DIGITAL SIGNALING ON FLAT FADING CHANNELS

The performance of a digital modulation scheme is degraded by many transmission impairments including fading, delay spread, Doppler spread, co-channel and adjacent channel interference, and noise. Fading causes a very low instantaneous received signal-to-noise ratio (SNR) or carrier-to-noise ratio (CNR) when the channel exhibits a deep fade, delay spread causes intersymbol interference (ISI) between the transmitted symbols, and a large Doppler spread is indicative of rapid channel variation and necessitates a receiver with a fast convergent algorithm. Co-channel interference, adjacent channel interference, and noise, are all additive distortions that degrade the bit error rate performance by reducing the CNR or SNR.

This chapter derives the bit error rate performance of digital signaling on frequency non-selective (flat) fading channels with AWGN. Flat fading channel models are appropriate for narrow-band land mobile radio systems or mobile satellite systems. Flat fading channels affect all frequency components of a narrow-band signal in exactly the same way and, therefore, do not introduce amplitude or phase distortion into the received signal. Frequency selective channels distort the transmitted signal and will be the subject of Chapter 6. Flat fading channel will be shown to significantly degrade the bit error rate performance unless appropriate countermeasures are taken. Diversity and coding techniques are well known methods for combating fading. The basic idea of diversity systems is to provide the receiver with multiple replicas of the same information bearing signal, where the replicas are affected by uncorrelated fading. Coding techniques introduce a form of time diversity into the transmitted signal which can be exploited to mitigate the effects of fading.
The remainder of this chapter is organized as follows. Section 5.1 introduces a vector representation for digital signaling on flat fading channels with additive white Gaussian noise (AWGN). Section 5.2 derives the structure of the optimum coherent receiver for the detection of known signals in AWGN. It will be shown that the optimum coherent receiver generally requires knowledge of the complex fading gain (amplitude and phase), although for some types of modulated signals such as PSK only the phase is required. Section 5.3 evaluates the performance of the various digital signaling techniques that were introduced in Chapter 4 on flat fading channels. Section 5.4 considers a simplified receiver structure for PSK and π/4-QPSK signaling that uses differential detection. A differential detector is a suboptimum receiver that detects phase changes between successive signaling intervals. Section 5.5 discusses various types of diversity and diversity combining techniques that can be used to combat the effects of fading. Finally, Section 5.5.7 introduces the concept of macroscopic diversity that is useful for mitigating the effects of shadow variations.

5.1 VECTOR REPRESENTATION OF RECEIVED SIGNALS

Suppose that one of the $M$ complex low-pass signals $\{v_k(t)\}_{k=1}^M$, say $v_i(t)$, is transmitted. For a flat fading channel, the received complex envelope is

$$w(t) = g(t)v_i(t) + z(t), \quad 0 \leq t \leq T$$

(5.1)

where $g(t) = a(t)e^{i\phi(t)}$ is the complex fading gain introduced by the channel, and $z(t)$ is zero-mean complex AWGN with a power spectral density (psd) of $N_0$ watts/Hz. The basic detection problem at the receiver is to determine which message waveform $v_k(t)$ was transmitted from the observation of received signal $w(t)$.

If the channel changes very slowly with respect to the symbol duration, i.e., $f_mT \ll 1$, then $g(t)$ will effectively remain constant over the symbol duration\(^1\). Under this condition, the explicit time dependency of $g(t)$ can be removed so the received signal becomes

$$w(t) = gv_i(t) + z(t), \quad 0 \leq t \leq T$$

(5.2)

where the fading gain $g = \alpha e^{i\phi}$ is a complex Gaussian random variable. If the Gaussian random process has zero (non-zero) mean then the magnitude $\alpha$

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\(^1\)For land mobile radio applications $f_mT \ll 1$ is a reasonable assumption.