Link Budget and Flat Fading Channels

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1

Reading Material

- Haykin Chapter 8.4, 8.5, 8.7
- Proakis Section 4.10

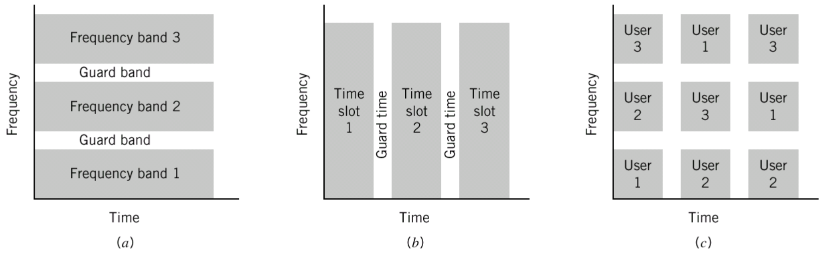
2

Multiple-Access Techniques

(*b*) Time-division multiple access.

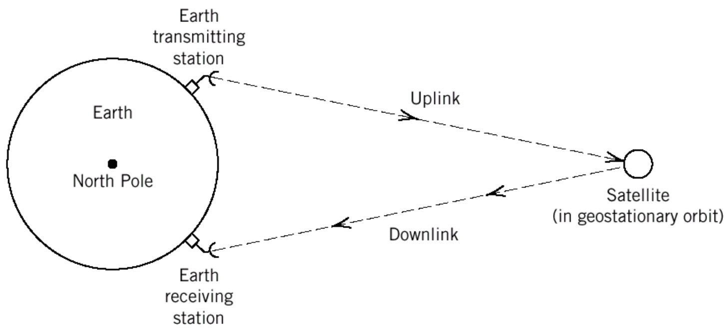
(*a*) Frequency-division multiple access

(*c*) Frequency-hop multiple access.



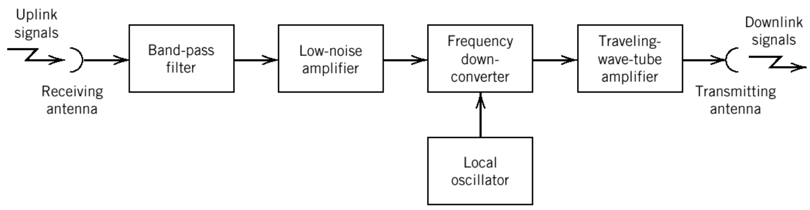
3

Satellite Communications System



4

Block Diagram of Transponder



5

Radio Link Analysis

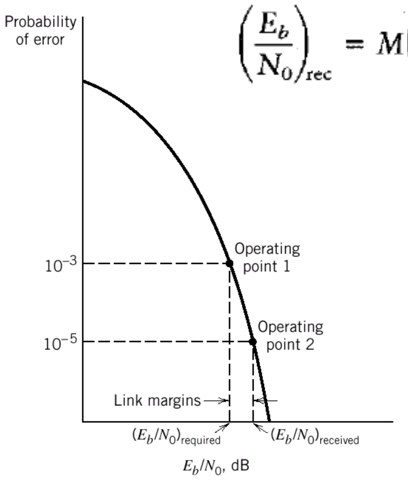
Link Budget is the totaling of all the gains and losses incurred in operating a communication link.

In particular, the balance sheet constituting the link budget provides a detailed accounting of three broadly defined items:

- Apportionment of the resources available to the transmitter and the receiver.
- Sources responsible for the loss of signal power.
- Sources of noise.

6

Radio Link Analysis



$$\left(\frac{E_b}{N_0}\right)_{rec} = M\left(\frac{E_b}{N_0}\right)_{req}$$

Where M is the link margin

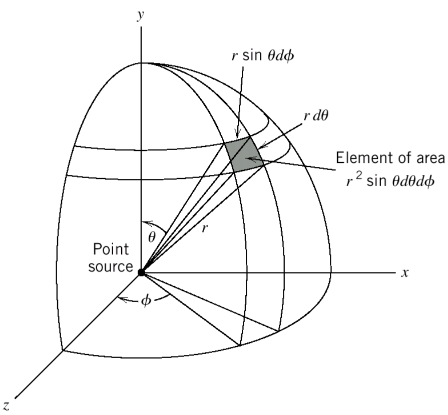
$$M(\text{dB}) = \left(\frac{E_b}{N_0}\right)_{rec}(\text{dB}) - \left(\frac{E_b}{N_0}\right)_{req}(\text{dB})$$

