SMART ANTENNA SYSTEMS AND WIRELESS LANS

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This book is dedicated to my parents, Matsuo and Betty Okamoto

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Preface

This book concerns two major topics, smart antenna systems and wireless local-area-networks (LANs). For smart antenna systems, it discusses the mechanics behind a smart antenna system, the setup of a smart antenna experimental testbed, and experimental and computer simulation results of various issues relating to smart antenna systems. For wireless LAN systems, it discusses the IEEE 802.11 worldwide wireless LAN standard, the operation of a wireless LAN system, and some of the technical considerations that must be overcome by a wireless LAN system designer. These two topics are combined in the discussion of the Smart Wireless LAN (SWL) system, which was designed to achieve the benefits which smart antenna systems can provide for wireless LAN systems while still remaining compatible with the 802.11 wireless LAN standard. The design of SWL calls for the replacement of the conventional wireless LAN base station (which are called access points in the 802.11 documentation) with an SWL base station, while leaving the individual terminal operation as unchanged as possible.

The material in this book is directly relevant to the design of smart antenna systems in wireless communications, including other applications besides wireless LANs such as terrestrial cellular systems, satellite cellular systems, wireless data distribution systems, and any advanced system that requires studies on the effects of advanced topics such as channel propagation and beamforming. This book details how smart antenna systems can be used to increase the capacity, decrease the effects of fading, increase battery life, and increase the range (the last two benefits due to the antenna diversity gain) of any wireless communications system. Of course, this book is especially relevant to the design of any wireless LAN system that wishes to utilize those benefits from smart antennas.

This book is organized as follows. Chapter 2 gives an overview of smart antenna and Space-Division-Multiple-Access (SDMA) concepts. The necessary background of a smart antenna system, including the definition of the spatial signature, and direction-of-arrival (DOA) estimation techniques are given. The various beamforming algorithms first studied for the SWL system are also defined and discussed. Chapter 3 presents the IEEE 802.11 wireless LAN standard, providing a brief background of the standard as well as descriptions of its MAC and PHY layers. Examples of leading 802.11 products are also given and the strategies their manufacturers take are also discussed. Chapter 4 gives a detailed description of the SWL protocol design, from the media access control to the physical layer design. The dynamic slot assignment and timing synchronization algorithms are discussed in greater detail due to their complex nature and specialization for the SWL system. Chapter 5 presents the experimental setup for two smart antenna testbeds built at The University of Texas at Austin, operating at 900 MHz and 1.8 GHz. The key individual components of a smart antenna testbed are shown and discussed, and the indoor and outdoor experimental environments are also described. Chapter 6 presents the experimental measurements of the spatial signature variation with time, to study the stability of the spatial signature for a stationary transmitter, and displacement, including the scenario in which there are closely spaced transmitters. The spatial signature variation with frequency shift is also discussed, which shows that Frequency-Division-Duplex (FDD) systems are not ideally suited for smart antenna systems. The experiments which show the effectiveness of smart antenna systems in reducing fading and providing antenna diversity gain are also presented. The effectiveness of various beamforming algorithms in increasing the capacity of a system is also examined. The multiple angle spread, feasibility of downlink beamforming, and Low Earth Orbit (LEO) satellite emulation results are also presented and discussed. Chapter 7 presents the simulation results for the SWL system. The physical layer simulation results include the results for the SIR performance for the beamforming algorithms, the dynamic slot allocation

results, the timing synchronization results, and the overall physical layer simulation results. The media access control layer simulation results include comparisons of the network utilization and voice delay failures for the SWL and IEEE 802.11 networks. Chapter 8 concludes the book.

This book is intended for *designers* and *would-be designers* of wireless communications systems. To limit the scope of this book to manageable proportions, the number of topics covered and the depth of coverage on some of those topics had to be limited. In the case of the computer simulation results for the MAC and PHY layers of the SWL system, for example, only representative results were given which allow for the reader to make their own conclusions as general as possible. For example, simulation results were given which as closely as possible related to the scenarios used in the experiments, to demonstrate how well the simulation results agreed with the experimental results, which both validated the results and allowed for conclusions to be drawn from their differences. Thus, simulation results which were too specific for the SWL or any specific smart antenna system were limited, as their usefulness to a reader desiring a different application would be limited. As another example, the discussion of the IEEE 802.11 standard is restricted to just providing the major details which influence the design of a wireless LAN system, since giving a complete description of the standard would require too much space and further information on the standard is readily available to anyone who wishes to learn more. The information provided about the standard should be sufficient for anyone seeking to acquire a general idea of how those systems work and are being implemented today, but this book is concerned about a potential future application for 802.11 and other wireless LAN systems.

