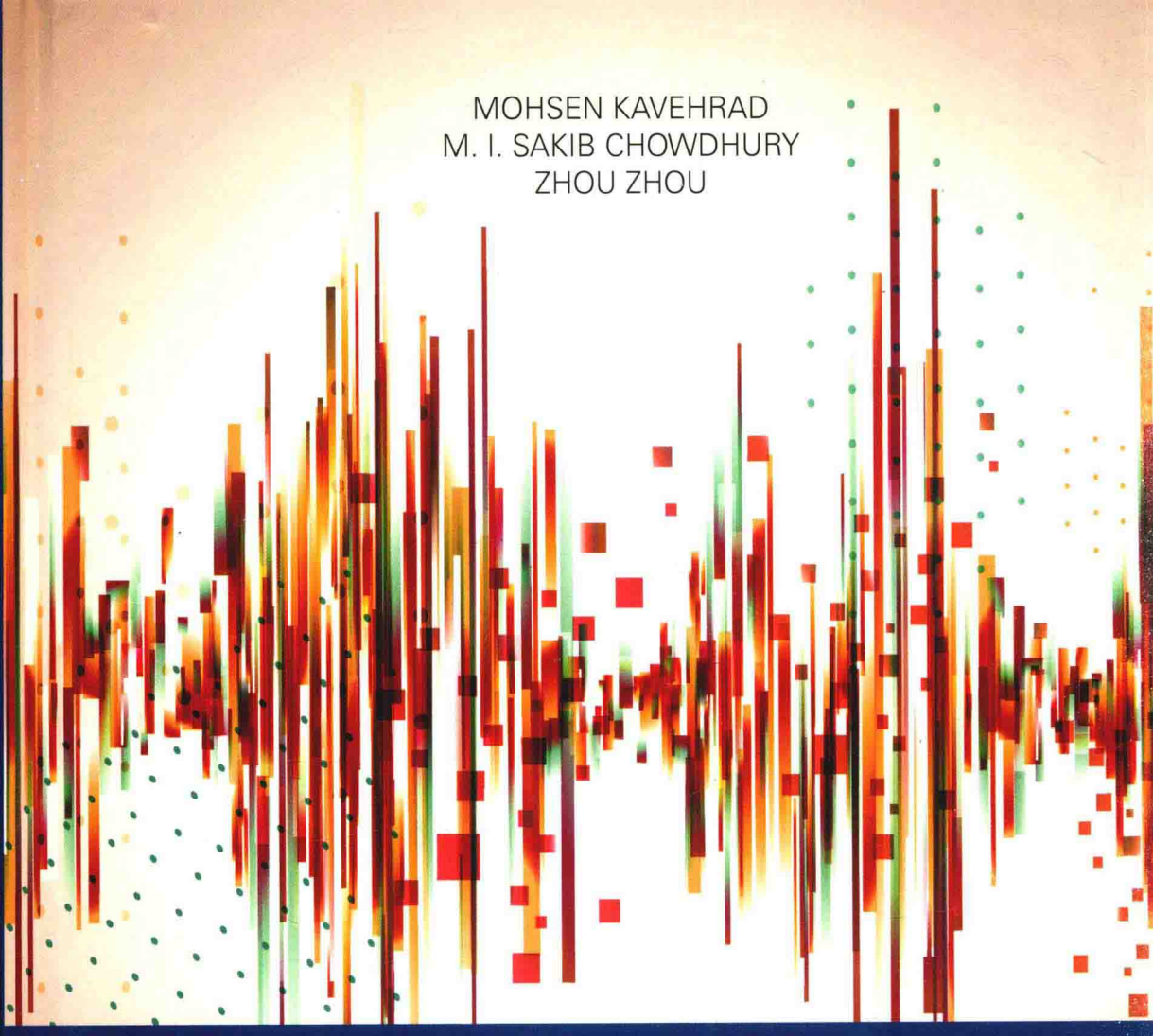
MOHSEN KAVEHRAD
M. I. SAKIB CHOWDHURY
ZHOU ZHOU



SHORT-RANGE OPTICAL WIRELESS

THEORY AND APPLICATIONS

WILEY

SHORT-RANGE OPTICAL WIRELESS

THEORY AND APPLICATIONS

Mohsen Kavehrad
The Pennsylvania State University
University Park, PA, USA

M. I. Sakib Chowdhury
The Pennsylvania State University
University Park, PA, USA

Zhou Zhou
The Pennsylvania State University
University Park, PA, USA

WILEY

This edition first published 2016
© 2016 John Wiley & Sons, Ltd

Registered Office
John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

The advice and strategies contained herein may not be suitable for every situation. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of experimental reagents, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each chemical, piece of equipment, reagent, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. The fact that an organization or Website is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Website may provide or recommendations it may make. Further, readers should be aware that Internet Websites listed in this work may have changed or disappeared between when this work was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the publisher nor the author shall be liable for any damages arising herefrom.

