Assignment 1: Physical Layer

1) Suppose a 128-kbps point-to-point link is set up between the Earth and a rover on Mars. The distance from the Earth to Mars (when they are closest together) is approximately 55 Gm, and data travels over the link at the speed of light—3×10^8 m/s.
   (a) Calculate the minimum RTT for the link.
   (b) Calculate the delay × bandwidth product for the link.

   A camera on the rover takes pictures of its surroundings and sends these to Earth. How quickly after a picture is taken can it reach Mission Control on Earth? Assume that each image is 5Mb in size.

2) Given the narrow (usable) audio bandwidth of a telephone transmission facility, a nominal SNR_{db} of 56dB (400,000), and a distortion level of <0.2%,
   a. What is the theoretical maximum channel capacity (kbps) of traditional telephone lines?
   b. What is the actual maximum channel capacity?

3) A modified NRZ code known as enhanced-NRZ (E-NRZ) is sometimes used for high-density magnetic tape recording. E-NRZ encoding entails separating the NRZ-L data stream into 7-bit words; inverting bits 2, 3, 6, and 7; and adding one parity bit to each word. The parity bit is chosen to make the total number of 1s in the 8-bit word an odd count. What are the advantages of E-NRZ over NRZ-L? Are there any disadvantages?

4) A sine wave is to be used for two different signaling schemes: (a) PSK; (b) QPSK. The duration of a signal element is 10^{-5} s. If the received signal is of the following form:

$$s(t) = 0.005 \sin (2\pi\ 10^6\ t + \theta) \text{ volts}$$

and if the measured noise power at the receiver is 2.5×10^{-8} watts, determine the E_b/N_0 (in dB) for each case.

5) Let $m_1(t)$ and $m_2(t)$ be message signals and let $s_1(t)$ and $s_2(t)$ be the corresponding modulated signals using a carrier frequency of f_c.
   a. Show that if simple AM modulation is used, then $m_1(t) + m_2(t)$ produces a modulated signal that is a linear combination of $s_1(t)$ and $s_2(t)$.
   b. Show that if simple PM modulation is used, then $m_1(t) + m_2(t)$ produces a signal that is not a linear combination of $s_1(t)$ and $s_2(t)$.

6) Assume that a telephone line channel is equalized to allow bandpass data transmission over a frequency range of 600 to 3000 Hz. The available bandwidth is 2400 Hz. For r = 1, evaluate the required bandwidth for 2400 bps QPSK and 4800-bps, eight-level multilevel signaling. Is the bandwidth adequate? Why?

7) One positive side effect of bipolar encoding is that a bipolar violation (two consecutive + pulses or two consecutive – pulses separated by any number of zeros) indicates to the receiver that an error has occurred in transmission. Unfortunately, upon the receipt of such a violation, the receiver does not know which bit is in error (only that an error has occurred). For the received bipolar sequence

   + – 0 + – 0 – +

   which has one bipolar violation, construct two scenarios (each of which involves a different transmitted bit stream with one transmitted bit being converted via an error) that will produce this same received bit pattern.

8) Consider an audio signal with spectral components in the range 300 to 3000 Hz. Assume that a sampling rate of 7000 samples per second will be used to generate a PCM signal.
   a. For SNR = 30 dB, what is the number of uniform quantization levels needed?

b. What data rate is required?

9) An NRZ-L signal is passed through a filter with r = 0.5 and then modulated onto a carrier. The data rate is 2400 bps. Evaluate the bandwidth for ASK and FSK. For FSK, assume that the two frequencies used are 50 kHz and 55 kHz.

10) Calculate the total time required to transfer a 1.5-MB file in the following cases, assuming an RTT of 80ms, a packet size of 1 KB data, and an initial 2×RTT of "handshaking" before data is sent:
   (a) The bandwidth is 10 Mbps, and data packets can be sent continuously.
   (b) The bandwidth is 10 Mbps, but after we finish sending each data packet we must wait one RTT before sending the next.
   (c) The link allows infinitely fast transmit, but limits bandwidth such that only 20 packets can be sent per RTT.
   (d) Zero transmit time as in (c), but during the first RTT we can send one packet, during the second RTT we can send two packets, during the third we can send four (2^3-1), etc.

11) Consider a channel with a 1-MHz capacity and an SNR of 63.
   (a) What is the upper limit to the data rate that the channel can carry?
   (b) The result of part (a) is the upper limit. However, as a practical matter, better error performance will be achieved at a lower data rate. Assume we choose a data rate of 2/3 the maximum theoretical limit. How many signal levels are needed to achieve this data rate?

12) Suppose that a digitized TV picture is to be transmitted from a source that uses a matrix of picture elements (pixels), where each pixel can take on one of 32 intensity values. Assume that 30 pictures are sent per second. (This digital source is roughly equivalent to broadcast TV standards that have been adopted.)
   (a) Find the source rate R (bps).

(b) Assume that the TV picture is to be transmitted over a channel with 4.5-MHz bandwidth and a 35-dB signal-to-noise ratio. Find the capacity of the channel (bps).

(c) Discuss how the parameters given in the first part of the question could be modified to allow transmission of colour TV signals without increasing the required value for R.