Preface

Nonlinear effects occur in optical communication systems at the transmitter, fiber channel, and receiver. First, at the transmitter, when a Mach–Zehnder modulator is used to modulate the optical carrier by electrical data, its transfer function is not linear. Second, the nonlinear effects in fibers such as the Kerr effect and the Raman effect lead to interaction among signals propagating down the fiber. Finally, in direct-detection systems, the nonlinearity occurs in the photodetector, which is a square-law device. However, with coherent detection, the linear translation of information in optical domain into electrical domain can be achieved. This book covers the various types of nonlinear effects that occur in fiberoptic communication systems. The performance degradations caused by the nonlinear effects and how to mitigate them are also discussed in various chapters.

The first chapter, by X. Liu and M. Nazarathy, introduces the recent developments in self-coherent, differentially coherent, and coherent fiberoptic transmission systems. The benefits of advanced detection schemes and the impact of fiber nonlinearity are also discussed. The second chapter, by Qi Yang, A.A. Amin and W. Shieh, reviews the basic principles of orthogonal frequency division multiplexing (OFDM). The authors discuss the recent experimental demonstrations of coherent optical OFDM systems with bit rates ranging from 100 Gb s$^{-1}$ to 1 Tb s$^{-1}$ and with off-line as well as real-time signal processing. These two chapters provide the basis for nonlinear impairment issues discussed in later chapters. Chapter 3, by M. Nazarathy and R. Weidenfeld, addresses the impact of fiber nonlinear effects on coherent OFDM systems and discusses electrical equalizing techniques to mitigate these nonlinear impairments. The authors analyze the impact of nonlinear effects using the Volterra approach and later, based on the analytical tools, they develop effective nonlinear compensators for OFDM systems.

Coherent technologies have enabled novel spectrally efficient and power-efficient modulation formats. The spectrally efficient formats allow upgrading to higher channel data rates using the existing lower speed transmission equipments. Chapter 4, by M. Seimetz, reviews the basics of modulation schemes, and optical implementation of novel modulation schemes and their detection techniques are discussed. The author provides the details of long-haul optical transmission experiments with RZ-QPSK, RZ-8PSK, and RZ-16QAM signals.
Single-mode fiber (SMF) is actually bimodal due to the x- and y-polarization components, and an optical carrier propagating in SMF has four degrees of freedom. They are in-phase (I) and quadrature (Q) components of the x- and y-polarizations. Chapter 5, by M. Karlsson and E. Agrell, discusses the modulation formats in the four-dimensional space. The authors explain the relation between dense sphere packing and power-efficient constellations. Fundamental sensitivity limits for the four-dimensional channel and influence of fiber nonlinearities are also presented in Chap. 5.

The novel modulation/multiplexing schemes have enabled high spectral efficiencies. However, as the spectral efficiency increases, typically the system reach reduces mainly because of nonlinear effects. Chaps. 6–9 focus on the various aspects of fiber nonlinearities and performance degradation caused by them. Chapter 6, by A. Mecozzi, discusses the intrachannel nonlinearities in pseudolinear systems. The full details of the first-order perturbation theory for the calculations of intrachannel nonlinear impairments in coherent and direct-detection systems are provided in this chapter. Although the main results obtained using a perturbation theory for direct-detection systems were published earlier by the author and his collaborators, the details of the theory and its derivations were never published before in the open literature.

Fiber nonlinearity translates the amplitude fluctuations caused by amplifier noise into phase fluctuations, which leads to nonlinear phase noise. Although the digital back-propagation can undo the deterministic and bit-pattern-dependent nonlinear effects, nonlinear phase noise cannot be compensated and it sets a fundamental limit on the achievable capacity. Chapters 7 and 8 focus on the impairments due to nonlinear phase noise. Chapter 7, by S. Kumar and X. Zhu, deals with nonlinear phase noise caused by self-phase modulation in single carrier and OFDM systems. Chapter 8, by K.-P. Ho, discusses the nonlinear phase noise due to cross-phase modulation (XPM) in quadrature-shift keying (QPSK) and differential QPSK (DQPSK) systems. The author explains the impact of penalty caused by the XPM-induced nonlinear phase noise from the adjacent on-off keying (OOK) channel for DQPSK signals.

Polarization division multiplexing (PDM), in which two sets of data are encoded onto x- and y-polarization components separately, could double the capacity of a fiberoptic transmission system in the absence of fiber nonlinearity. However, the nonlinear interaction between x- and y- polarization components leads to signal distortions and impairments. Chapter 9, by C. Xie, deals with nonlinear polarization scattering in PDM systems. Although the digital signal processing (DSP) can equalize the distortions due to polarization mode dispersion (PMD) and polarization-dependent loss (PDL), it is hard to compensate nonlinear polarization scattering as the state of polarization (SOP) changes caused by nonlinear effects are typically in the scale of a symbol period. The author also discusses the techniques to mitigate the nonlinear polarization scattering.

To assess the quality of the received signal, the Monte-Carlo simulation of the fiberoptic transmission system needs to be carried out. This simulation takes too much time because of fiber nonlinearities especially when the bit error rate (BER)
is low. Chapter 10, by A. Bononi and L.A. Rusch, deals with the multicanonical Monte-Carlo (MMC), which is a simulation-acceleration technique for the estimation of the statistical distribution of a desired system output variable. The authors present several examples from optical communication, where MMC techniques have provided accurate performance predictions.

In a fiberoptic transmission system, the noise accumulation can be suppressed by introducing optical regenerators at certain locations on the transmission line. Typically, optical regenerators suppress the amplitude noise rather than the phase noise and therefore, they cannot be used directly for phase-modulated systems. Chapter 11, by M. Matsumoto, reviews the all-optical regeneration schemes for phase-encoded signals. The author discusses various regeneration schemes for the suppression of linear and nonlinear phase noise in systems based on (D)BPSK and (D)QPSK.

Chapter 12, by I.B. Djordjevic, reviews the basics of forward error correction (FEC), coded modulation, and turbo equalization for high speed optical communication system. The details of low-density parity-check (LDPC)-coded turbo equalizer to compensate for dispersion, PMD, and fiber nonlinearities are provided in this chapter. The author also addresses the limits on channel capacity of fiberoptic systems with coded modulation schemes.

The understanding of the ultimate limits on the capacity of fiberoptic communication system is of fundamental importance. The last chapter, by A. Ellis and J. Zhao, explores the system design trade-offs to maximize the channel capacity of the nonlinear fiberoptic channel. The authors discuss various techniques that promise to allow the capacity limits to be extended.

I thank the authors for all the trouble they have taken to make their work accessible to a wide readership.

Hamilton, Canada
February 2011
Impact of Nonlinearities on Fiber Optic Communications
Kumar, S. (Ed.)
2011, XII, 544 p., Hardcover
ISBN: 978-1-4419-8138-7