7

Free Space Propagation Model

Power Density $\rho(d) = \frac{P_t}{4\pi d^2}$ watts/m^2

Radiation Intensity $\Phi = d^2\rho(d)$



Total Power Radiated

$$P = \int \Phi(\theta, \phi)\, d\Omega \quad \text{watts}$$

The *average* power radiated per unit solid angle is

$$P_{av} = \frac{1}{4\pi}\int \Phi(\theta, \phi)\, d\Omega$$

$$= \frac{P}{4\pi} \quad \text{watts/steradian}$$

8

Directive Gain, Directivity, and Power Gain

the *directive gain* of an antenna, denoted by *g*(θ, Φ) is defined as *the ratio of the radiation intensity in that direction to the average radiated power*

$$g(\theta, \phi) = \frac{\Phi(\theta, \phi)}{P_{av}} = \frac{\Phi(\theta, \phi)}{P/4\pi}$$

the directivity D is the maximum value of the directive gain *g*(θ, Φ)

Power Gain (G) is :

$$G = \eta_{radiation} D$$

9

Friis Free-Space Equation

The received power at distant d is

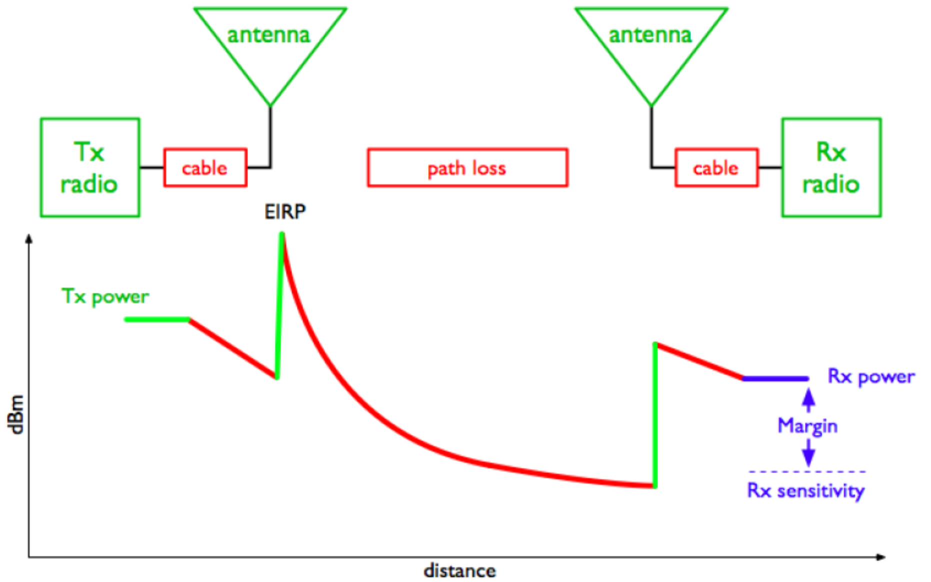
$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$$

The *path loss,* PL, representing signal "attenuation" in decibels across the entire communication link, is defined as *the difference (in decibels) between the transmitted signal power P_t and received signal power P_r*

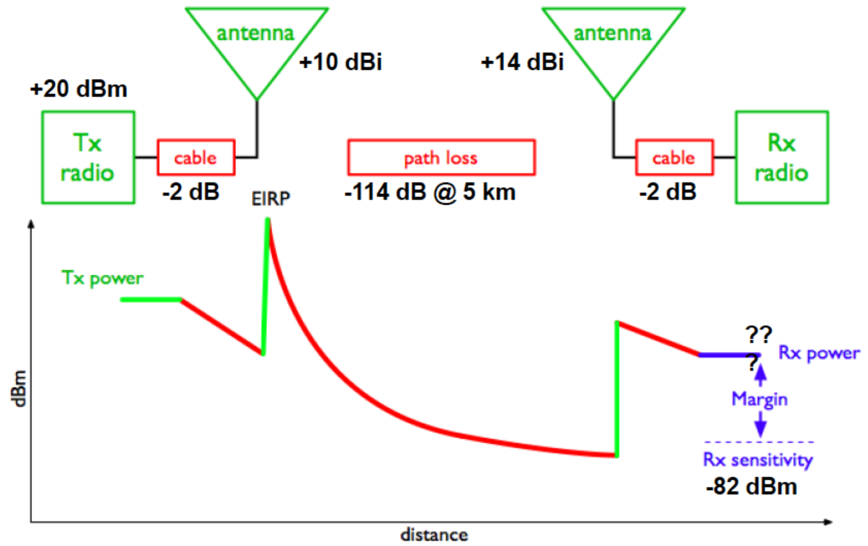
$$\mathrm{PL} = 10 \log_{10}\left(\frac{P_t}{P_r}\right) = -10 \log_{10}(G_t G_r) + 10 \log_{10}\left(\frac{4\pi d}{\lambda}\right)^2$$

