1. [36%] **Propagation Models.** A communication system in a large city transmits 100 W (50.0 dBm) of power at a carrier frequency of $f_c = 1500$ MHz ($\lambda = 0.2$ m). The transmit antenna is at a height of 80 m and has a gain of 6 dBi. The receive antenna is at a height of 2 m and has a gain of 2 dBi. Assume that system losses are negligible and that the earth is flat between the two antennas.

   a) [7%] What is the path loss (in dB) at a distance of 10 km assuming an *reflective earth* propagation model?
   
   $$ L_{\text{path}} |_{\text{dB}} = \, \text{___________} \, \text{dB} $$

   b) [4%] What is the correction factor (in dB) for receiver antenna height in the *Hata* propagation model?
   
   $$ a(h_{re}) = \, \text{___________} \, \text{dB} $$

   c) [7%] What is the path loss (in dB) at a distance of 10 km assuming the *Hata* propagation model?
   
   $$ L_{\text{path}} |_{\text{dB}} = \, \text{___________} \, \text{dB} $$

   d) [6%] What is the received power level (in dBm) at a distance of 10 km assuming the *reflective earth* propagation model?
   
   $$ P_r |_{\text{dBm}} = \, \text{___________} \, \text{dBm} $$

   e) [4%] What is the received power level (in dBm) at a distance of 10 km assuming the *Hata* propagation model? (You can use the difference in path loss in parts (a) and (c) and your answer in (d) to find this quickly.)
   
   $$ P_r |_{\text{dBm}} = \, \text{___________} \, \text{dBm} $$

   f) [8%] The required receiver sensitivity is -90 dBm. Assuming a *reflective earth* propagation model what is the maximum distance (in km) at which the average received power level is greater than the sensitivity?
   
   $$ d = \, \text{___________} \, \text{km} $$
2. [30%] **Multipath.** The following problems involve propagation in a multipath environment.

   a) [6%] A receiver is moving at a velocity of 20 m/s. The received wave arrives at an angle of \( \theta = 20^\circ \) from the horizontal. The carrier frequency is 1 GHz. What is the Doppler shift?

   \[ f_d = \] ________________

   b) [6%] In a multipath environment, two signal components arrive with a doppler spread of 150 Hz. What is the null-to-null time interval?

   \[ t_{n-n} = \] ________________

   c) [4%] Pulses of width \( T_{sig} = 1 \text{ ms} \) are being transmitted. Is this a slow or fast fading environment?

   slow fading or fast fading

   d) [7%] In a multipath environment with two paths, the relative received power levels along the two paths are \( p_1 = 0 \text{ dB} = 1 \) and \( p_2 = 1.5 \text{ dB} = 1.413 \). The arrival times along the two paths are \( t_1 = 3 \mu \text{s} \) and \( t_2 = 6 \mu \text{s} \). What is the mean (weighted) delay time?

   \[ <t_i> = \] ________________

   e) [7%] A signal in a multipath environment is received with an average power of -90 dBm. Assuming variation in received power level is due to multipath (Rayleigh fading) and not due to shadowing what is the probability that the actual receiver power level is greater than -95 dbm?

   \( \text{Prob}[ P_r > -95 \text{ dBm } ] = \) ________________
3. [34%] **Area Coverage.** A particular cell has a radius of \( R = 6 \) km. Assume a standard deviation for path loss of \( \sigma_{\text{path}} = 6 \) dB and a path loss exponent of \( \nu = 3 \).

   a) [6%] The desired *area coverage* \((F_u)\) is 90%. What is the required *boundary coverage* (the probability that the received power level is greater than the receiver sensitivity at the cell boundary)?

   \[
   P_{p_{\text{sens}}}(R) = \text{__________________________}
   \]

   b) [8%] What is the corresponding required fade margin (average power level above receiver sensitivity in dB) at the boundary?

   \[
   \text{fade margin} = \text{__________________________ dB}
   \]

   c) [6%] For the fade margin in part (b) and a receiver sensitivity of \( p_{\text{sens}} = -100 \) dBm, what is the required average receiver power level (in dBm) at the boundary?

   \[
   \overline{P_r}_{\text{dB}} = \text{__________________________ dBm}
   \]

   d) [8%] With the average power as calculated in part c), what is the probability that the received power level is 6 dB above the receiver sensitivity at the cell boundary?

   \[
   \text{Prob}[P_r_{\text{dB}} > (p_{\text{sens}}_{\text{dB}} + 6 \text{ dB})] = \text{__________________________}
   \]

   e) [6%] If the transmitted power level is increased so the boundary coverage is now 0.90, what is the corresponding area coverage?

   \[
   F_u = \text{__________________________}
   \]