Library of Congress Cataloging-in-Publication data applied for

ISBN: 9781118887707

A catalogue record for this book is available from the British Library.

Set in 10/12pt Times by SPi Global, Pondicherry, India
Printed and bound in Singapore by Markono Print Media Pte Ltd

1 2016

Preface

This book provides a detailed overview of physical layer optical wireless communications. The basic pedagogic methodology is to include fully detailed derivations from the basic principles. The text is intended to provide enough principle materials to guide the novice student, while at the same time to have plenty of detailed materials to satisfy graduate students inclined to pursue research in the area. The book is intended to stress the principles of optical wireless communications that are useful for a wide array of applications that these techniques are devised for. It is also intended to serve as a possible textbook and reference for graduate students and a reference for practicing engineers.

Organization of the Book

In Chapter 1, we offer an introduction to optical wireless field. This covers a broad array of issues like potential of solving complicated communications problems considering a shortage of radio frequency spectrum suitable for mobile applications and suggestion of moving some of the less mobile applications to the optical frequencies range of infrared and visible light, radio frequency interference, and necessity of transmission at very high data rates, etc. by optical wireless systems. Optical wireless links can establish communications channels even millions of miles apart, as evidenced by the usage of optical links in space exploratory missions. For shorter terrestrial distances, optical wireless links in outdoor free space are a good choice for establishing pointed links few miles apart.

In general, the optical wireless communications area of research did not receive much attention for several years, except in some military applications for the security that it offers. Yet the largest number of wireless devices ever sold, namely TV remote controls use wireless infrared light in order to function. The advantages of using optical radiation over RF include the following:

- Virtually unlimited bandwidth with over 540 THz for wavelengths in the range of 200–1550 nm. This band is unregulated and available for immediate utilization.

- Use of baseband digital technology.
- A small receiver (photodetector) area provides spatial diversity that eliminates multipath fading in intensity modulation with direct detection links. Multipath fading degrades the performance of an unprotected RF link.
- Light is absorbed by dark surfaces, diffusely reflected by light-colored objects and directionally reflected from shiny surfaces. It does not penetrate opaque objects. This provides spatial confinement that prevents interference between adjacent cells operating in environments separated by opaque dividers.
- Spatial confinement of optical signals allows for secure data exchange without the fear of an external intruder listening in. This provides physical layer security which is the safest type.
- No electromagnetic interference with other devices, making it very suitable for environments employing interference-sensitive devices, such as hospitals, airports and factories, power plants, and military and national security buildings.

Visible light (VL) applications are emerging technology areas that utilize the high-speed switching properties of VL LEDs for wireless data applications with data rates higher than conventional 802.11 wireless networks and have additional benefits of the following:

- Sustainable solution for the current **Spectrum Crunch.**
- Energy efficiency in luminous efficacy—LEDs are far more efficient than incandescent and far more flexible than compact fluorescent lights (CFLs).

As LEDs increasingly displace incandescent lighting over the next few years, general applications of VL technology are expected to include wireless Internet access, vehicle-to-vehicle communications, broadcast from LED signage, machine-to-machine communications, positioning systems, and navigation. Furthermore, since smart LEDs have IP addresses, each will add a node to the Internet. Hence, *the most compelling story of how Internet of Light will transform our world is the one still being written: the future of lighting/communications/sensing and the birth of a new enterprise lighting network.*

As the next step to delve further into optical wireless communications systems, we discuss some fundamentals of this technology in Chapter 2. We point out the differences between radio-frequency-based and optical wireless communications systems and provide some details on optical transmitters and receivers.

In Chapter 3, we aim to establish a proper channel modeling method to ensure that modeling can be done accurately and fast. Channel modeling helps us to understand effects of intersymbol interference (ISI) at high data rates which is caused by multiple reflections of optical signals from the walls within a room.