10

Power in a wireless system



AP to Client link



Calculations

20 dBm (TX Power AP)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)
+ 14 dBi (Antenna Gain Client)
- 2 dB (Cable Losses Client)

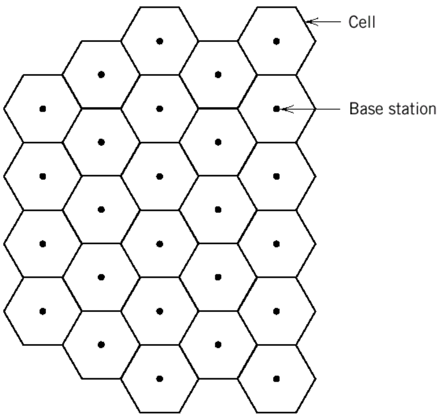
40 dB Total Gain
-114 dB (free space loss @5 km)

-73 dBm (expected received signal level)
--82 dBm (sensitivity of Client)

8 dB (link margin)

13

Wireless Communications

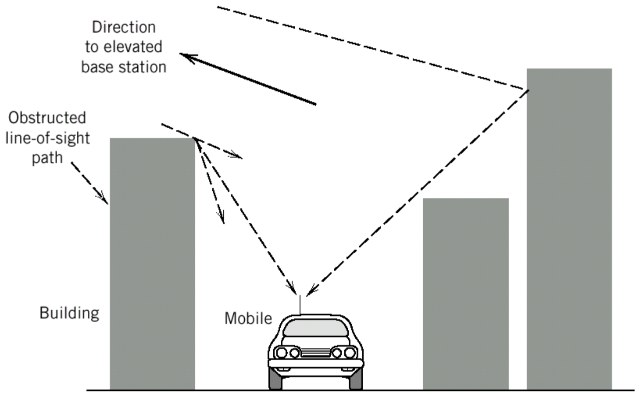


The cellular concept relies on two essential features, as described here:

- *Frequency reuse*
- *Cell splitting*

14

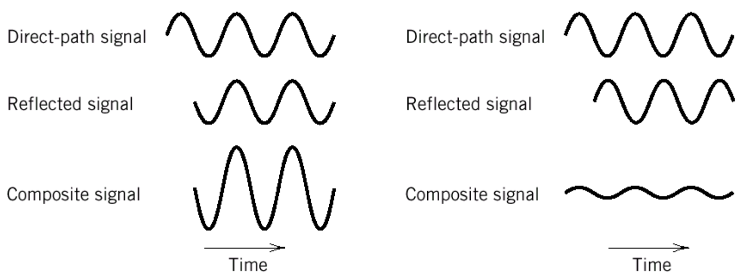
PROPAGATION EFFECTS



PROPAGATION EFFECTS

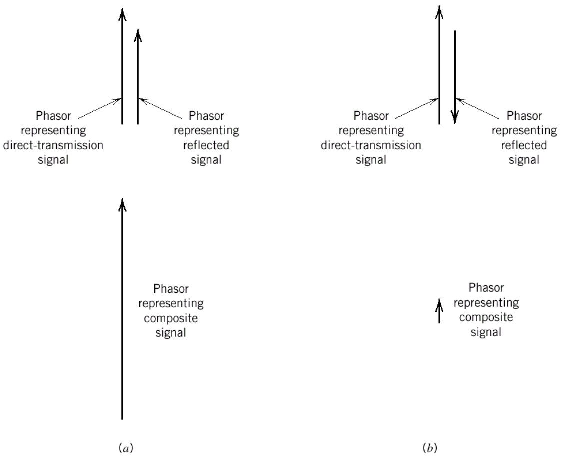
(*a*) Constructive

(*b*) destructive forms of the multipath phenomenon for sinusoidal signals



(*a*) (*b*)

