Errata

Introduction to Wireless Systems

P. Mohana Shankar

• Page numbers are shown in blue
• Corrections are shown in red

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The power detected by a typical receiver is shown in Figure 2.5.

\[ P_r (d) = P_r (d_{ref}) \left( \frac{d_{ref}}{d} \right)^2, \quad d > d_{ref}, \quad (2.4) \]

Expressing the frequency in MHz, eqn. (2.6) can now be expressed as

\[ L_{free} = 32.44 + 20 \log_{10} (f) + 20 \log_{10} (d), \quad (2.7) \]

where \( d \) must be larger than 1 km. The unit of \( f \) is in MHz and \( d \) is in kilometers.

to account for the terrain. Additional correction factors can be included to account for other factors such as street orientation. These correction factors take into account the following:
Figure 2.7  Transmitted power = 100 mW instead of 100 dBm

Example 2.3
Find approximate values of the loss parameter, \( v \), using Hata model for the four geographical regions, namely large city, small-medium city, suburb, and rural area.

Answer:
Using Figure 2.12, the loss values at a distance of 3 km are 131.36 dB, 131.34 dB, 121.40 dB, and 102.8 dB, respectively, for large city, small-medium city, suburb, and rural area.

Sentence below eqn. (2.40) ………where \( p_0 \) is the average power

Eqn. (2.40) \( p_{out} = 1 - \exp \left( -\frac{P_{thr}}{p_0} \right) \)

2.3.3 Frequency-dispersive Behavior of the Channel

2.3.5 Frequency dispersion vs Time dispersion
We have seen that fading can be in the frequency domain or in the time domain. It is possible to treat the fading in wireless communications systems as constituted by independent effects. The channel shows time dispersive behavior when multipath phenomena are present. At the same time, independent of this effect, the channel will also exhibit frequency dispersion if the mobile unit is moving.
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Figure 2.31

The diagram illustrates the classification of signal dispersion and time selectivity based on two parameters: signal bandwidth $B_c$ and bit duration $T_c$. The plane is divided into regions based on these parameters:

- **Fast and Frequency Selective**
- **Fast and Flat**
- **Slow and Frequency Selective**
- **Slow and Flat**

The areas correspond to different types of signal behavior:

- **Time dispersive/frequency selective**
- **Time selective/frequency dispersive**
Rayleigh Fading (no **Direct Path**)

Rician Fading (contains a **Direct Path**)

![Diagram of transmission paths with labels for Transmitter and Receiver.](image-url)
Figure 2.33
Page 41
First sentence on top of the page The Rician probability density function is shown in Figure 2.33 for different values of the parameter K.

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Eqn. 2.66

\[
f(p_{dB}) = \frac{1}{\sqrt{2\pi}\sigma^2_{dB}} \exp\left[-\frac{(p_{dB} - p_{av})^2}{2\sigma^2_{dB}}\right]
\]

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2.4.5 Summary of Fading
The various fading mechanisms and the attenuation described can be summarized in a diagram shown in Fig. 2.38. Note that Rician and Rayleigh arise out of multipath effects and Nakagami can represent them both. This is not shown in the figure. For most of the cases, analyses based on Rayleigh or Rician fading are sufficient to understand the nature of the mobile channel. A number of recent publications (Alhu 1985, Anna 1998, 1999) have suggested the use of Nakagami fading models to provide a generalized view of fading in wireless systems.

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Exercise 2.1 Using MATLAB, generate plots similar to the ones shown in Figure 2.7 to demonstrate the path loss as a function of the loss parameter for distances ranging from 2 Km to 40 Km. Calculate the excess loss (for values of \( \nu > 2.0 \)) in dB.
Exercise 2.17 Compare the maximum data transmission capabilities of the two channels characterized by the impulse responses shown below.