Our goal in Chapter 4 is to analyze various channel properties using the models obtained from channel modeling techniques. We discuss different topics related to indoor optical wireless channels such as average delay spread and path loss. We have shown effects of additional room furniture on these parameters compared to an empty room.

Chapter 5 consists of several fundamental results on VL communications (VLC) utilizing multiple sources. Source layout is one of the most important factors that affect overlapping of light footprints and thus produce ISI. We explore VLC performance in conventional household layouts and investigate the impact of these layouts to VLC.

此为试读,需要完整PDF请访问: www.ertongbook.com

Orthogonal frequency division multiplexing (OFDM) is a good candidate for VLC as it offers robustness against multipath dispersion caused by diffuse indoor optical wireless (OW) channel. But OFDM systems contain certain disadvantages like high peak-to-average power ratio (PAPR) and an additional requirement in optical domain that the modulating signal has to be unipolar. In Chapter 6, we develop some techniques to reduce high PAPR in OFDM-based OW systems since the non-linear characteristics of LED transmitters can severely affect system performance. We then analyze performance of various OFDM-based OW schemes in multipath diffuse indoor wireless channel.

In Chapter 7, multiple-input and multiple-output (MIMO) techniques are included as they provide either reliability improvement or bandwidth efficiency increase.

In Chapter 8, based on these investigations, we further explore VLC performance in real applications, such as aircraft cabin wireless communications.

In Chapter 9, we discuss about multi-spot diffusing configuration where multiple spots on the ceiling of a room are created with the help of a holographic diffuser. We also discuss about angle-diversity receivers which are set up in such a way that several photodiodes are arranged at different angles relative to one another and thus face different directions, or can be constructed using holographic mirrors.

In Chapter 10, we investigate several fundamental research topics of indoor positioning and navigation systems based on VLC technology. Despite the fact that indoor positioning has become an attractive research topic within the past two decades, no satisfying solution has been found with consideration of both accuracy and system complexity. Recently, research on VLCs offers new opportunities on realizing accurate indoor positioning with relatively simple system configurations. We compare and discuss several positioning algorithms and describe an asynchronous positioning system.

Acknowledgments

I am grateful to my past and present doctoral students, in particular, both my coauthors, who have contributed to this book through their thesis research.

Mohsen Kavehrad
The Pennsylvania State University,
University Park, PA, USA

Contents

Preface ix

Acknowledgments xiii

1 Introduction 1
1.1 Motivation 1
1.1.1 Spectrum Scarcity Issues and Optical Wireless Communications as a Solution 3
1.2 Organization 8
References 9

2 Fundamentals of Optical Wireless Communications 11
2.1 Introduction 11
2.2 Communications Blocks in an OWC System 12
2.3 Intensity Modulation/Direct Detection (IM/DD) 14
2.4 Optical Transmitters 15
2.5 Optical Receivers 16
2.6 Optical Wireless Channel Propagation Characteristics 20
2.7 Conclusions 24
References 25

3 Indoor Optical Wireless Channel Modeling Methods 27
3.1 Introduction 27
3.2 Source and Receiver Configurations 27
3.3 Steps for Modeling of Indoor OWC Environment 31
3.4 Models of the Room and Other Reflecting Surfaces 32
3.5 Radiation Patterns 32
3.5.1 Radiation Patterns of Point Sources 33
3.5.2 Radiation Patterns of Reflections 34

3.6 Received Power from LOS Links 37
3.7 Received Power from NLOS Links 39
3.7.1 Barry's Algorithm 39
3.7.2 MIMO Modeling Method 41
3.7.3 Modified Monte Carlo Algorithm and Variations 44
3.7.4 Combined Deterministic and MMC Algorithm 45
3.7.5 Other Approaches for Impulse Response Calculation 63
3.8 Conclusions 63
References 64

4 Analyses of Indoor Optical Wireless Channels Based on Channel Impulse Responses 67
4.1 Introduction 67
4.2 Analyses of Optical Wireless Channel Impulse Responses 67
4.2.1 Non-Directed LOS Links 70
4.2.2 Non-Directed NLOS Links 82
4.3 Effects of Furniture on Root-Mean-Square Delay Spread 89
4.4 SNR Calculations and BER Performance 93
4.5 Impact of Higher Order Reflections 96
4.6 Conclusions 107
References 109

