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信息与通信技术教程

英文版

SIGNAL PROCESSING ADVANCES IN WIRELESS AND MOBILE COMMUNICATIONS

VOLUME 2: TRENDS IN SINGLE-AND MULTI-USER SYSTEMS

无线与移动通信中的信号处理新技术

第2册：单用户与多用户系统

GEORGIOS B.GIANNAKIS YINGBO HUA PETRE STOICA LANG TONG

编 著

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内容提要

《无线与移动通信中的信号处理新技术》丛书，介绍了近年来无线与移动通信中使用的信号处理（SP）工具的最新的重要进展，以及世界范围内该领域的领先者的贡献。本书是两本书中的第2册。本丛书的内容涵盖了范围广泛的技术和方法论，包括噪声与干扰消除、调制解调器设计、移动互联网业务、下一代音频/视频广播、蜂窝移动电话和无线多媒体网络等。

本书（第2册）重点阐述单用户与多用户通信系统。本书内容包括下列专题的最新成果：

- 单个或多个传感器阵列的盲同步
- 空—时收发分集合并系统
- 时变信道的建模
- 恒模约束的信号分离
- 并行因子分析工具
- CDMA 与多载波系统物理层中的多用户干扰删除及多径影响减轻的新方法
- 网络层的关键信号处理技术

本书介绍了在世界范围内各种期刊中的研究成果，为通信工程师、研究人员、管理人员、通信系统设计人员和参与最新通信系统设计或构造的同行全面汇集了用于优化单用户点对点链路的先进信号处理技术。

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PREFACE

The wireless revolution has brought unprecedented excitement into the field of signal processing. On the one hand, communicating over wireless channels presents formidable challenges to signal processing; the wireless channel introduces time-varying interference of various types: interference from multipath propagation, interference from other users and interference from other services. In order to provide reliable communications over a spectrum of limited bandwidth and under strict power constraints, sophisticated signal processing techniques are necessary to cope with various issues ranging from efficient source and channel coding to modulation and receiver designs. On the other hand, communication signals and systems are man-made, and there are ample structures that can be exploited for high performance algorithms. Finally, the advent of low cost and low power DSP makes implementation of highly advanced signal processing algorithms a reality.

This volume includes samples of some of the most exciting applications of signal processing to wireless communications. The underlying theme of these articles is the emphasis on signal processing perspectives of key issues in wireless communications. The 10 chapters offer tutorials on several trends and recent activities in signal processing for communications.

Channel Modeling One of the most challenging aspects of wireless system is the time-varying nature of the wireless channel. Without careful characterization and modeling of wireless channels, reliable transmissions would not be possible. Chapter 1 focuses on the general models of wireless channels, limitations of communication over these channels and performance bounds of channel estimation and prediction. Barbarossa and Scaglione present a systematic overview of various models, both deterministic and random, that often serve as the starting point of signal processing techniques for channel and signal estimation. While the literature on channel modeling is extensive, this chapter offers a fresh signal processing perspective. The emphasis of channel eigenfunction lends itself nicely into estimation and coding strategies for time varying channels. To that end, the authors address some of the important questions about the maximum transmission rate and the appropriate transceiver design criteria. Because knowledge of the channel plays such an important role in the adaptive receiver design for wireless systems, performance bounds for channel estimation and prediction are derived.

Space-Time Diversity A key to reliable communications over wireless channels is the exploitation of diversity—diversity introduced by coding, by the use of transmitting and receiving antennae and by the design of signal waveforms. In Chapter 2, Ganesan and Stoica present a signal processing framework for exploiting space-time diversity. For fading channels, the authors consider the joint optimization of transmitter and receiver coefficients as well as the allocation of transmission power under different constraints. Performance evaluation is also presented. In order to exploit both temporal and spatial diversities while maintaining a fixed data rate, the authors present a space-time coding technique that simultaneously transmits a block of symbols. One of the interesting results of their analysis is the connection between the family of Hurwitz-Radon family of matrices and the design of transmitter coefficients.

Signal Separation in a Multi-user Environment Chapters 3 and 4 deal with the problem of separating multiple signals from interference. Both chapters assume a general model with a wide range of applications including signal processing using an antenna array as discussed in Chapter 2, multi-user detection for code division multiple access (CDMA) communications and the equalization of communication channels introducing intersymbol interference (ISI). Referred to as blind signal separation, these techniques are particularly attractive for wireless communications because signal estimation is accomplished without prior knowledge of the communication channel. Two critical issues in signal separation are: (i) model identifiability that addresses the problem of whether it is possible to uniquely recover the signals of interest from the observed mixture; and (ii) estimation algorithms capable of simultaneously exploiting different forms of diversity (structure) embedded in the model.

In Chapter 3, Alle-Jan van der Veen presents a tutorial on a class of techniques that exploit the constant modulus (CM) property of communication signals for blind signal separation. In a deterministic setting, a signal has constant modulus if its magnitude is constant. It turns out that the CM property is sufficiently strong to guarantee, under certain rank conditions, unique decomposition of the received signal into the channel and the source. Compared to the stochastic formulation of the constant modulus criteria, the deterministic CM algorithms considered in this chapter, although applicable to a smaller class of signals, usually exhibit faster convergence. In this chapter, the author presents algebraic techniques for the estimation of signals with CM properties. The performance, especially in asymptotic form, of these algorithms is also analyzed.