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Exercise 2.18. Generate a plot similar to the lognormal fading shown in Figure 2.36.
Figure 3.18

The diagram illustrates the power spectrum $P(f)$ and the magnitude squared $|M(f)|^2$ for a signal with frequencies $f_0 - R$, $f_0$, and $f_0 + R$. The frequency axis is marked from 0 to $2R$. The peaks at $f_0 - R$ and $f_0 + R$ correspond to the sidebands of the signal.
The output noise, \( n(T) \), has a spectral density, \( G_{out}(f) \), given by (See Appendix A.6)

\[
H(f) = K M^*_f \exp(-j2\pi f T) \quad \text{(3.51)}
\]

The probability of error can be expressed (Taub 1986) as (Exercise 3.21)

\[
p(e) = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{E}{2N_0}} \right) \quad \text{(3.79)}
\]

The plot of error probability for different values of \( E/N_0 \) (signal-to-noise ratio) is shown in Figure 3.28. Comparing eqn. (3.83) with the bit error rate for ASK systems (eqn. (3.79)), it is seen that the performance of a coherent BPSK is 3dB better than that of coherent ASK.

Table 3.2 DPSK encoding: \( d_k = b_k \oplus d_{k-1} \)
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In Figure 3.32, use $x_k$ and $y_k$ in place of $X_k$ and $Y_k$.

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<table>
<thead>
<tr>
<th>Data</th>
<th>$\phi_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1</td>
<td>$\pi/4$</td>
</tr>
<tr>
<td>-1 1</td>
<td>$3\pi/4$</td>
</tr>
<tr>
<td>-1 -1</td>
<td>$-3\pi/4$ (or $5\pi/4$)</td>
</tr>
<tr>
<td>1 -1</td>
<td>$-\pi/4$ (or $7\pi/4$)</td>
</tr>
</tbody>
</table>

Table 3.4   Phase encoding in QPSK
In Figure 3.35a, the line at 2 should be broken as shown.
In the Figure the line at 1 should be broken as shown.
Figure 3.43

$\pi/4$ QPSK Phase Constellation
As the number of levels of modulation increases, the minimum power required to maintain a fixed bit error rate decreases. This can be seen from the decision boundaries shown in Figure 3.71.

\[ T_s = \left\lfloor \log_2 M \right\rfloor T \]  (3.139)

Detection and Reception of MSK and GMSK. Since MSK can be generated starting from OQPSK, the bit error performance of MSK will be identical to that of BPSK, QPSK or OQPSK. However, MSK and GMSK can also be detected using a 1-bit differential detector, 2-bit differential detector or a frequency discriminator. The block diagrams of these receiver structures are shown respectively in Figure 3.69 a, 3.69 b, and 3.69 c.
\[ C = B \log_2 \left[ 1 + \left( \frac{E}{N_0} \right) \left( \frac{R}{B} \right) \right] \text{ bits / s} \]  

(3.145)

\[
\frac{R}{B} = \log_2 \left[ 1 + \left( \frac{E}{N_0} \right) \left( \frac{R}{B} \right) \right]
\]  

(3.146)
Figure 4.5 Frequency reuse pattern of cells. The alphabets (except D) represent the different channels. D is the distance between cells having the same frequency.

\[ D = D_R \sqrt{3}R = \sqrt{1+4+2\sqrt{3}}R = \sqrt{21}R \]

TABLE 4.2

<table>
<thead>
<tr>
<th>i</th>
<th>j</th>
<th>( N_c )</th>
<th>q</th>
<th>S/I(dB)</th>
</tr>
</thead>
</table>

Because of this, \( q = D/R = \sqrt{3N_c} \) is also known as the frequency reuse factor.

Figure 4.6 Expanded view of the cell structure showing a seven cell reuse pattern. H is the channel reused.

Figure 4.7 A three-cell pattern \( (N_c = 3) \) showing six interfering cells

\[
\left( q = \frac{D}{R} = \sqrt{3N_c} = 3 \right)
\]
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\[ p(\gamma) = \frac{1}{\gamma_0} \exp\left(-\frac{\gamma}{\gamma_0}\right), \gamma \geq 0 \quad (5.5) \]

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5.2.2 Effects of Frequency Selective Fading, Co-Channel Interference

As discussed in Chapter 2, frequency selective fading arises when the coherent bandwidth of the channel is less than the message bandwidth. The error rates vary with the form of modulation and demodulation used. The performances of the modems also depend on the ratio of \((\sigma_d/T)\), where \(\sigma_d\) is the r.m.s delay spread (eqn. 2.42) and \(T\) is the symbol period. The exact equations governing the error probability, taking frequency selective fading into account, are once again very complex, and are beyond the scope of this book. Numerical results are available in a number of research papers (Fung 1986, Guo 1990, Liu 1991a,b).

