Chapter 3
Digital Modulation Techniques in MIMO Systems

The basic work related to digital communication techniques was carried out by Shannon [1]. Since then, the theory and applications of digital communication systems have been greatly advanced [2-6]. With the introduction of mobile and cellular communications, digital communication techniques have been investigated for wireless systems [7-10]. In addition, a new stream of research on and implementation of digital communication techniques has been established with the advent of multiple input multiple output (MIMO) communication systems during the last decade, [11-14].

This chapter provides an overview of different digital modulation techniques and their applications in single input single output (SISO) and MIMO wireless systems with an emphasis on their implementation techniques. The fundamentals of digital modulation techniques are presented. Then, the analysis and the modeling of the various modulation schemes both in single carrier, multicarrier and orthogonal frequency-division multiplexing (OFDM) systems are described. The last section of the chapter is devoted to the accuracy metrics of digital modulation implementation.

3.1 Criteria to Design Digital Modulators

The design of any digital communication system is initiated with a description of the channel (received power, available bandwidth, attenuation, noise statistics, and other impairments such as fading) and a definition of the system requirements (data rate and error performance). Design choices that match the channel and meet the performance requirements then need to be determined [4], [15]. The general criteria to select a digital modulation method are spectral efficiency, bandwidth efficiency, and implementation complexity. These criteria are even more critical in wireless communications, due to spectrum limitations. In addition, the proper operation of a digital modulation scheme in a wireless channel is an important factor that must be considered.
3.1.1 Spectral Efficiency

The spectral efficiency of a digital modulator is defined as the number of bits per second that can be transmitted in one Hertz of system bandwidth. A suitable starting point to describe the spectral efficiency is the Shannon capacity theorem, which can be stated as:

$$ C = W \log_2 (1 + \frac{S}{N}) $$

where \( S/N \) is the ratio of the average received signal power to the noise power, and \( W \) is the channel bandwidth. The capacity, \( C \), is given in bit/sec. The capacity of a channel defines the maximum number of bits that can be reliably sent per second over the channel. Accordingly, the maximum spectral efficiency, \( \eta_{\text{max}} \), is defined as:

$$ \eta_{\text{max}} = \frac{C}{W} = \log_2 (1 + \frac{S}{N}) $$

Relationship (3.1) can be written as:

$$ \frac{C}{W} = \log_2 (1 + \frac{S}{N_oW}) $$

where \( N_o \) is the power spectral density of white noise.

On the other hand, for any digital communication system, the relationship between the received \( S/N \) and the received bit energy to noise-power spectral density, \( E_b/N_o \), is as follows [4],[15]:

$$ \frac{S}{N} = \frac{E_b}{N_o} r_b $$

where \( r_b \) is the data rate in bits per second.

Figure 3.1 shows the relationship between \( r_b/W \) and \( E_b/N_o \) for the case where the data (information) rate, \( r_b \), is equal to \( C \). As can be seen, a curve separates a region of practical communication systems from a region where such communication systems cannot operate reliably. In the spectral efficient region, a modulation scheme can be designed to transmit a number of bits in one hertz using a practical \( E_b/N_o \).