The emphasis on topics important to designers results in a more detailed treatment of some topics than is traditional in academic textbooks, such as the experimental setup of a smart antenna testbed. In fact, the setup of two smart antenna testbeds (900 MHz, 1.8 GHz) are provided because information such as that is not generally available and

not duplicated in other books to my knowledge. Another example of a non-traditional topic is the wide range of experimental results provided from those testbeds, to demonstrate the feasibility of using a smart antenna system for wireless communications applications, with the SWL system designed with those results in mind. Many examples are given which relates the design of the SWL system to the knowledge gained from the experiments. This book also covers advanced topics such as dynamic slot assignment, timing synchronization, and several problems which smart antenna systems face that don't exist in conventional wireless communications systems.

This book is based on my dissertation at The University of Texas at Austin. However, the material included here is broader in scope and has more depth because I added chapters in areas of a more general interest (such as the IEEE 802.11 wireless LAN standard chapter and the experimental setup chapter) and I was fortunate to receive the contributions of a number of my former colleagues at The University of Texas at Austin. I was also able to include in this book numerous experimental results that I collaborated on but didn't include in my dissertation because I was not the lead investigator on those experiments.

This book is suitable as a first- or second-year graduate textbook, for a class covering advanced wireless communications or signal processing topics, or for any wireless communications professional in industry interested in these topics. Smart antenna systems are a fairly advanced topic in wireless communications, but this book was written so that it should be able to be understood by even those who don't have too much of a background in these advanced signal processing topics. I attempted to make the book more attractive to both audiences through the inclusion of many practical examples and a practical relation between design and the experimental and simulation results.

This book is not intended to be the definitive work on either of its major topics, smart antenna systems and wireless LANs. Rather, it should provide the reader with a solid base of understanding on both

topics, as well as an understanding of the SWL system which I designed. Many of the subjects in this book would require entire books of their own to be fully explored, but this book should provide enough information for a reader to further explore areas in which more advanced study is desired.

I would like to express my deepest appreciation to Professor Guanghan Xu, my thesis advisor, for his guidance throughout the course of my doctoral research. I would also like to express my appreciation to Shiann-Shiun Jeng for his invaluable contribution to our collaborative efforts, much of which is presented in the experimental results chapter. He also wrote about the 900 MHz testbed for the experimental setup chapter and contributed to the smart antenna background chapter.

I would like to thank Lars K. Hansen for writing about the experimental setup of the 1.8 GHz testbed, Adnan Kavak for writing about his LEO experiments, and John Stine for writing about the IEEE 802.11 MAC description. I would also like to thank my colleagues Sang-Youb Kim, Weidong Yang, Michael Montgomery, Murat Torlak, Hui Liu, Liang Dong, Roberto Vargas, Jr., Wei-Lin Yang, Ching-Fong Su, Alberto Arredondo, Kapil Dandekar, and Tae-Jin Lee for their help and valuable discussions.

I owe a debt of gratitude to the members of my Ph.D. committee for all of their suggestions which improved my dissertation and consequently this book, Guanghan Xu, Mario Gonzalez, Gustavo de Veciana, Edward Powers, and Wolfhard Vogel. Special thanks go to my committee member (and longtime supervisor at the Jet Propulsion Laboratory) James Lesh, who provided the most comprehensive proofreading of my dissertation that I received. While many of these colleagues and others have pointed out many errors and omissions, any remaining errors are of course my full responsibility.

Finally, I would like to thank my parents, sister Nan, and brother-in-law David for their help. Without their continual support and encour-

agement over the years, none of my accomplishments would have been possible. I am truly blessed to have them in my life.

I hope the result is a readable and useful book, and always appreciate comments and suggestions from the readers.

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