Book Review

Fundamentals of Wireless Communication—David Tse and Pramod Viswanath (Cambridge University Press). *Reviewed by Daniel J. Costello, Jr.*

This book provides a thorough coverage of wireless communication fundamentals, with emphasis on information-theoretic concepts. The authors are well-respected researchers who have themselves made numerous important contributions to the field. The book makes a concerted effort to emphasize and explain fundamental concepts and to provide strong motivation for the various topics covered. Although the book contains more than sufficient analytical material, its strength lies in the intuition that one gains from a careful reading. As such, it is an ideal resource for graduate students seeking a first exposure to the field.

As a graduate textbook, it can be used for a one or two semester graduate course in wireless communication. The first six chapters make an ideal first course covering all the basic concepts: physical models, fading and diversity, an introduction to MIMO systems, cellular systems, including GSM, CDMA, and OFDM, single-user and multiuser capacity, and opportunistic communication. Chapters 7–10, which take a detailed look at MIMO communication, can then be used for a second course, perhaps with some current supplementary material added. Alternatively, a one semester course emphasizing point-to-point communication can cover Chapters 1, 2, 3, 5, 7, 8, and 9. In the preface, the authors suggest other possible arrangements. A course using this book should be preceded by a solid graduate level course in digital communication that emphasizes complex signal representations. In order to take full advantage of the insights in the book, a prior course in information theory is desirable, although this could be taken concurrently.

The book contains many nice features that facilitate its use as a textbook. Among these are the following:

- frequent section and chapter summaries that allow the student to review the main concepts and formulas;
- occasional discussions that amplify important related topics;
- practical real system examples, such as GSM, Flash-OFDM, IS-136, IS-95, IS-856, V-BLAST, D-BLAST, and ArrayComm's SDMA system;
- biographical notes at the end of each chapter that place important prior contributions to the field in context;
- extensive exercises to challenge the student and, sometimes, the instructor;
- two appendices that cover some fundamental topics from digital communication and information theory that are needed for a full understanding of the book;
- solutions to most of the exercises and high-level overview slides of some chapters, available as supplementary material.

A particularly refreshing feature of the book is that it is extremely well written and remarkably free of typos. The authors clearly took a great deal of care in preparing the manuscript, and it shows in the final product. This, combined with the emphasis on intuition and motivation for all the basic concepts, makes it a very student-friendly book.

In addition, the book contains numerous recent research results, particularly in the last five chapters. For this reason, it is also very useful as a reference book for research professionals. In fact, researchers will particularly appreciate the way the material is woven together from an information theory perspective. This unified viewpoint allows the reader to connect a wide array of topics in wireless communication based on a few fundamental concepts.

Despite my obvious like and appreciation for this book, there are a few shortcomings. Although the book contains many exercises, most of these are quite advanced, with some amounting to mini research projects. These, of course, are fine for a graduate level course, but there is a need for some more routine problems designed to give students confidence that they have understood the material. This, combined with a sparsity of similar types of examples in the text, leaves the students sometimes guessing as to how to apply certain concepts. This is something that could easily be corrected in a new edition, and I would urge the authors to consider this. All in all, though, these shortcomings do not detract from what is on the whole an excellent book.

A chapter-by-chapter summary of the main features of the book now follows.

- **Chapter 1: Introduction.** This chapter briefly introduces the concept of wireless communication and includes a preview of the rest of the book.
- **Chapter 2: The Wireless Channel.** This chapter is devoted to mathematical models for the physical channel. The authors do a good job of motivating both the deterministic and statistical models that are used in wireless communication without falling into the trap of delving into unnecessary details of the underlying physical situation. Basic concepts such as Doppler spread, delay spread, coherence time, and coherence bandwidth are clearly presented. Also, the idea of degrees of freedom, or signal dimensionality, is introduced here and is a recurring theme throughout the book.
- **Chapter 3: Point-to-Point Communication: Detection, Diversity, and Channel Uncertainty.** This chapter contains the basic building blocks of the book, including the rudiments of digital communication and the concept of diversity transmission for fading channels. The level of detail is just about right, avoiding significant overlap with topics that are normally covered in an introductory graduate course on digital communication. The basics of the major diversity schemes are introduced here: time diversity and the idea of repetition coding; antenna diversity and space-time coding, including an introduction to the Alamouti code and V-BLAST; and frequency diversity. The section on frequency diversity introduces several important system designs and shows how they can be used to achieve diversity gain over wideband channels, including a single-carrier system with intersymbol interference equalization and maximum-likelihood sequence detection using the Viterbi algorithm, a direct-sequence spread spectrum system with the Rake receiver, and a multicarrier system with OFDM. The chapter concludes with a brief discussion of the impact of noncoherent detection on diversity gain.

