Optical Code Division Multiple Access

A Practical Perspective

This book is a comprehensive guide to optical fiber communications, from the basic principles to the latest developments in OCDMA for next-generation Fiber-to-the-Home (FTTH) systems. Part I starts with the fundamentals of light propagation in optical fibers, multiple access protocols, and their enabling techniques. Part II is dedicated to the practical characteristics of current and next-generation passive optical network (PON) technology. It covers the key building blocks of OCDMA devices such as optical encoders and decoders, signal impairment due to noise, and data confidentiality, a unique property of OCDMA. This is followed by a discussion of hybrid system architectures with TDM and WDM and practical aspects such as system cost, energy efficiency and long-reach PONs. Featuring the latest research, with cutting-edge coverage of system design, optical implementations, and experimental demonstrations in testbeds, this text is ideal for students, researchers and practitioners in the industry seeking to obtain an up-to-date understanding of optical communication networks, particularly optical access networks.

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To my wife, Michiyo, my daughters, Hiromi and Midori

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Preface

Between 2000 and the end of 2011, almost two thirds of subscribers to the plain old telephone service (POTS) in Japan switched to the broadband service, and half of the subscribers to the broadband service are now connected to the Fiber-to-the-Home (FTTH) system. The rate of increase in new FTTH subscriptions is already showing signs of leveling off. This is the case not only in Japan but also in the rest of the world where a similar trend will be observed in the near future as the FTTH system becomes widespread.

This rapid growth of the broadband service, along with the emerging need for back-hauling the huge data traffic of mobile phones and inter-data center traffic, will eventually trigger the problem of "capacity crunch" in long-haul optical fiber transmission systems. The capacity crunch happens when the data traffic to be transferred from one end of the network to the other end overflows the total capacity of optical fiber cables deployed on the planet. Only incessant innovation of the transmission system and optical network technologies can solve this problem. Technologies of optical fiber transmission systems currently under intense development include digital coherent transmission and space division multiplexing (SDM). There are two approaches to SDM: one is via a multicore fiber which has a number of cores embedded in the cladding of the fiber, and the other is mode division multiplexing (MDM) via a multimode fiber which supports more than one waveguide mode. The digital coherent transmission has the capability of equalizing the impairments of multi-level phase-shift-keying modulated optical signals, incurred by chromatic and polarization dispersions and non-linear effects, with the aid of powerful digital signal processing (DSP). This is a result of rapid progress in silicon complementary metal oxide semiconductor (CMOS) LSI technology, underpinned by Moore's law. In this way, the limitations in the transmission distance and the bit rate have been overcome, although the system is not perfect.

Such advanced technologies developed for backbone networks will be adopted in metro/access networks after a few or ten years as their costs go down. For example, the first commercial 10 Gb/s system was deployed in a long-haul transmission line between Tokyo and Osaka in Japan in 2003, and now the commercial 10 Gb/s passive optical network (PON) is almost ready to be deployed. Thus, current optical access networks will soon evolve to the next-generation (NG) PON with higher bit rate and longer reach. A forum of the world telecommunications industries has studied a roadmap of the NG-PON: one system is NG-PON1 aiming at evolutionary growth, which supports "brown field" deployment, and the other is NG-PON2 aiming at revolutionary growth, supporting

a "green field" deployment. Note that in the brown field deployment newly introduced technology has to coexist with ongoing PONs, while the green field deployment can be disruptive, with little requirement for coexistence with other PONs. At the time of writing, the objective of NG-PON2 has been altered from revolutionary to evolutionary. However, this will not be the end of the NG-PON scenario because there remain plenty of green fields on the globe where a revolutionary technology might be deployed from the beginning. Therefore, further advanced NG-PON in a true sense is likely to appear on the scene as post NG-PON2.

Optical code division multiple access (OCDMA) has been emerging as a promising technology of choice for the NG-PON. OCDMA has unique capabilities such as fully asynchronous transmission, low latency access, and soft capacity on demand. Another advantage is inherent data confidentiality. Messages are encoded at the transmitter and can be recovered only by the authorized subscriber, who knows the optical code.

This book should be valuable to both students at universities and mid-career professionals in the telecom industry. I reference very recent research progress as much as possible, which will be useful to researchers in this field. This book can be added to collections as a popular item in university libraries and R&D centers of industry. Parts I and II in this book serve different purposes. Part I is devoted to the fundamental technology underlying optical fiber communications. Part II offers an extensive coverage of a wide variety of technologies, relevant to OCDMA-PON systems. Those who are new to this field would be better to start with Part I and then proceed to Part II. Part II is for those who have a solid background in optical communication and networks but need to understand the practical perspectives and future-proof technology of FTTH systems. To aid in teaching and learning the material, selected problems are provided at the ends of the chapters in Part I.

The book consists of ten chapters with the following organization. Chapter 1 offers an introduction to optical fiber communications and networks. In Part I, Chapter 2 describes the basics of PONs and multiple access techniques. Chapter 3 describes how light propagates in an optical fiber and what the guided modes are. In Chapter 4 the model and building blocks of optical transmission systems as well as the methodology of performance evaluation are described. Chapter 5 deals with enabling techniques of OCDMA. In Part II, Chapter 6 defines OCDMA, including its roots, system classification, and noise unique to OCDMA. In Chapter 7 various techniques of optical encoding and decoding are described. Chapter 8 covers data confidentiality which is inherently provided with OCDMA. Chapter 9 offers an extensive coverage of experimental demonstrations done by the author's group in the OCDMA testbeds, including hybrid systems of TDM-OCDMA, WDM-OCDMA, and WDM-TDM-OCDMA PONs, followed by space-OCDMA. Chapter 10 includes a comparison of the cost and the power consumption of various PON systems, applications of optical code labeling in optical networks, and practical aspects of PON such as testing and equipment, and safety issues with respect to exposure of the human body.

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