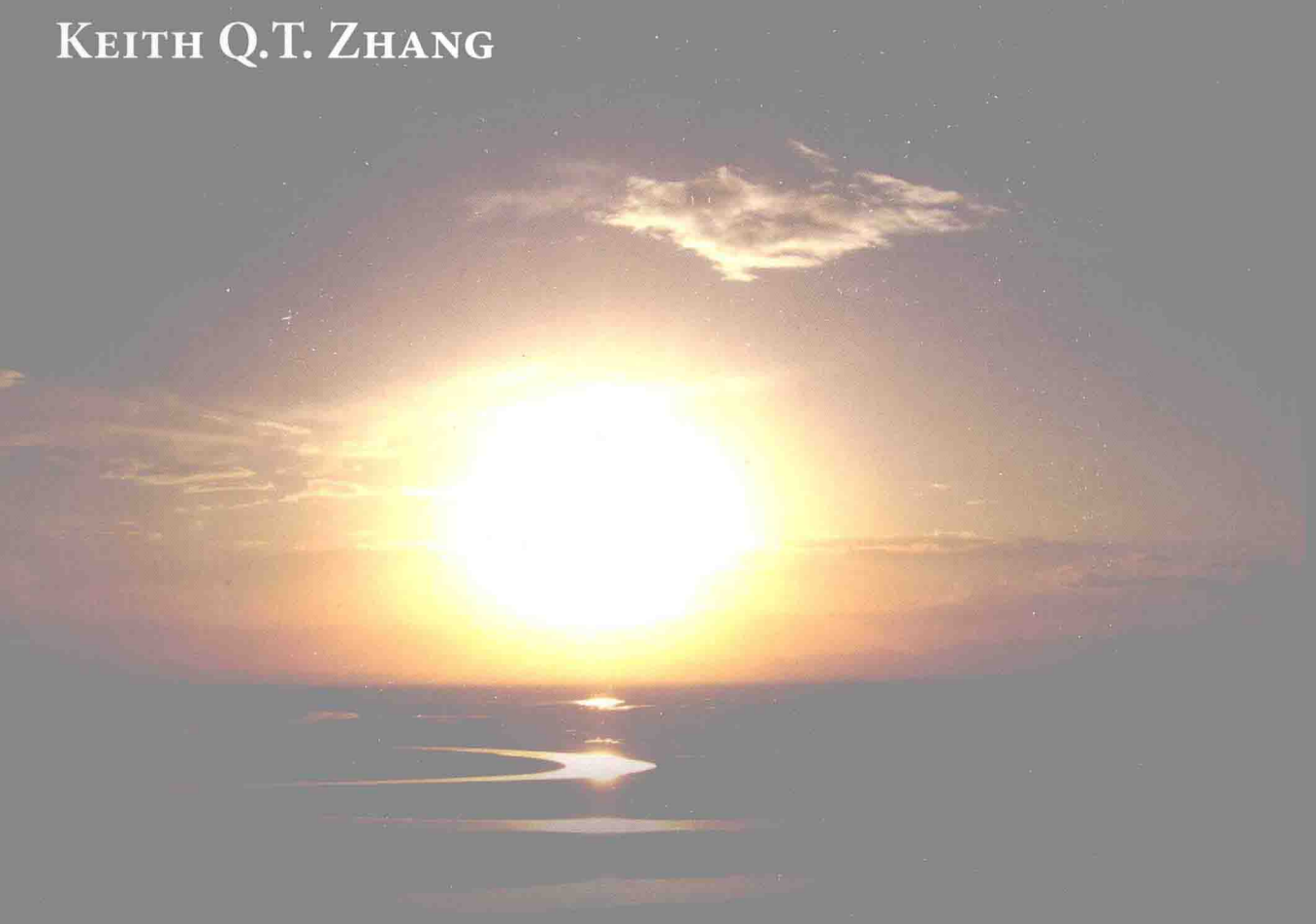
KEITH Q.T. ZHANG



WIRELESS COMMUNICATIONS

Principles, Theory and Methodology

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Wireless Communications

Principles, Theory and Methodology

KEITH Q.T. ZHANG

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Wireless Communications

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Preface

This book is intended for graduate students and senior undergraduates majoring in wireless communications, but can be also used as a reference book for practicing engineers. Human society is now in an information era, and knowledge has been explosively accumulating, especially in the last three decades. It is, therefore, impossible to embody all new developments in a single textbook. In selecting the contents of this book, we have tried to cover the most representative achievements since C.E. Shannon established his revolutionary foundation for information theory in 1948, with emphasis on the thoughts, philosophy, and methodology behind them. Indeed, the existing knowledge is undoubtedly important. It is the thoughts and methodology that help create new knowledge for the future.