5 Bit-Error-Rate Distribution and Outage of Indoor Optical Wireless Communications Systems 111
5.1 Introduction 111
5.2 Simulation Parameters 111
5.3 Optimal Detection and BER Outage Analysis 113
5.3.1 Optimal Detection 113
5.3.2 BER Analysis 115
5.4 Simulation Results (Receiver FOV = 60°) 117
5.4.1 BER Distribution and Outage 118
5.4.2 Impulse Response Distortion 121
5.5 Simulation Results (Receiver FOV = 30°) 123
5.6 Analytical Results and Comparisons 126
5.7 Conclusions 126
References 130

6 Orthogonal Frequency-Division Multiplexing (OFDM) for Indoor Optical Wireless Communications 131
6.1 Introduction 131
6.2 OFDM Overview 132
6.2.1 Basic OFDM System 132
6.2.2 System Operation 132
6.2.3 Discrete Time Implementation of OFDM 134
6.2.4 Drawbacks of OFDM 134

6.3 OFDM-Based OW Systems 136
6.3.1 ACO-OFDM 137
6.3.2 PAM-DMT 137
6.3.3 DHT-OFDM 139
6.4 Precoding and PAPR Reduction in AC OFDM OW Systems 140
6.4.1 Precoding-Based Optical OFDM System Model 140
6.4.2 Precoding Schemes 143
6.4.3 Simulation Results and Discussions 144
6.5 Performance of AC OFDM Systems in AWGN and Multipath Channel 149
6.5.1 Precoding-Based OW OFDM System Model with AWGN 149
6.5.2 Multipath Indoor Channel 150
6.5.3 Frequency-Domain Equalization (FDE) 151
6.5.4 Analytical BER Performance Results 152
6.5.5 Electrical and Optical Performance Metrics 154
6.5.6 Clipping and PAPR Reduction 154
6.5.7 Simulation Results 155
6.6 Conclusions 164
References 167

7 MIMO Technology for Optical Wireless Communications using LED Arrays and Fly-Eye Receivers 169
7.1 Introduction 169
7.2 MIMO Configurations 169
7.2.1 MIMO System Model 169
7.2.2 Spatial Diversity 170
7.3 Angle-Diversity Receivers 171
7.3.1 Angle-Diversity Receiver Overview 171
7.3.2 Fly-Eye Receiver Design 171
7.4 Simulation Results and Discussions 173
7.4.1 Simulation Parameters 173
7.4.2 BER Spatial Distributions for MIMO OWC Systems 174
7.4.3 Impact of Ambient Noise 182
7.5 Conclusions 189
References 190

8 Wireless Solutions for Aircrafts Based on Optical Wireless Communications and Power Line Communications 193
8.1 Introduction 193
8.2 Powerline Communications Channel Model 195
8.3 Optical Wireless Communications 196
8.3.1 Simulation Configurations 196
8.3.2 Illuminance Distribution Results 197
8.3.3 Delay Spread Distribution Results 199
8.3.4 Bit-Error-Rate Distribution and Outage Probability 200

8.4 Wireless Applications for Commercial Airplanes 204
8.4.1 Reading Light Passenger Service Units 204
8.4.2 Passenger Infotainment 205
8.4.3 Cabin Interphones 205
8.4.4 Interconnection of Line-Replaceable-Units Over Environmental Barrier 205
8.5 Conclusions 205
References 205

9 Multispot Diffusing Transmitters Using Holographic Diffusers for Infrared Beams and Receivers Using Holographic Mirrors 207
9.1 Introduction 207
9.2 CGH for Intensity-Weighted Spot Arrays 208
9.3 Communication Cells for Multispot Diffusing Configuration 211
9.4 Receiver Optical Front-End 214
9.4.1 Holographic Mirrors 215
9.4.2 Signal Effective Area 215
9.4.3 Figure-of-Merit 216
9.5 Wave Propagation through Materials and Metamaterials and Relation with Holography 218
9.6 Conclusions 222
References 222

10 Indoor Positioning Methods Using VLC LEDs 225
10.1 Motivation 225
10.2 Positioning Algorithms and Solutions 228
10.2.1 Triangulation 228
10.2.2 Scene Analysis 234
10.2.3 Proximity 234
10.2.4 Comparison of Positioning Techniques 235
10.3 An Asynchronous Indoor Positioning System based on VLC LED 237
10.3.1 Basic Framed Slotted ALOHA Protocol 237
10.3.2 System Design and DC Channel Gain 243
10.3.3 Positioning Algorithm 244
10.3.4 Signal-to-Noise Ratio Analysis 250
10.3.5 Results and Discussions 252
10.3.6 Extended Simulation and Results 256
10.4 Conclusions 260
References 260

