1. Find out why modern modems can support 36 Kbps data rate for phone lines with 4 KHz bandwidth.

**Ans:** Shannon’s theorem says that the signal to noise ratio will limit the data rate. The majority of the noise in the local loop is due to the analog to digital conversion (via a codec) upstream from a client to an internet service provider (ISP), not due to the digital to analog conversion downstream from the ISP to the client’s home computer.

(a) For upstream data rate: it is practically limited to about 33-35 Kbps because of the noise (called quantization noise) generated in the analog to digital process which cannot be eliminated. The quantization noise results from converting continuous analog signals into discrete digital signals and is normally somewhere around 30dB.

(b) For downstream data rate: the ISP is normally directly connected to the telephone digital system by leased digital lines (e.g., T1) and therefore an ISP can transmit digital signals all the way to the client’s local end office, at which point a digital to analog conversion is done. This conversion does not introduce quantization noise to the signal, so it is possible to ignore Shannon’s rule and assume a noiseless phone line in the local loop downstream to the customers’ home modem. A straightforward amplitude modulation method called Pulse Amplitude Modulation (PAM) can be used here to encode 8 bits per signal element at 8KHz for a 64kbps data rate. Tests revealed that there was still some noise (I guess Shannon could not be ignored) for a home X2 or flex modem to pick 1 out of 256 voltage levels, so 7 bits are encoded per signal element instead at 8KHz for an effective data rate at 56Kbps. Note that there is no carrier or phase encoding here, just a straightforward amplitude modulation at 8KHz when doing the digital to analog conversion downstream.

2. Problem 1.14. **Ans:** 1/(1 - p). One way to get this is as follows. Let $P_k$ be the probability of the frame requiring $k$ transmissions. Then $P_k = p^{k-1}(1 - p)$ since $k - 1$ transmissions fail before it succeeds. The mean number of transmissions is then given by

$$\sum_{k=1}^{\infty} k P_k = \sum_{k=1}^{\infty} k(1 - p)p^{k-1} = (1 - p)\sum_{k=1}^{\infty} kp^{k-1} = (1 - p)\frac{1}{(1 - p)^2} = \frac{1}{1 - p}$$

3. Problem 1.15. **Ans:** (a) Data link layer. (b) Network layer.

4. Problem 2.3. **Ans:** 24Mbps. According to the Nyquist limit, the maximum data rate is $2 \times 6 MHz \times \log_2(2) = 24$ Mbps.

5. Problem 2.4. **Ans:** 6Kbps. The Shannon limit is $3 KHz \times \log_2(1 + 100) = 19.5 Kbps$ but the Nyquist limit is only 6Kbps. The bottleneck is the Nyquist limit.
6. Problem 2.7. **Ans:** 30,000 GHz or 30THz. Use $\Delta f = c\Delta\lambda/\lambda^2$ with $\Delta\lambda = 10^{-7}$ and $\lambda = 10^{-6}$.

7. Problem 2.8. **Ans:** The answer varies depending on the assumption on the data rate per Hz. If assume 1 bps per Hz: the bandwidth needed is 442 MHz and $\Delta\lambda = 2.5 \times 10^{-6}$ microns or $2.5 \times 10^{-12}$ meters. If assume 2 bps per Hz: the bandwidth needed is 221 MHz and $\Delta\lambda = 1.25 \times 10^{-6}$ microns. Both answers are correct. The data rate is $480 \times 640 \times 24 \times 60$ bps, which is 442 Mbps. Use $\Delta f = c\Delta\lambda/\lambda^2$ with the bandwidth $\Delta f = 442$ MHz based on 1bps per Hz (or 221 MHz based on 2bps per Hz) and $\lambda = 1.3 \times 10^{-6}$ meters.

8. Problem 2.17 **Ans:** 2400 bps.

9. Problem 2.23 **Ans:** 13%. The end users get $7 \times 24 = 168$ of the 193 bits in a frame. The overhead is $25/193 = 13\%$.

10. Problem 2.32 **Ans:**
    star: best case=2, average case=2, worst case=2.
    ring: best case=1, average case=n/4, worst case=n/2.
    fully connected: best case=1, average case=1, worst case=1.

11. Problem 2.33 **Ans:** packet switching is better if $s > (k-1) \times p/b$. The delay by circuit switching is $s + x/b + kd$ and that by packet switching is $x/b + kd + (k-1) \times p/b$.

12. Problem 2.35 **Ans:** 96 for Fig. 2-39(a); 144 for Fig. 2-39(b); and 120 (assume duplex lines) or 256 (assume simplex lines) for a full single-stage crossbar switch.

13. Problem 2.36. **Ans:** 2. If lines 1 and 2 are in use (see the left most switch), line 3 will not be able to get a line to the intermediate switches and is blocked.

14. Problem 3.38 **Ans:** $n = 1250$ lines. Use the formula $2 \times n \times 50ns = 125\mu s$. 