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Figure 5.5

The legends should read dB instead of db.

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\[ f(\gamma) = \frac{2^{M-1}M^M \gamma^{M-1}}{(2M-1)!} \gamma_0^M \quad (5.34) \]

The performances of the three signal processing schemes are shown in Figure 5.17, with \(\gamma_{av}\) equal to the signal-to-noise ratio after combining. They are also given in tabular form in Table 5.1.

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\[ H_c(f) = A(f) \exp\left[j \theta(f)\right] \quad \text{Eqn. 5.47} \]
The PN sequence is unique to each user and is almost orthogonal to the sequences of other users. Thus, the interference from other users in the same band will be much less. The number of orthogonal codes, however, is limited. As the number of users increase, the codes become less and less orthogonal and more and more correlated (orthogonality is compromised) and the interference will increase.

Example 6.1 In a DS-CDMA cell, there are 24 equal power channels that share a common frequency band. The signal is being transmitted on a BPSK format. The data rate is 9600 bps. A coherent receiver is used for recovering the data. Assuming the receiver noise to be negligible, calculate the chip rate to maintain a bit error rate of 1e-3.

Answer:

Assuming that there is no thermal noise, the bit error rate is given by eqn. (6.15) where $K$ is the processing gain and $k$ is the number of channels. \[
BER = 10^{-3} = 0.5 \text{erfc}(\sqrt{z})
\]

where $Z = \frac{K}{k-1}$ Using the MATLAB function \text{erfinv}(.), we can solve for $z = [\text{erfinv}(1 - 2 \cdot BER)]^2$

We get $z = 4.77$. We are given $k=24; K=23\times4.77=109.82$. Since $K = \frac{\text{chip rate}}{\text{data rate}}$

chip rate = 109.82\times9600=1.05$\text{Mchip/s}$. 
The radio capacity of the system, $m$, is defined as

$$m = \frac{\text{total allocated spectrum}(B_t)}{\text{channel bandwidth}(B_c) \times \text{number of cells}(N_c)} \text{ radio channels/cell.} \quad (6.21)$$

Making use of the relationship between $q$ and $N_c$ (Chapter 4),

$$q = \sqrt{3N_c}. \quad (6.22)$$
Let us start by considering a single cell with \( N (= k \text{ of eqn (6.11)}) \) users who share the cell.

\[
\frac{E}{N_0} = \frac{S}{R} \frac{(N-1)}{B_c} = \frac{B_c}{R} \frac{1}{(N-1)}
\]

(6.27)

where \( R \) is the information bit rate and \( B_c \) is the RF bandwidth. We have divided the signal power \( (S) \) in the numerator by the bandwidth \( (\text{data rate } R) \) of the message data, while the signal power in the numerator has been divided by the bandwidth \( (B_c) \) occupied by the interfering signal. (See Section 3.2.7) The quantity \( (B_c / R) \) is the processing gain \( K \) of the CDMA processing, defined in connection with Figure 6.7.

\[
\eta_0 = B_c N_0
\]

(6.29)

\[
\left( \frac{E}{N_0} \right)_{\min} = K \left( N_{\max} - 1 + \frac{B_c N_0}{S} \right)^{-1}
\]

\[
N_{\max} = 1 + K \left[ \frac{\left( \frac{E}{N_0} \right)_s - \left( \frac{E}{N_0} \right)_{\min}}{\left( \frac{E}{N_0} \right)_{\min} \left( \frac{E}{N_0} \right)_s} \right]
\]

(6.33)
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\[ g(t) = \sum_{n=-\infty}^{\infty} a_n \exp(jn2\pi f_0 t) \quad (A.1.7) \]

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Normal or Gaussian distribution

\[ f(x) = \frac{1}{\sqrt{2\pi}\sigma_x^2} \exp\left[-\frac{(x-\mu)^2}{2\sigma_x^2}\right], \quad -\infty \leq x \leq \infty \]

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where \( \Gamma \) is the gamma function

\[ \Gamma(z) = \int_{0}^{\infty} w^{z-1} e^{-w} dw \]