Index 263

此为试读,需要完整PDF请访问: www.ertongbook.com

1

Introduction

1.1 Motivation

Optical wireless communications (OWC) has become an increasingly important research area. The potential of solving complicated communications problems, such as the shortage of radio frequency (RF) spectrum, interference, and the necessity of transmission at very high data rates by optical wireless systems has seen vast improvement. Optical wireless links can establish communications channels even millions of miles apart, as evidenced by the use of optical links in space exploratory missions by NASA [1]. For shorter terrestrial distances, optical wireless links in outdoor free space are a good choice for establishing pointed links a couple of miles apart. On a much smaller scale, the existence of millions of remote controls that operate using infrared light-emitting-diodes (LEDs) is a proof of the usefulness of optical wireless systems.

Apart from the various applications of OWC that are currently in use, probably the main motivating factor to focus on this area is the possibility of mitigating the increasing spectrum shortage issue. As consumption of high data rate multimedia materials is increasing day by day and the use of handheld devices is becoming more and more widespread, the precious RF spectrum range of about 1.9 GHz that is used for mobility is getting scarcer [2]. Users are encouraged to shift to the Wi-Fi bands instead of the bands used for cellular services in order to alleviate this increasing load of high data rate applications. However, there are places where even Wi-Fi bands do not operate as expected or are found to be so congested that their use becomes next to impossible, for example, heavily crowded conference halls. Also, supported data rates of Wi-Fi as well as cellular data services should be considered in this discussion. Though IEEE 802.11ac and IEEE 802.11ad standards are supposed to support high bit rates, they are not yet widespread, and so the cost issue is involved. LTE and LTE-Advanced standards are also supposed to support high bit rates, but they use the same precious cellular

Short-Range Optical Wireless: Theory and Applications, First Edition. Mohsen Kavehrad, M. I. Sakib Chowdhury and Zhou Zhou.
© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.

spectrum band and thus due to congestion cannot provide satisfactory performance. Hence, the pursuit of and research on alternatives to these radio frequency-based solutions such as optical wireless-based systems and technologies are greatly desirable [3, 4].

OWC can be both indoors and outdoors and are usually broadly divided into two categories based on the type of optical source employed. Two types of optical sources—LEDs and lasers—are currently in use as transmitters of optical links. The difference between these two sources lies in their supported bandwidth: where LEDs have a much lower electrical bandwidth than lasers, and hence if very high data rate transmission in the range of Gbps is required, lasers are the popular choice. Also, lasers emit monochromatic light signals, that is, light signals that have only one wavelength in it, whereas LEDs have a very broad spectral line-width. LED-based communications mainly involve visible light communications (VLC) using white LEDs (WLEDs), and lasers are used only as very high-speed infrared sources. Hence, these two types of optical sources have different application scenarios. In this book, we will cover different types of applications where both LEDs and lasers are used.

The energy-saving aspect of WLEDs is probably one of the most important benefits that can be obtained using VLC. Lighting is a major source of electric energy consumption. It is estimated that one-third of the global consumption of electricity is spent for lighting purposes; therefore, development of more efficient lighting sources is important. This acknowledgment of concerns about significant consumption has generated significant activity toward the development of solid-state sources, to replace incandescent and fluorescent lights. Fluorescent lamps contain environmental pollutants, thus their elimination will remove a significant source of environmental pollution and more specifically, their replacement with highly efficient LEDs generating "white light" will reduce energy consumption. It is fortunate that WLEDs are already commercially available. WLEDs require roughly 20 times less power compared to conventional light sources, even 5 times less power compared to fluorescent bulbs that consume less energy. An entire rural village can be lit with less energy than that used by a single conventional 100 W light bulb. Switching to solid-state lighting would reduce global electricity use by 50% and reduce power consumption by 760 GW in the United States alone over a 20-year period. To get a clear picture of the positive impact the use of WLEDs will have, some concrete estimates can be provided. If all existing bulbs were replaced by WLED sources, within 10 years we will have the following benefits: energy savings of 1.9×10^{20} J, US$1.83 trillion financial savings, 10.68 GT reduction of carbon dioxide emissions, and 962 million barrels less consumption of crude oil [4].

