MULTIUSER DETECTION

*Multiuser Detection* provides the first comprehensive treatment of the subject of multiuser digital communications. Multiuser detection deals with demodulation of the mutually interfering digital streams of information that occur in areas such as wireless communications, high-speed data transmission, satellite communication, digital television, and magnetic recording. The development of multiuser detection techniques is one of the most important recent advances in communications technology, and this self-contained book gives a comprehensive coverage of the design and analysis of receivers for multiaccess channels, while focusing on fundamental models and algorithms.

The author begins with a review of multiaccess communications, dealing in particular with code-division multiple-access (CDMA) channels. Background material on hypothesis testing and the effect of multiuser interference on single-user receivers are discussed next. This is followed by the design and analysis of optimum and linear multiuser detectors. Also covered in detail are topics such as decision-driven multiuser detection and noncoherent multiuser detection.

The elements of multiuser detection are clearly and systematically presented along with more advanced recent results, some of which are published here for the first time. The extensive set of references and bibliographical notes offer a comprehensive account of the state of the art in the subject.

The only prerequisites assumed are undergraduate-level probability, linear algebra, and introductory digital communications. The book contains over 300 exercises and is a suitable textbook for electrical engineering students. It is also an ideal self-study guide for practicing engineers, as well as a valuable reference volume for researchers in communications and signal processing.

Sergio Verdú is Professor of Electrical Engineering at Princeton University. His contributions to the technology of multiuser detection span his pioneering work in the early 1980s to recent results included in this text. Professor Verdú is also well known for his work on information theory, in which he explores the fundamental limits of data transmission and compression systems. Recipient of a number of awards, he is a Fellow of the IEEE and served as President of the IEEE Information Theory Society in 1997.
MULTIUSER DETECTION

SERGIO VERDÚ
To Mercedes and Ariana
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PREFACE

He that will not apply new remedies
must expect new evils:
for time is the greatest innovator.

Francis Bacon (1561–1626)

Research and development of digital communications systems is undergoing a revolution fueled by rapid advances in technology. With the ever-growing sophistication of signal processing and computation, advances in communication theory have an increasing potential to bridge the gap between practically feasible channel utilization and the fundamental information theoretic limits on channel capacity. If conquering channel capacity is the manifest destiny of communications technology, the need for efficient use of channel bandwidth and transmission power is felt most acutely in wireless communication, where the exponentially growing demand for data rate must be accommodated in a finite segment of the radio spectrum. To add to the challenge, information is transmitted not by a single source but by several uncoordinated, bursty, and geographically separated sources.

Multiuser Detection deals with the demodulation of mutually interfering digital streams of information. Cellular telephony, satellite communication, high-speed data transmission lines, digital radio/television broadcasting, fixed wireless local loops, and multitrack magnetic recording are some of the communication systems subject to multiaccess interference. The superposition of transmitted signals may originate from nonideal characteristics of the transmission medium, or it may be an integral part of the multiplexing method as in the case of Code-Division Multiple-Access (CDMA). Multiuser detection (also known as cochannel interference suppression, multiuser demodulation, interference cancellation, etc.) exploits the considerable structure of the multiuser interference in order to increase the efficiency with which channel resources are employed.
PREFACE

Although isolated generalizations of digital communication models to multi-input multi-output channels had taken place as early as the 1960s, it was not until the mid 1980s that multiuser detection started developing as a cohesive body of analytical results that took into account the specific features of multiuser channels. Since then, the number of researchers working within this discipline has rapidly multiplied, to the point where it is now one of the most active and vibrant branches of digital communications. The extensive set of references collected in this book, although not pretending to be comprehensive in any way, gives evidence of the level of activity in multiuser detection in the past few years. The bibliographical notes at the end of each chapter provide an account of the development of the main results as well as a snapshot of the current state of the art. I can only hope that that part of the book will become quickly obsolete in view of the speed at which the field is currently evolving.

While aiming for a fairly comprehensive coverage of the design and analysis of receivers for multiaccess channels, my goal has been to distill the elements of multiuser detection in the simplest setting that brings out the key concepts. A fertile ground for geometrical intuition, the linearly modulated synchronous multiuser channel proves to be a garden of Euclidean delights. Borrowing from the tradition in multiuser information theory, most of the main ideas are first introduced in the two-user channel, which emerges as a powerful pedagogical tool.

Chapter 1 gives a brief introduction to the main approaches in multiaccess communications. Chapter 2 introduces the basic channel models used throughout the book. The main paradigm is the Code-Division Multiple-Access channel, in which each user modulates its own signature waveform. This channel is general enough to encompass orthogonal and non-orthogonal multiplexing methods, with or without spread-spectrum signaling. Chapter 3 covers background material on hypothesis testing and single-user detection and analyzes the effects of multiaccess interference on the single-user receiver. Chapter 4 is devoted to the design and analysis of optimum multiuser detectors. Linear signal processing for multiuser detection is studied in Chapters 5 and 6, with and without the constraint of complete multiuser interference suppression, respectively. Adaptive linear multiuser detection is covered in Chapter 6. Chapter 7 deals with nonlinear multiuser detectors that use decisions on the interfering digital streams to mitigate their effect.

Whether it is used as a textbook, self-study tool, or research reference, the set of over 300 problems comprises an essential component of this book. They range from simple drill exercises to research results that complement
PREFACE

the theory expounded in the text. I hope the reader will draw some sense of accomplishment from solving them.

No prerequisites are assumed beyond undergraduate-level probability, linear algebra, and an introductory course on communications. At Princeton, I have used this text to teach a one-semester course on Multiuser Detection to first- and second-year graduate students with diverse backgrounds. Although previous or concurrent exposure to a conventional detection and estimation course may be beneficial, Chapter 3 gives a self-contained presentation of the required material. A typical “single-user” digital communications course covering the fundamentals of equalization is not required either. In fact, it is my contention that (synchronous) multiaccess channels provide an easier setting for learning many of the fundamentals of equalization in digital communications than the conventional single-user intersymbol interference channel.

The text contains substantial material that can be tailored to serve as the core of various master’s and doctoral courses on multiuser communication. In addition, the book can be used as a self-study guide for practicing engineers and as a reference volume for academic and industrial researchers in communications and signal processing.

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http://www.cam.org/59/0521593735.html