}{29901.6} \]
\[ \log_2\left(1 + S'/N\right) = 18.666 \]
\[ S'/N = 2^{18.666} - 1 \]
\[ = 413934.41. \]

You can also increase the bandwidth of the channel (if you are the phone company, anyway):

\[ B' = 3000 \times \frac{56000}{29901.6} \]
\[ = 5618 \text{Hz}. \]

So, you can have the line carry the frequencies between 300 Hz and 5918 Hz.

c. What if you restrict the modem to use only a binary signal (that is, only two levels are possible)? \( (2 \text{ point}) \)

With only two levels possible, we will be doing worse than what Shannon predicts. Nyquist’s theorem says that the maximum data rate of a channel is \( 2B \) symbols per second. If we have two symbols, or \( \log_2(2) \) bits per symbol, the maximum rate then is \( 2B \) bits/sec. With \( B = 3000 \text{Hz} \), we can send only 6000 bits/sec, and to transmit at 56 Kbps, we would have to increase \( B \) to 28,500 Hz!

This result shows that the modems are doing much better than this. Shannon’s theorem essentially says what the maximum number of bits per symbol we can send is, given that the noise in the channel prevents us from distinguishing too many different encoded levels in the signal.

(b) PPP, like BISYNC, is a byte-oriented protocol that uses byte-stuffing. The special flag byte 0x7E needs to be escaped if it appears anywhere in the data, as it signifies the start and end of a frame. The escape byte in PPP is 0x7D. (PPP also XORs the escaped byte with 0x20, but you can ignore that).

a. What is the transmitted sequence for the sequence of bytes 01 7E 65 7D 7E 61 ? \( (1 \text{ point}) \)
b. If you are transmitting $n$ bytes, what is the worst case expansion? (1 point)

It would be a factor of 2, if all the bytes are any combination of either 7D or 7E.

c. Consider HDLC, which uses bit stuffing to escape 01111110.

a. If you are transmitting a payload of $n$ bytes using HDLC ($8n$ bits), what is the worst-case expansion, as a function of $n$, that you can get? For what pattern? (1 point)

If you transmit 0xFF $n$ times, you would get 1 extra 0 bit for every 5 consecutive 1’s, for a total of $8n + \lfloor \frac{8n}{5} \rfloor$ bits.

b. How can you detect a bit-stuffing error with this scheme? (1 point)

After seeing 5 consecutive 1’s, if the next bit is a 0, all is fine. Otherwise, if the next two bits are 10, it’s a delimiter pattern, and if the next two bits are 11, it is an error.

**Problem 3 - Bandwidth, Delay, and Windows**

Consider a copper cable of 800 Km connecting two computers. Consider the speed of transmission in copper to be $2 \times 10^8$ m/s.

a. What is the propagation delay in this link? (1 point)

\[
\frac{800,000 \text{ m}}{2 \times 10^8 \text{ m/s}} = 4 \text{ ms}
\]

b. Consider that the nodes can transmit at 10 Mbps ($10 \times 10^6$ bps). What is the transmission delay for a 1250-byte packet in this link? (1 point)

\[
\frac{1250 \text{ bytes} \times 8 \text{ bits}}{10 \times 10^6 \text{ bps}} = 1 \text{ ms}
\]

c. Assuming that acknowledgment packets have negligible transmission delay, what is the throughput that you can obtain from this link using a stop and go protocol? (You can only count a bit transmitted after it has been acknowledged). (1 point)

\[
\begin{align*}
\text{Throughput} & = \frac{\text{TransferSize}}{\text{TransferTime}} \\
\text{TransferTime} & = \text{RTT} + \tfrac{1}{\text{Bandwidth} \times \text{TransferSize}} \\
 & = 8 \text{ ms} + 1/(10 \times 10^6 \text{ bps}) \times 1250 \text{ bytes} \times 8\text{bits/byte} = 9 \text{ ms} \\
\text{Throughput} & = (1250 \text{ bytes} \times 8 \text{ bits/byte})/9 \text{ ms} \\
& = 1.11 \text{ Mbps or } 138,888.88 \text{ bytes/sec}
\end{align*}
\]
d. With the same assumptions, and with no losses in the link, how large does your sending window have to be in a sliding window protocol to fill the pipe? (1 point)

In order to fill the pipe, the sending window must be large enough for the sender to transmit packets until the first acknowledgement is received. With no losses, the first acknowledgement arrives 9 ms after the sender begins transmitting the first packet. As each 1250-byte packet takes 1 ms to transmit, the sending window must be large enough to permit 9 ms / 1 ms/packet = 9 packets to be in flight.

e. If you set the receiver window to the same size as the sending window, how many sequence numbers will you need? (1 point)

If the Receive Window Size (RWS) = Sending Window Size (SWS), then we must have SWS < (Max. Sequence Number + 1) / 2. Therefore, the max sequence number is SWS × 2. We will need 18 sequence numbers.

Problem 4 - Ethernet Networks

In the switched ethernet network above, which bridge ports will be disabled after the spanning tree algorithm finishes? Consider the bridges to be ordered B1, B2, ... B7. (3 points)

The cut links will be B2-A, B5-B, B5-F, and B6-I. This will result in Bridge B5 not forwarding any packets. However, it is still available as a redundant route in case bridge B2 or B3 fails.