The field of photonics starts with the efficient generation of light. The generation of efficient yet highly controllable light can indeed be accomplished using LEDs. Using a WLED instead of conventional lighting means the size, cost, and energy consumption will decrease considerably, as optical devices are smaller and simpler than electrical devices. WLEDs are semiconductor devices. About 13 000 LEDs can be formed on a substrate, which can be about 0.25×0.25 units in size. WLEDs use 5% of the energy of a regular incandescent bulb. An entire rural village can be lit with less energy than that used by a single conventional 100 W light bulb. By replacing the conventional lights with WLEDs and by using them for both data transmission and lighting, large amounts of energy can be saved. Undoubtedly, white light emitting solid-state devices will be the lighting sources of the twenty-first century. About 10–15 years ago, researchers came to the realization that WLED devices, in addition to being very fit for lighting the surrounding space, could also be used for wireless communications purposes. The advantages of such technology applications are many. It belongs to the "green

technologies" category when used for lighting purposes, becoming even more environmentally friendly when it supports communication functionality compared to RF alternatives. Also, LEDs and photodetectors tend to be considerably cheaper compared to RF counterparts. OWC allows easy bandwidth reuse and improves security, as light is confined within the room it illuminates. It does not generate RF contamination, nor is it impacted by RF interference. Thus, replacing RF devices with devices using white light for communications (at least for indoor environments) will reduce interference in the RF bands. It should be pointed out that while the consumer market and the product developers will benefit from this, the technology can also make a major breakthrough in cases where RF radiation is of great concern, as in the case of hospitals, schools, airplanes, and mines. RF interference has caused accidental triggering of explosions when using remote detonator devices. Federal regulation places 1 W as the maximum acceptable RF power within mines using remotely triggered detonators. Also, baby monitoring RF signals have interfered with landing instructions of planes approaching airport runways.

1.1.1 Spectrum Scarcity Issues and Optical Wireless Communications as a Solution

Let us delve a bit deeper into the RF spectrum scarcity problem that we mentioned earlier and how OWC using either LEDs or lasers can help in this regard.

With the increasing popularity of multimedia services supplied over the RF networks and services such as web browsing, audio and video on demand, it is for sure only a matter of time before users will face extreme congestion while trying to connect to avail themselves of these aforementioned services. Advancements in displays, battery technology, and processing power have made it possible for users to afford and carry around smart phones and tablets. As we are entering a new era of always on connectivity, the expectation from users for not only ubiquitous but also seamless voice and video services presents a significant challenge for today's telecommunications systems. The prospects for the delivery of such multimedia services to these users are crucially dependent on the development of low-cost physical layer delivery mechanisms.

According to market research published by Cisco Systems, Inc. [5], the largest manufacturer of networking equipment, mobile data consumption is going to explode in the next 5 years, largely due to the proliferation of mobile video and mobile web applications. Cisco market research includes the Visual Networking Index (VNI). The VNI research predicts mobile data use to expand from 2.5 to 24.3 EB monthly. This is an increase of a factor of 10 in 5 years, or about 57% cumulative annual growth rate (CAGR). This is an enormous growth in mobile data, a very large portion of which is growth due to the proliferation of mobile video (66%). Much of this mobile data growth (about 70%) will be consumed by laptops and other mobile ready portables such as pico-projectors, wireless reading devices, digital photo frames, and smart phones. These mobile devices can generally be thought of as in-building networked devices that are used to share information (video) within a classroom, conference, or meeting room. The report predicts that a greater amount of traffic will migrate from fixed to mobile networks.

In the past few years, we have witnessed rapid growth in technologies producing low-cost communications devices, using the RF license-free bands: ISM (2.4–2.4835 GHz), UNII

(5.15–5.25 and 5.35–5.825 GHz). As technology advances, the service capability of such devices will strengthen. However, uncontrolled deployment of devices using the same spectrum allocation can generate interference beyond the level that these systems can afford, thus leading to service quality deterioration. The IEEE 802.15.2 working group was formed to address this growing problem; however, without controlling the number of devices operating within certain areas, the problem cannot be solved, unless more bandwidth becomes available. The 57–64 GHz band has been added to license free bands; however, the design of communication systems at these extremely high frequencies is very challenging. It will take some years for products of reasonable cost and satisfactory performance to be introduced in the market. Also, adding bandwidth does not address the problem at its root. What is needed is a broadband, interference-free, or at least interference-resistant technology, allowing easy frequency reuse made available to the customer at an affordable cost [4]. Considering the rapidly growing wireless consumer devices, it is evident that the need for such technology is quite urgent.