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A particular strength of the chapter is its ability to weave the diversity theme throughout the discussion of the various system designs.

- **Chapter 4: Cellular Systems: Multiple Access and Interference Management.** This chapter focuses on cellular systems and includes detailed coverage of both narrowband and wideband (CDMA and OFDM) systems. GSM, IS-95, and Flash-OFDM are treated in some depth as examples of each system type. Basic concepts such as frequency reuse, interference averaging, power control, soft handoff, frequency hopping, and sectorizing are all covered. The emphasis throughout the chapter is on the interference issues that are central to multiuser system design.
- **Chapter 5: Capacity of Wireless Channels.** This chapter treats capacity for wireless channels in an intuitive manner. A concurrent course in information theory would be desirable to provide the student with a more formal approach to the subject. After a summary of capacity results for the point-to-point AWGN channel, multiple receive, multiple transmit, and parallel channel examples are used to provide a bridge to fading channels, and the waterfilling technique is introduced to determine the capacity of an OFDM system with independent AWGN subchannels. These results are then extended to slow fading channels, and the notions of outage probability and epsilon-outage capacity are introduced. Here the same examples used previously are revisited to illustrate receive diversity, transmit diversity, and time and frequency diversity. The chapter concludes with a discussion of capacity for fast fading channels and an illustration of how waterfilling can be used to design an opportunistic, rate-adaptive signaling strategy when the transmitter can track the channel.
- **Chapter 6: Multi-User Capacity and Opportunistic Communication.** This chapter extends the capacity results of Chapter 5 to the multiuser case and further develops the concept of opportunistic communication, one of the major themes of the book. First, the uplink and downlink of a multiple access AWGN channel are treated, and the techniques of successive interference cancellation and superposition coding are introduced. Then fading is considered and the opportunistic signaling strategy for fast fading with channel side information is generalized to the multiuser case. The chapter concludes with an extensive treatment of multiuser diversity and techniques that improve diversity gain, with emphasis on opportunistic beamforming using multiple transmit antennas.
- **Chapter 7: MIMO I: Spatial Multiplexing and Channel Modeling.** The last four chapters of the book contain an extensive treatment of MIMO systems that, along with selected sections from earlier chapters, could form the basis for a self-contained course on this topic. Chapter 7 begins by developing approximate capacity expressions for MIMO systems that highlight the achievable degree-of-freedom, or dimensionality, gains compared to single-antenna systems. The remainder of the chapter is devoted to the physical and mathematical models that are used to analyze MIMO systems. This treatment parallels that of Chapter 2 for point-to-point communication, with the added complication of the angular separation of antennas.
- **Chapter 8: MIMO II: Capacity and Multiplexing Architectures.** This chapter begins with a thorough treatment of the V-BLAST transceiver architecture and shows how it achieves capacity on the MIMO fast fading channel. Several less complex suboptimum receiver architectures are also discussed in the context of their performance relative to capacity. The chapter concludes by examining the outage performance of V-BLAST on the MIMO slow fading channel and shows how the modified D-BLAST architecture, which codes across transmit antennas, is needed to approach optimum performance.
- **Chapter 9: MIMO III: Diversity-Multiplexing Tradeoff and Universal Space-Time Codes.** This chapter develops the concept of the diversity–multiplexing tradeoff for slow fading MIMO channels in order to quantify the interaction between the increased data rates available with multiple antennas and the improved performance resulting from diversity gain. Diversity–multiplexing tradeoff curves are then computed for a number of commonly used space-time codes. Finally, design criteria for universal space-time codes that achieve optimum performance from the perspective of the diversity–multiplexing tradeoff are introduced for slow fading MIMO channels.
- **Chapter 10: MIMO IV: Multi-user Communication.** This chapter extends the results of the previous two chapters to multiuser systems. Both uplink and downlink channels, as well as slow and fast fading, are treated. For the more challenging downlink problem, an optimal transmit beamforming power allocation strategy is introduced, and both the Tomlinson–Harashima and dirty-paper precoding techniques for interference cancellation are treated in some detail. Finally, an opportunistic beamforming approach is introduced for the case when only partial channel state information is available at the base station.

Overall, the book develops the various themes and concepts central to wireless communication in a logical, consistent fashion. The careful reader will emerge with an in-depth understanding of the fundamental issues in the field. The list of references is extensive and the index has been prepared with considerable care. The authors should be given an A+ for the thought and effort that went into the development of this book.