In Chapter 4, Sidiropoulos and Bro introduce a new approach to signal separation using the so-called PARAllel FACtor (PARAFAC) analysis. Based on the theory of low-rank decompositions of multidimensional arrays, the authors present a series of identifiability results that have a direct impact on various blind signal separation problems. Also discussed are algorithms that can be used to compute PARAFAC decompositions, many of which have been used in various signal processing applications. The utility of PARAFAC is demonstrated through several applications, from sensor array processing to blind multiuser detection for CDMA, from fluorescence spectroscopy to sensor profiling. In CDMA, for example, the signal model can be decomposed naturally into a trilinear form that includes signal gain at an antenna element, the spreading code and the information symbol. For such an model, PARAFAC allows the simultaneous exploitation of spatial and code diversities.

Code Division Multiple Access As digital wireless moves toward its third generation, code division multiple access (CDMA) is becoming one of the dominant communication techniques. Because the performance of CDMA is interference limited, there has been extensive effort in developing sophisticated signal processing techniques that effectively deal with multi-user interference (MUI). The next three chapters focus on signal processing problems in CDMA systems.

Chapter 5 deals with the problem of multi-user detection for multipath interference channels. From a signal processing perspective, Tsatsanis presents a unifying framework for channel estimation and multi-user detection in CDMA communications. The author first carefully derives the corresponding multiple-input/multiple-output (MIMO) model that includes the transmitter filters implementing the direct sequence spreading, the propagation channels that may have substantial time dispersion and receiver filters providing sufficient statistics for detection. It is this model on which many recent multi-user detection techniques are based. Next, suboptimal multi-user detection schemes are presented. Here the author provides an interesting insight into the connection between multi-user detection and array processing, and shows how some of the array processing techniques find their equivalent forms in multi-user detection. Finally, the author also considers the problem of blind estimation of multipath channels.

In Chapter 6, Wang and Giannakis consider the joint transmitter and receiver design of a CDMA system in the presence of frequency-selective multipath. Based on a quasi-synchronous model, they design MUI/ISI-resistant CDMA systems by combining block-spreading with multicarrier modulation. Block-spread user codes guarantee deterministic symbol recovery regardless of the underlying (possibly unknown) multiple frequency-selective fading channels. The resulting Generalized Multicarrier (GMC) CDMA converts a multi-user system to multiple parallel single-user channels and thereby enables application of single-user algorithms for symbol recovery. They also show how fine-resolution multiple data rate transmissions can be readily incorporated and how the multirate user channels can be estimated blindly.

In Chapter 7, Lai et al. outline the class of multistage interference cancellation techniques for the direct-sequence CDMA systems. The basic idea is to estimate signals iteratively so that the interference from those users whose signals have already been detected can be minimized. There are two types of approaches: the sequential interference cancellation (SIC) detects users sequentially and subtracts signals of each detected user from the observation. As a result, detection of weaker users can be improved after strong interference has been subtracted from the observation. The parallel interference cancellation (PIC), on the other hand, estimates signals from all users at every stage. These estimates are then used as tentative decisions to improve performance at the next stage. This chapter includes analysis and simulation studies of several SIC and PIC schemes.

Random Access Networks While signal processing has played a prominent role in the physical layer design of wireless networks, there have been strong efforts in extending the application of signal processing to upper layers of wireless networks.

Chapter 8 illustrates one such effort. In random access access packet switching networks, users transmitting at the same time slot give rise to packet collisions. Traditionally, collisions are resolved by a careful design of medium access control (MAC) protocols, or by the use of modulation techniques such as CDMA. When the wireless network is ad hoc, namely, there is no base station in the network, neither MAC nor CDMA can eliminate collisions among different users. In Chapter 8, Zhao, Bao, and Tong take the view that the problem of collision resolution is one of signal separation. They present a least squares (LS) algorithm that separates colliding packets in the observation space using known symbols embedded in the colliding packets. In order to reduce the overhead associated with the least squares algorithm, they also develop a least squares smoothing (LSS) algorithm that separates colliding packets in the space of smoothing errors. It is shown that, because there is less amount of interference in the smoothing error, resolvability of the LSS is stronger than that of the LS algorithm. Network throughput and delay analyses of these signal processing techniques is also presented.

Synchronization Two chapters in this volume deal with synchronization issues. In Chapter 9, Vazquez and Riba present an estimation-theoretic treatment of carrier and timing recovery, for both linear and continuous-phase modulated signals. Within the framework of maximum likelihood estimation, they tackle the problem of estimating parameters associated with the timing offset, phase error and frequency offset. Also presented are Cramér-Rao bounds for the corresponding estimators.

Motivated by the benefits of spatial diversity, in Chapter 10 Seco, Swindlehurst and Astély investigate synchronization problems in a multi-user environment using antenna arrays. While the model used in this chapter is familiar in the context of array processing, the new twists include introduction of signal structures and joint estimation of both timing and channel parameters. Iterative techniques based on the maximization of likelihood functions are presented along with simpler initialization strategies. Performance bounds are also derived.

G. B. Giannakis, Y. Hua, P. Stoica and L. Tong
May 2000

CONTENTS

Chapter 1

TIME-VARYING FADING CHANNELS[1]

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The increasing demand of multimedia communications among mobile users is one of the main motivations for the study of time-varying channels. Examples of mobile communications include cellular communications among users located in cars, trains or airplanes, and digital broadcasting from low Earth orbit (LEO) satellites. Of course, relative motion between transmitter and receiver is one of the most common sources of channel variability, but it is not the only one. Channel fluctuations are also induced by instabilities of the transmit/receive equipments, such as oscillators' phase noise, frequency drifts and sampling jitter, or by the motion of the scatterers composing the transmission medium (especially evident in underwater acoustic links or in radio links involving refraction from the ionosphere, for example). The Doppler effect, which is one of the main causes of channel variability, is directly proportional to both carrier frequency and relative velocity between transmitter and receiver. Hence, both current trends towards higher carrier frequencies and mobility induce higher Doppler shifts and thus faster channel fluctuations. Nonetheless, channel variations can be classified as slow or fast only with respect

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