The wireless handheld devices require ever-increasing bandwidth, and along with that, explosive growth in interdevice wireless communications is already creating huge demands on spectrum resources, which can be resolved only by near-zero-sum allocation decisions, made through a mixture of bidding and politics.

In economy, the game theoretic Nash equilibrium (named after John Forbes Nash, who proposed it) [6] is a solution concept of a game involving two or more players, in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only his own strategy unilaterally. If each player has chosen a strategy and no player can benefit by changing his or her strategy while the other players keep theirs unchanged, then the current set of strategy choices and the corresponding payoffs constitute Nash equilibrium. The practical and general implication is that when players also act in the interests of the group, then they are better off than if they acted in their individual interests alone.

Unfortunately, with spectrum usage, Nash equilibrium may result in a spectrum crunch [2], if the participants do not cooperate. An example of this was the Cellular Digital Packet Data (CDPD). This was a wide-area mobile data service, which used unused bandwidth normally used by AMPS mobile phones between 800 and 900 MHz to transfer data. Speeds up to 19.2 Kbps were possible. The service was discontinued in conjunction with the retirement of the parent AMPS service; it has been functionally replaced by faster services such as 1xRTT, EV-DO, and UMTS/HSPA. Developed in the early 1990s, CDPD was large on the horizon as a future technology. However, it had difficulty competing against existing slower but less-expensive Mobitex and DataTac systems, and never quite gained widespread acceptance before newer, faster standards such as GPRS became dominant. CDPD had very limited consumer offerings. Though AT&T Wireless first offered the technology in the United States under the PocketNet brand, they eventually refused to activate the devices. Despite its limited success as a consumer offering, CDPD was adopted in a number of enterprises and government networks. It was particularly popular as a first-generation wireless data solution for telemetry devices (machine-to-machine communications) and for public safety mobile data terminals. In 2004, major carriers in the United States announced plans to shut down CDPD service. In July 2005, the AT&T Wireless and Cingular Wireless CDPD networks were shut down. Equipment for this service now has little to no residual value [7].

Another example of co-existence with already existing services over radio spectrum (a form of bandwidth sharing) is the idea of ultra wideband (UWB) [8] that proposed to use

direct-sequence spread spectrum sharing bands over 7 GHz of already allocated radio spectrum. This technology did not go too far either, although a huge amount of resources was spent on demonstrating the feasibility of the technology through research and development. The developed technologies work perfectly according to the specifications, but there is no public acceptance in adopting these techniques.

Some views on bandwidth sharing, be it through cognitive radios or dynamic spectrum allocation (DSA) [9], are given here. The wireless/mobile environment is very dynamic. To capture when a piece of spectrum is free and available (known as white space) in order to reallocate it, many accurate energy sensors have to be installed to identify these available bands. Then a command has to be sent to a cloud (database) at a distance in order to make the availability of the idle bands known to users in order to reallocate these available bands. This is a very difficult and expensive proposition in a densely populated metropolitan area where bandwidth sharing is needed the most. There might be several available portions of bands idle in rural areas; however, bandwidth and channel borrowing concepts only work over short distances. In dense metropolitan areas, by the time sensing is done and a reallocation decision is reached, the spectrum availability status may be different.

There are many practical odds against bandwidth sharing through cooperation, and there are commercial risks involved with the results (as with CDPD). Some of these are (i) cost effectiveness of sensors and the number of sensors required; (ii) willingness of spectrum resource managers (FCC, NTIA, ITU) to allow a commercial enterprise to resell spectrum and to dynamically allocate spectrum resources; (iii) ability to raise sufficient capital to deploy a network of sensors and spectrum monitoring/allocation system in a dense geographical area; (iv) and ability to sign customers onto a plan to utilize dynamically allocated spectrum.

These are the common problems with dynamic allocation of spectrum. Regulations and protocols attempt to address these but are usually difficult to construct, and even harder to enforce. Therefore, we look for viable approaches.

