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# Wireless Infrared Communications

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# Contents

# Foreword

The demand for wireless access to network services is growing in virtually all communications and computing applications. Once accustomed to unteathered operation, users resent being tied to a desk or a fixed location, but will endure it when there is some substantial benefit, such as higher resolution or bandwidth. Recent technological advances, however, such as the scaling of VLSI, the development of low-power circuit design techniques and architectures, increasing battery energy capacity, and advanced displays, are rapidly improving the capabilities of wireless devices.

Many of the technological advances contributing to this revolution pertain to the wireless medium itself. There are two viable media: radio and optical. In radio, spread-spectrum techniques allow different users and services to coexist in the same bandwidth, and new microwave frequencies with plentiful bandwidth become viable as the speed of the supporting low-cost electronics increases. Radio has the advantage of being available ubiquitously indoors and outdoors, with the possibility of a seamless system infrastructure that allows users to move between the two. There are unanswered (but likely to be benign) biological effects of microwave radiation at higher power densities. Optical communications is enhanced by advances in photonic devices, such as semiconductor lasers and detectors. Optical is primarily an indoor technology — where it need not compete with sunlight — and offers advantages such as the immediate availability of a broad bandwidth without the need for regulatory approval. There are well-characterized dangers to the human eye from optical radiation at higher power densities.

While optical wireless communication is attractive for certain high-speed applications, there are a number of challenging design problems that must be faced. One is to obtain sufficient signal-to-noise ratio in the presence of strong interference, such as natural and man-made light, while staying within the margins of eye safety. Another is to obtain full coverage of a room by diffusing the light, allowing the user to go anywhere, which further compromises the signal power density at the receiver. Yet another is to design detectors with sufficient area and simultaneously enough bandwidth to allow a high data rate. In addition, as with radio systems, there is the challenge of dealing with intersymbol interference created by multipath.

This book provides a comprehensive description of the technical challenges inherent in diffuse infrared wireless networking. It is an outgrowth of a research project at the University of California at Berkeley which led to John Barry's doctoral dissertation, supplemented by his subsequent work at the Georgia Institute of Technology. The original goal of this research was a 100 Mb / s diffuse optical transmission to a single wireless terminal. We are indebted to the IBM T. J. Watson Research Center, and to Scott Kirkpatrick and Colin Harrison in particular, for first presenting us with the challenges and encouraging our research on wireless infrared. Prototyping efforts have continued at Berkeley under the direction of Professor Joseph Kahn and his students, with the support of IBM and Hewlett Packard.

I believe that the prospects for commercial applications of optical-based wireless communications are very bright, particularly for high-performance indoor local-area networks. I hope that John Barry's book will play a significant role in convincing the technical community of the viability of this technology. A wealth of exciting new applications await.

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# Preface

The capabilities of infrared technology extend far beyond the mere remote control of home appliances. A natural application is wireless networking for portable computers, a concept that was first proposed over 15 years ago by IBM researchers,[1] and has recently become a commercial reality; several companies now offer wireless infrared modems, with data rates of 1 to 4 Mb/s and ranges of 10 to 15 m. Despite a growing interest in wireless infrared communications, surprisingly little has been published by the research community. Fundamental questions have gone unanswered. For example, can infrared support broadband data rates of 100 Mb/s and higher? What are the inherent obstacles to achieving high transmission speeds, and how can they best be mitigated? These are the questions that my colleagues and I were asking in 1989, when we teamed up with IBM-Hawthorne and began our work on wireless infrared communication. The ensuing research led to my doctoral dissertation at the University of California at Berkeley, which in turn formed the basis for this book.

The original goal of this project was to investigate the communication-theoretic aspects of the physical layer of a wireless infrared network, with emphasis on determining which modulation techniques can best exploit the unique characteristics of the medium. We soon realized, however, that a prerequisite for such a study is a thorough understanding of the underlying channel itself, including the effects of background light, optical components, multipath optical propagation, and receiver electronics. Therefore, a bulk of our effort was directed at these issues, as reflected in the structure of this book: chapter 2 addresses optics design, chapter 3 addresses electronic receiver design, and chapter 4 address multipath optical propagation. Modulation is not addressed until chapter 5.

This book differs from my doctoral dissertation in several substantial ways. For example, chapter 2 has been completely rewritten, and a more accurate method for accommodating reflection losses has been included. In addition, new material

1. F. R. Gfeller, H. R. Müller, and P. Vettiger, "Infrared Communication for In-House Applications," *IEEE COMPCON*, Washington D. C., pp. 132-138, September 5-8, 1978.

addressing non-hemispherical concentrators and isotropic radiation has been added. The new numerical results of chapter 2 propagate into chapter 3 as well. Chapter 5 has also been improved with the addition of a detailed discussion on equalization for pulse-position modulation in the presence of intersymbol interference. Finally, where possible, the pace has been relaxed and the tone made more conversational. I hope the resulting book provides a useful introduction for both design engineers and communication theorists to the principles of wireless infrared communications.

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Many colleagues and friends deserve thanks for their influence on this project. I am especially grateful to Professors Edward Lee and David Messerschmitt for their constant encouragement and inspiration. I am also greatly indebted to Professor Joseph Kahn, whose guidance has strongly influenced much of this book. I am grateful to Peter Hortensius of IBM for providing early guidance during the summer of 1990, and also for sharing his ideas on multipath dispersion that led to the theory of chapter 4. Professor David Brillinger, Malik Audeh, and Gene Marsh provided useful comments on an early draft of this manuscript. Bill Krause deserves credit for the experimental multipath measurements of chapter 4. Conversations with the following colleagues were also helpful: Andy Burstein, Jeff Carruthers, Shih-Fu Chang, Andrea Goldsmith, Paul Haskell, Jim Hollenhorst, Chris Hull, Phil Lapsley, Chung-Sheng Li, Horng-Dar Lin, Vijay Madisetti, Kris Pister, Annis Porter, Rajiv Ramaswami, Gil Sih, Ravi Subramanian, and Greg Uehara.

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