PROPAGATION EFFECTS



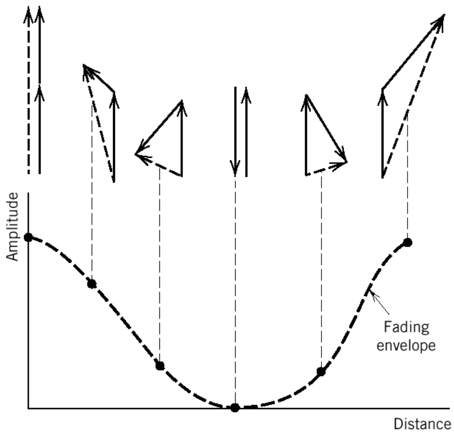
Phasor representations of

(*a*) constructive

(*b*) destructive forms of multipath.

17

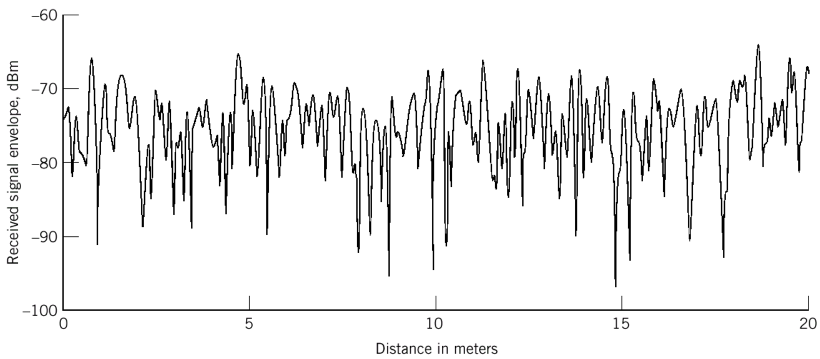
PROPAGATION EFFECTS



Illustrating how the envelope fades as two incoming signals combine with different phases.

18

PROPAGATION EFFECTS



Experimental record of received signal envelope in an urban area.

19

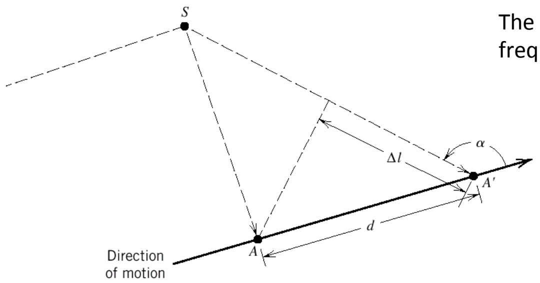
Doppler Shift

the incremental change in the path length of the radio wave is

$$\Delta l = d \cos\alpha$$
$$= -\nu\,\Delta t \cos\alpha$$

the change in the phase angle of the received signal

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta l$$
$$= -\frac{2\pi\nu\,\Delta t}{\lambda}\cos\alpha$$



The apparent change in frequency, or the *Doppler-shift*

$$\nu = -\frac{1}{2\pi}\frac{\Delta\phi}{\Delta t}$$
$$= \frac{\nu}{\lambda}\cos\alpha$$

20

Binary Signaling over a Rayleigh Fading Channel

The (low-pass) complex envelope of the received signal is modeled as follows:

$$\tilde{x}(t) = \alpha \exp(-j\phi)\tilde{s}(t) + \tilde{w}(t)$$

α is a Rayleigh distributed random variable describing the attenuation in transmission, Φ is a uniformly distributed random variable describing the phase-shift in transmission

The received SNR $\gamma = \frac{\alpha^2 E_b}{N_0}$

For BPSK $P_e(\gamma) = \frac{1}{2}\,\mathrm{erfc}(\sqrt{\gamma})$

The average P_e will be

$$P_e = \int_0^\infty P_e(\gamma) f(\gamma)\, d\gamma$$

Where γ is chi-square distributed

$$f(\gamma) = \frac{1}{\gamma_0}\exp\left(-\frac{\gamma}{\gamma_0}\right), \qquad \gamma \geq 0$$

21

Binary Signaling over a Rayleigh Fading Channel

the *mean value of the received signal energy per bit-to-noise spectral density ratio*

$$\begin{aligned}\gamma_0 &= E[\gamma] \\ &= \frac{E_b}{N_0} E[\alpha^2]\end{aligned}$$

carrying out the integration, we get the final result

$$P_e = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_0}{1 + \gamma_0}}\right)$$