We need "new spectrum," and we also need mechanisms to address the "tragedy of the commons" problem [10] with the allocated spectrum. The tragedy of the commons is a dilemma arising from the situation in which multiple individuals, acting independently and rationally, consulting their own self-interest, will ultimately deplete a shared limited resource, even when it is clear that it is not in anyone's long-term interest for this to happen. This dilemma was described in an influential article titled "The tragedy of the commons," written by ecologist Garrett Hardin and first published in the *Science* journal in 1968 [10]. Therefore, unless some sort of regulation is implemented, the rational strategy for individual users never produces Pareto optimality among permitted users [6]. This optimality is also borrowed from game theory arguments, except that here the users have a self-policing or self-regulation imposed on them.

Self-regulation is achieved by utilizing higher frequency carriers. Higher frequency waves above 30 GHz tend to travel only a few miles or less and generally do not penetrate solid materials very well. This offers a sustainable solution for the current spectrum crunch [2]. Actually, the July, 1997 Federal Communications Commission's Office of Engineering and Technology in USA Bulletin #70 "Millimeter Wave Propagation: Spectrum Management Implications" [11] reads thus: "The absorption bands (e.g., at 23 GHz or 60 GHz) would be applicable for high data rate systems where secure communications with low probability of intercept is desirable; for services with a potentially high density of transmitters operating in proximity; or for applications where unlicensed operations are desirable."

To address the spectrum scarcity problem in current wireless systems, we are examining the concept of adaptive rate delivery of future mobile and portable multimedia services with high bit rates (>100 Mbps) for localized areas [4]. The motivation for operators of such bands to actually choose to self-limit is that by doing so, they improve the signal-to-noise ratio against competing users at a lower cost than trying to overcome interference. These characteristics of wave propagation are not necessarily disadvantageous as they enable more densely packed communications links. Thus, high frequencies can provide very efficient spectrum utilization through "selective spectrum reuse," and naturally increase the security of transmissions. Hence, OWC is a direct solution in the spectrum reuse scenario.

Two branches of optical wireless have emerged contemporaneously. In one branch, semiconductor LED is considered to be the future primary lighting source for buildings, automobiles, and aircrafts. LED provides higher energy efficiency compared to incandescent and fluorescent light sources, and it will play a major role in the global reduction of carbon dioxide emissions, as a consequence of the significant energy savings. Lasers are also under investigation for similar applications. These core devices have the potential to revolutionize how we use light, including not only for illumination but also for communications, sensing, navigation, positioning, surveillance, and imaging. The second branch uses coded optical signals within two coherent optical side bands centered at different wavelengths. The two sidebands, at least one of which carries a message, are transported over long distances to a broadcast station, at which point, heterodyne interference of light within the two bands produces an electromagnetic wave at microwave or millimeter wave frequencies that is modulated by the lower frequency optically coded message. The electromagnetic wave carrying the coded message is then broadcast by an antenna. A wireless receiver can reply wirelessly over a return path via an electrically generated wave carrying an electrically generated coded message. Wired optical networks and various wireless networks are thus merged. Each of the optical wireless networks briefly described earlier has its unique applications, message coding, security features, and technology for sending and receiving messages. Among applications in this area are multiband, multiservice wireless over optical access, distributed radio-over-fiber access network for cloud-computing, broadband millimeter-wave wireless sensor communications, and microwave photonics for integrated multigigabit wireless systems.

Visible light and infrared light (IR) exhibit very similar qualitative behavior because of the closeness of their wavelengths; however, in terms of indoor communications, only IR has been used mostly until now. The reason is that until recently, it was not possible to manufacture highly efficient WLEDs. As LEDs increasingly displace incandescent lighting over the next few years, general applications of VLC technology are expected to include wireless Internet access, vehicle-to-vehicle communications, broadcast from LED signage, machine-to-machine communications, positioning systems, navigation, and so on. The VLC technology has potential in a number of specialized application areas including the following: (i) Indoors/Outdoors Light Positioning System (LPS) in analogy to GPS; (ii) Light Navigation Systems; (iii) Hospital and Healthcare—enabling mobility and data communications in hospitals; (iv) Hazardous Environments—enabling data communications in environments where RF might be potentially harmful (i.e., Oil and Gas, Petrochemicals and Mining); (v) Commercial Aviation—enabling wireless data communications such as in-flight entertainment and personal communications; (vi) Corporate and Organizational Security—enabling the use of Wireless Networks in applications where Wi-Fi presents a security risk; (vii) Wi-Fi Spectrum

此为试读,需要完整PDF请访问: www.ertongbook.com