CHAPTER 8

Problem 8.1

(a) Free space loss = \(10 \log_{10} \left( \frac{4\pi d^2}{\lambda} \right)\)

\[= 20 \log_{10} \left( \frac{4 \times \pi \times 150}{3 \times 10^8 / 4 \times 10^9} \right) \text{dB}\]

\[= 88 \text{ dB}\]

(b) The power gain of each antenna is

\[10 \log_{10} G_r = 10 \log_{10} G_t = 10 \log_{10} \left( \frac{4 \times \pi \times A}{\lambda^2} \right)\]

\[= 10 \log_{10} \left( \frac{4 \times \pi \times \pi \times 0.6}{(3/40)^2} \right)\]

\[= 36.24 \text{ dB}\]

(c) Received Power = Transmitted power + \(G_r\) - Free space loss

\[= 1 + 36.24 - 88\]

\[= -50.76 \text{ dBW}\]

Problem 8.2

The antenna gain and free-space loss at 12 GHz can be calculated by simply adding \(20 \log_{10}(12/4)\) for the values calculated in Problem 8.1 for downlink frequency 4 GHz. Specifically, we have:

(a) Free-space loss = 88 + 20\(\log_{10}(3)\)

\[= 97.54 \text{ dB}\]

(b) Power gain of each antenna

\[= 36.24 + 20\log_{10}(3)\]

\[= 45.78 \text{ dB}\]

(c) Received power = -50.76 dBW

The important points to note from the solutions to Problems 8.1 and 8.3 are:
1. Increasing the operating frequency produces a corresponding increase in free-space loss, and an equal increase in the power gain of each antenna.
2. The net result is that, in theory, the received power remains unchanged.
(b) Major differences between satellite and wireless communications:

- Multipath fading and user mobility are characteristic features of wireless communications, which have no counterparts in satellite communications.
- The carrier frequency for satellite communications is in the gigahertz range (Ku-band), whereas in satellite communications it is in the megahertz range.
- Satellite communication systems provide broad area coverage, whereas wireless communications provide local coverage with provision for mobility in a cellular type of layout.

Problem 8.13

In a wireless communication system, transmit power is limited at the mobile unit, whereas no such limitation exists at the base station. A sensible design strategy is to make the path loss (i.e., free-space loss) on the downlink as small as possible, which, in turn, suggests that we make

\[(\text{Path loss})_{\text{uplink}} < (\text{Path loss})_{\text{downlink}}\]

Recognizing that path loss is inversely proportional to wavelength, it follows that

\[\lambda_{\text{uplink}} > \lambda_{\text{downlink}}\]

or, equivalently,

\[f_{\text{uplink}} < f_{\text{downlink}}\]

Problem 8.14

The phase difference between the direct and reflected waves can be expressed as

\[
\phi = \frac{2\pi d}{\lambda} \left[ \sqrt{\left( \frac{h_b + h_m}{d} \right)^2 + 1} - \sqrt{\left( \frac{h_b - h_m}{d} \right)^2 + 1} \right]
\]

where \(\lambda\) is the wave length. For large \(d\), Eq. (1) may be approximated as

\[
\phi \approx \frac{4\pi(h_b h_m)}{\lambda d} \text{ radians}
\]

With perfect reflection (i.e., reflected coefficient of the ground is -1) and assuming small \(\phi\) (i.e., large \(d\), the received power \(P_r\) is defined by

\[
P_r = P_o |1 - e^{j\phi}|^2 \approx P_o \sin^2 \left( \frac{4\pi(h_b h_m)}{\lambda d} \right)
\]

446
\[ P_r = P_o \left( \frac{4\pi(h_b h_m)}{\lambda d} \right)^2 \]

where \( P_o = P_t G_b G_m \left( \frac{\lambda}{4\pi d} \right)^2 \) (3)

Using Eq. (3) in (2):

\[ P_r = P_t G_b G_m \left( \frac{4\pi(h_b h_m)}{\lambda d} \right)^2 \left( \frac{\lambda}{4\pi d} \right)^2 \]

\[ = P_t G_b G_m \left( \frac{h_b^2 h_m^2}{d^4} \right) \]

which shows that the received power is inversely proportional to the fourth power of distance \( d \) between the two antennas.

Problem 8.15

The complex (baseband) impulse response of a wireless channel may be described by

\[ h(t) = a_1 e^{-j\phi_1} \delta(t - \tau) + a_2 e^{-j\phi_2} \delta(t - \tau) \] (1)

where the amplitudes \( a_1 \) and \( a_2 \) are Rayleigh distributed, and the phase angles \( \phi_1 \) and \( \phi_2 \) are uniformly distributed. This model assumes (2) the presence of two different clusters with each one consisting of a large number of scatterers, and (2) the absence of line-of-sight paths in the wireless environment. Define

\[ h(t) = \tilde{h}(t) e^{-j\phi_1} \]

\[ \theta = \phi_2 - \phi_1 \]

We may then rewrite Eq. (1) in the form

\[ h(t) = a_1 \delta(t - \tau) + a_2 e^{-j\theta} \delta(t - \tau) \]

as stated in the problem.

(a) (i) The transfer function of the model is
\[ H(f) = F[h(t)] = a_1 e^{-j2\pi f \tau_1} + a_2 e^{-j(2\pi f \tau_2 + \theta)} \]

(ii) The power-delay profile of the model is

\[ P_h = E[|h(t)|^2] = E[a_1^2 \delta(t - \tau_1) + a_2 e^{-j\theta} \delta(t - \tau_2) + a_2 e^{j\theta} \delta(t - \tau_2)] \]

\[ = E[a_1^2 \delta^2(t - \tau_1) + a_2^2 \delta^2(t - \tau_2) + a_1 a_2 \cos \theta \delta(t - \tau_1) \delta(t - \tau_2)] \]

\[ = E[a_1^2] \delta^2(t - \tau_1) + E[a_2^2] \delta^2(t - \tau_2) \] (1)

(b) The magnitude response of the model is

\[ |H(f)| = \left| a_1 e^{-j2\pi f \tau_1} + a_2 e^{-j2\pi f (\tau_2 + \theta)} \right| \]

\[ = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos (2\pi f (\tau_2 - \tau_1) + \theta)} \]

which exhibits frequency selectivity due to two factors: (1) variations in the coefficients \(a_1\) and \(a_2\), and (2) variations in the delay difference \(\tau_2 - \tau_1\).

Problem 8.16

The multipath influence on a communication system is usually described in terms of two effects: selective fading and intersymbol interference. In a Rake receiver, selective fading is mitigated by detecting the echo signals individually, using a correlation method, and adding them algebraically (with the same sign) rather than vectorially, and intersymbol interference is dealt with by reinserting different delays into the various detected echoes so that they fall into step again.

Making each correlator perform at its assigned value of delay can be done by inserting the right amount of delay in either the reference (called the delayed-reference) or received signals (called the delayed-signal). Independent of the form of the reference signals employed, the output SNR from the integrating filters is substantially the same for both configurations, under the assumption that the length of the delay \(T_d\) is significantly smaller than the symbol duration \(T\). Each integrating filter responds to signals only within about \(\pm 1/T\) of the frequency \(f\). Therefore, the noises adding