The transportation of information requires energy and channel resources, the latter of which can be further subdivided into frequency resource and spatial resource. The purpose of wireless communications is to fully exploit these resources to implement satisfactory transmission of information over a wireless channel with a desired data rate and a reasonable transceiver complexity. The satisfaction is usually measured in terms of three metrics: reliability, spectral efficiency, and system complexity. The impedance to reliable and spectrally efficient transmission stems from the impairments of a physical channel, which may include additive white Gaussian noise (AWGN), interference, and multipath propagation.

Wireless communication is a legend. In early 1980s, people talked about data rates of 9.6 kbps on telephone lines, but today cellular phones are everywhere with data rates exceeding 100 Mbps on wireless channels. Wireless communication evolves from generation to generation by developing various key technologies, strategies, and principles to handle challenges arising therein.

The first strategy is related to coding and turbo principle. As revealed by Shannon, channel coding is an effective means to implement reliable communications in AWGN. Digital modulation provides a basic data rate for communications. It converts the problem of analog waveform reception to the one of discrete statistical decision, thereby significantly increasing the transmission reliability. However, digital modulation, when used alone, leaves a big gap from the maximum possible rate that can be offered by a physical channel. This gap can be shortened by error-correction encoding. It is, thus, fair to say that without coding there is no modern communications. Through coding, certain algebraic structures are embedded into an information-bearing sequence. Once embedded, such code structures belong not only to the coder/decoder subsystem but also to the entire communications link. Thus, symbol estimation at the receiver end is, in essence, a global optimization problem. Global decoding, though optimal, is computationally prohibitive in practice. A much less complex strategy moving along this way is the *turbo principle*. By combining code structures with other functional blocks of communications for joint processing in an iterative manner, the turbo principle represents a great leap toward the globally optimized symbol estimation. The consequence is a significant improvement in reliability and spectral efficiency.

The second principle is the orthogonality strategy used in interference management. Traditional channel equalization represents a defensive strategy for combating inter-symbol interference (ISI), aiming to minimize the influence of ISI under certain criteria, the details of which are addressed in Chapter 9. In its nature, ISI has a similar generating mechanism as multi-user interference (MUI). The only difference is that the former results from a set of sequentially transmitted symbols that compete for the use of a temporally dispersive channel, whereas the latter stems from sharing the same frequency band by multiple users. Thus, a proactive strategy is to remove the source that generates interference by assigning an orthogonal or approximately

orthogonal subspace to each symbol or each user to avoid their mutual collision. This orthogonality principle is a widely used paradigm in modern wireless communications. The application of this paradigm to a temporally dispersive ISI channel of Toeplitz structure leads to the multi-carrier or the orthogonal frequency division multiplexing (OFDM) technique, as detailed in Chapter 10. Using this orthogonality paradigm to multiple-access channels, the resulting schemes are code division multiple access (CDMA), time division multiple access (TDMA), and OFDMA, which are treated in Chapter 12. The orthogonality principle is also successfully applied to adjacent-interference management in cellular systems.

The third principle is multiple strategies for exploiting spatial electromagnetic resources. Mobile communication is characterized by multipath propagation, a phenomenon that causes a significant drop in the system error performance. Therefore, multipath fading is historically treated as a harmful effect, as clearly indicated in the phrase "combating multipath fading." However, random scattering and random motion that create multipath propagation constitute a two-dimensional random field. Such a random field embodies an abnormal channel capacity, representing a spatially distributive resource for wireless communications. Powerful techniques to exploit such a spatial resource include diversity combining, multi-input multi-output (MIMO) antenna systems, and cooperative relay communications, which are addressed in Chapter 7, Chapter 13, and Chapter 14, respectively.

Apart from the aforementioned principles, energy allocation between modulation/coding, over different frequencies, and along spatial beamformers to approach the channel capacity is also very important. The discussion of this issue is scattered over different chapters. Fully understanding the above principles represents a grasp of thoughts behind modern wireless communications, at least at a philosophical level. This is one effort made in this book.

In addition to providing the reader with an overall picture of wireless communications, we also carefully expound its technical details, not only covering a variety of main results and conclusions but also revealing the methodology used for their derivations. The solution to a communication problem is often not unique, but rather allows different formulations. This flexibility is demonstrated in this book, wherever possible, to provide a platform for students to foster their ability of divergent thinking.

Many problems at the end of each chapter are adapted from IEEE Transactions papers, aiming to give students a smooth transition from the course study to frontier research. As an aid to the teacher of the course, a solution manual for all the problems in the book is available from the publisher. The book covers enough topics and materials for two one-semester courses. For example, Chapters 3–7 and Chapter 9 can be used for a course on wireless communications, while Chapter 8 and Chapters 10–15 can be used for a course on advanced topics in wireless communications.

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