Preface

This book provides a summary of the research conducted at UCLA, Stanford University, and UCSD over the last five years in the area of nonlinear dynamics and chaos as applied to digital communications. At first blush, the term "chaotic communications" seems like an oxymoron; how could something as precise and deterministic as digital communications be chaotic?

But as this book will demonstrate, the application of chaos and nonlinear dynamics to communications provides many promising new directions in areas of coding, nonlinear optical communications, and ultra-wideband communications. The eleven chapters of the book summarize many of the promising new approaches that have been developed, and point the way to new research directions in this field.

Digital communications techniques have been continuously developed and refined for the past fifty years to the point where today they form the heart of a multi-hundred billion dollar per year industry employing hundreds of thousands of people on a worldwide basis. There is a continuing need for transmission and reception of digital signals at higher and higher data rates. There are a variety of physical limits that place an upper limit on these data rates, and so the question naturally arises: are there alternative communication techniques that can overcome some of these limitations?

Most digital communications today is carried out using electronic devices that are essentially "linear," and linear system theory has been used to continually refine their performance. In many cases, inherently nonlinear devices are linearized in order to achieve a certain level of linear system performance. However, as device technology reaches its fundamental limits, the natural question arises: can the intrinsic *nonlinearity* of electronic devices be exploited in some fundamental way to improve communications system performance?

One example of the type of improvement that can potentially be achieved with the judicious application of the intrinsic nonlinearity of an electronic device is the well-known use of *solitons* in fiber-optic transmission systems. The inherent nonlinearity of an optical fiber ensures that a digital pulse — a soliton — retains a constant shape over a large distance, and that the pulses do not diffuse or disperse during transmission. In this case, the nonlinearity of the fiber compensates for its dispersion, and vice versa. Solitons have many interesting and useful properties, including essentially distortionless propagation over enormous distances and "damage-free" soliton-soliton collision.

The potential advantages of operation of nonlinear devices for generation of digital communications signals include improved efficiency, lower dc power, lower probability of intercept, and lower probability of detection. These potential advantages have to be balanced against the need for efficient spectrum management, and the cost of this new technology.

Figure 0.1 shows a block diagram of a typical digital communications system. Each block in the transmission chain performs a unique function. The source encoding block takes the data provided by the information source, and codes it in an optimum way for further transmission — either by removing redundant bits, or compressing it in some other fashion. The encryption block re-codes the data in order to enhance transmission security. The channel encoding performs a variety of transformations on the input data to minimize the overall degradation due to channel impairments. Modulation impresses the encoded data onto the radio frequency carrier, which is then combined with other signals in a multiple access scheme, and finally delivered to the transmit antenna. Each block in the receiver chain performs the inverse operation to that of the transmit chain.

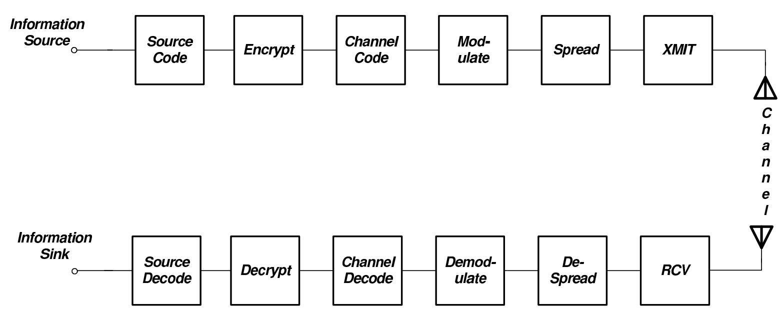

Fig. 0.1. Block diagram of modern digital communications system

The advantages of digital communications compared to traditional analog techniques can immediately be seen from this brief overview. First, the transmitted information is coded in such a way to make its reception insensitive to channel impairments, private, and free of unnecessary redundant information that would waste valuable spectrum. The data is then modulated onto a carrier in a manner that can predictably minimize the bandwidth and power requirements for a given desired data and error rate. The level of control over the security, bandwidth, and error rate that digital communications techniques allow is significantly greater than that of traditional analog techniques.

Nonlinear techniques can be applied in a straightforward manner to the encryption/decryption blocks of the system. In this manner, data can be "embedded" in a chaotic sequence, which is only known to the desired receiver – significantly enhancing security. Nonlinear techniques can also be potentially applied to channel encoding/decoding functions, where there may be some benefit to chaotic channel coding techniques for greater immunity to channel fading problems. Chaotic modulation and spreading techniques may allow for improved multiple channel access approaches and improved immunity to potential jamming and fading conditions. Chaotic modulation of digital data may be less sensitive to electronic nonlinearities in the transmit and receive portions of the device.

The spectra of chaotic signals make them very attractive for use as carriers in spread spectrum communications. Because chaotic signals are generated by deterministic dynamical systems, two coupled chaotic systems can be synchronized to produce nearly identical chaotic oscillations. This insight provides the key to the recovery of information that is modulated onto a chaotic carrier. In addition, a chaos-based communications system could also improve privacy, security, and probability of intercept, because chaotic sequences, unlike pseudorandom sequences, can be made completely nonperiodic.

Optically-based chaotic communications, which are based on the transmission of messages encoded on a chaotic waveform, have attracted very extensive research activity. Most of the systems are based on synchronization of chaos between a transmitter and a receiver, which are linked by a transmission channel. For such systems, synchronization between the transmitter and receiver is mandatory, since the bit-error rate (BER) of the decoded message at the receiver depends on the accuracy and robustness of synchronization.

Many systems based on either semiconductor lasers or fiber lasers have been proposed and studied for chaotic optical communications based on nonlinear dynamics and chaos. Chaotic optical systems that can reach the rates typically employed by traditional optical communications systems, such as the OC-48 standard bit rate of 2.5 Gb/s and the OC-192 standard bit rate of 10 GB/s, are particularly attractive. In this book, we present three of the leading semiconductor laser systems that are most actively investigated and are most promising for high-bit-rate chaotic optical communications: optical injection system, optical feedback, and the optoelectronic feedback.

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