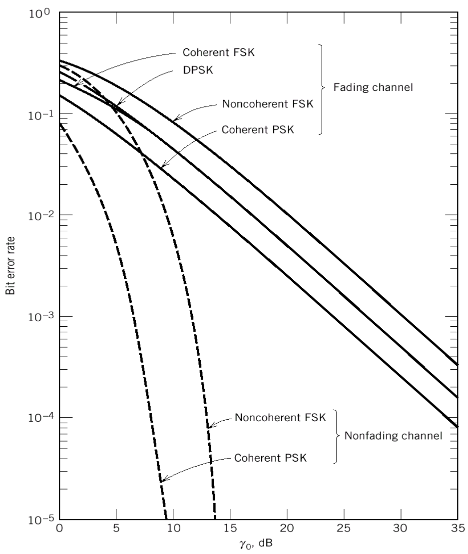
22

TABLE 8.2 ***Bit error rates for binary signaling over a flat-flat Rayleigh fading channel***

Type of Signaling	*Exact Formula for the Bit Error Rate* P_e	*Approximate Formula for the Bit Error Rate, Assuming Large* γ_0
Coherent binary PSK	$\frac{1}{2}\left(1 - \sqrt{\frac{\gamma_0}{1 + \gamma_0}}\right)$	$\frac{1}{4\gamma_0}$
Coherent binary FSK	$\frac{1}{2}\left(1 - \sqrt{\frac{\gamma_0}{2 + \gamma_0}}\right)$	$\frac{1}{2\gamma_0}$
Binary DPSK	$\frac{1}{2(1 + \gamma_0)}$	$\frac{1}{2\gamma_0}$
Noncoherent binary FSK	$\frac{1}{2 + \gamma_0}$	$\frac{1}{\gamma_0}$

23

Binary Signaling over a Rayleigh Fading Channel

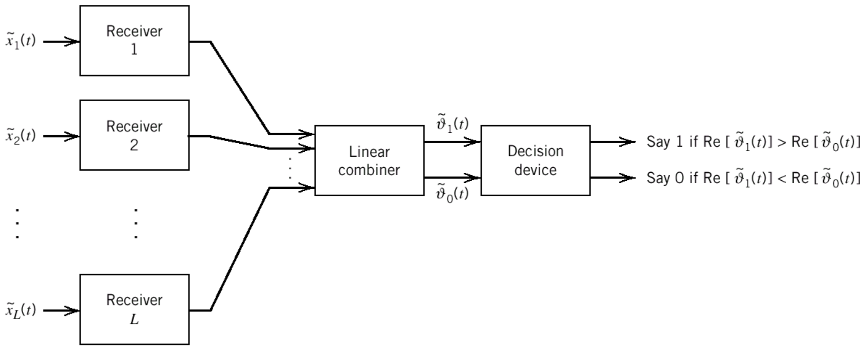


Performance of binary signaling schemes over a Rayleigh fading channel, shown as continuous curves; the dashed curves pertain to a nonfading channel

24

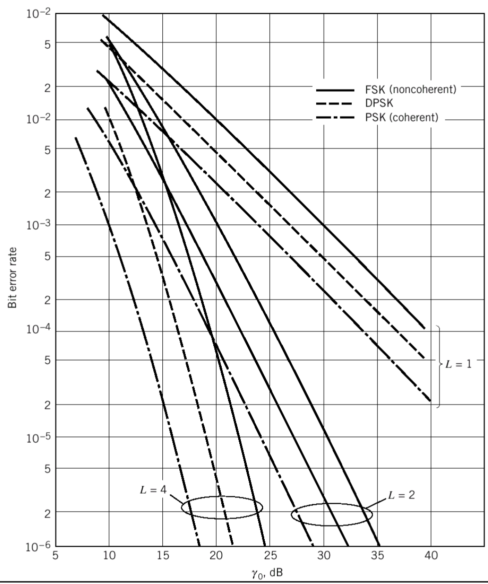
DIVERSITY TECHNIQUES

- Frequency diversity
- Time (signal-repetition) diversity
- Space diversity



25

DIVERSITY TECHNIQUES



Performance of binary signaling schemes with diversity.

26

Practice Problems

- Proakis 4.50, 4.63, 4.64, 4.65
- Haykin 8.1, 8.4, 8.5, 8.6, 8.10, 8.11

27