MILORAD CVIJETIC

Optical Transmission

SYSTEMS ENGINEERING

Optical Transmission Systems Engineering

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Optical Transmission Systems Engineering

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Preface

Optical transmission systems deliver information between two distinct physical locations through optical fiber, while achieving a specified system performance. System performance is dependent on a number of parameters related to the transmission signal and conditions and effects that might occur during signal generation, propagation, amplification, and detection. Optical transmission systems engineering can be understood as a process in which these parameters are combined in the most favorable way possible with respect to a defined performance goal.

This book is aimed at enabling the reader to attain a broader perspective of the parameters involved in the transmission of optical signals, gain insight into the systems engineering process, and discuss potential trade-offs between different system parameters and transmission system optimization. It is structured to provide straightforward guidance to readers looking to capture systems engineering fundamentals and gain practical knowledge that can be easily applied. As such, it provides an understanding of parameters and processes involved in overall engineering considerations and establishes conservative (worst case) scenarios that serve as a reference and reality check for any other calculations. In addition, it builds up the knowledge and skills necessary for using numerical modeling and computer-based calculations.

The theme of the book is simple: it consists of the stated goal (optimized optical system engineering), the key system parameters that make the system operate properly, and the impairments that degrade the system characteristics. These three elements will be put together to form a seamless functional relationship. The reader will be guided from the basics (described in an encyclopedic manner), through relevant parameters and impairments, to systems engineering and trade-offs. The process of optical transmission system engineering is explained in detail with several examples related to real-world applications. There are a number of tables throughout the book that contain the practical data related to system engineering parameters.

The principal objective of this book is to serve as a handbook to systems engineers dealing with optical transmission line design and planning in both vendor and carrier communities. This includes engineers, product managers, and network planners. Developers and researchers interested in entering the field of optical networking will also find this book beneficial since it contains topics related to advanced optical transmission technologies and solutions. The secondary objective of the book is to act a reference manual to an audience of graduate and undergraduate students of electrical engineering, as well as the attendants of the short courses organized by leading technical conferences related to optical communication topics.

Finally, the book can serve as a guide for technical managers and marketers who wish to become more familiar with the large spectrum of issues and solutions related to optical transmission systems.

The subject of the book is not limited to any particular geographical region, or any specific transmission scenario. The background knowledge necessary to study this book and fully understand the topics is that of a typical senior-year undergraduate engineering student.

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I would like to express my appreciation to the scientists and engineers whose contributions from open literature were the basic material for this book. I am very grateful to numerous colleagues from both industry and academia for the useful discussions we have had in the past. I also extend my personal thanks to my friends from NEC Corporation for their helpful suggestions and comments. Finally, I would like to express my deep gratitude to my wife Rada and my daughters Neda and Marija for their unconditional moral support and understanding.

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Contents

CHAPTER 1

Introduction to Optical Bandwidth and Lightwave Paths

This chapter introduces all relevant parameters and defines terms associated with optical transmission systems engineering. It should help the reader to establish a clear picture about both the subject and the goal of the engineering process. In addition, this chapter should help the reader to recognize the place and the role of optical components and modules placed along the lightwave path.

A number of parameters related either to optical signal or to different impairments will have an impact on the transmission quality. Optical transmission systems engineering can be understood as a process in which these parameters are combined in the most favorable way with respect to a defined goal. In most cases the defined goal is identified through the required bit error rate of the optical bandwidth channel over specified transmission distance, which is associated with the lightwave path.

Optical bandwidth channels and lightwave paths, which are introduced in this chapter, are the main objects of optical systems transmission engineering. In addition, the structure and basic principles of digital signal transmission over optical fibers and the role of the key optical elements are also described in this chapter.

1.1 Optical Transmission and Networking

We live in time officially proclaimed as "the information era," which has been characterized by the insatiable demand for information capacity and distance-independent connectivity. Internet data traffic has become the driving force behind this demand, requiring a networks infrastructure of huge information capacity, as well as equipment and methods that can tailor the bandwidth and deliver it to an end user. Optical networking technology has become closely related to Internet technology with the same ultimate goal: to satisfy these never-ending demands for bandwidth and connectivity in a sophisticated and automated manner.

Optical transmission links have been built all around the globe. High-capacity submarine optical transmission links are being built to connect continents and provide protected transmission of data, while multiple terrestrial physical optical fiber–based networks have been built both for transmission and distribution of different bandwidth channels. The optical fiber connection has been coming all the way down to the curb, building, home, and the desk.

Both theoretical and operational aspects of optical networking and optical transmission have been widely analyzed in open literature, such as [1–5]. The operational aspect has also been captured under recommendations from different national and international standards institutions [6–12]. There are also a number of publications that provide more detailed treatment of specific subjects related to optical transmission and networking [13–18].

In terms of ownership, networks and transmission systems can belong either to private enterprises or be owned by telecommunication carriers. Ownership can be related either to networking equipment and infrastructure associated with a specified network topology or to a logical entity known as the optical virtual private network that resides within the physical network topology.

The optical networking structure can be represented by three concentric circles, as shown in Figure 1.1. The central part of this structure is a long-haul core network interconnecting big cities or major communication hubs. The connections between big cities on different continents have been made by using submarine optical transmission systems. The core network is a generic name, but very often it can be recognized as either a wide area network (WAN) if it belongs to an enterprise or as an interchange carrier (IXC) network if operated by telecommunication carriers.

The second part of the optical network structure is the edge optical network, which is deployed within a smaller geographical area (usually in a metropolitan area or smaller geographic region). The edge network is often recognized as a metropolitan area network (MAN) if it belongs to an enterprise or as a local exchange carrier (LEC) network if operated by telecommunication carriers. Finally, the access network is a peripheral part of the optical network related to the last-mile access and bandwidth distribution to the individual end users (corporate, government, medical, entertainment, scientific, and private). Access networks examples include the enterprise local area networks (LAN) and a distribution network that connects the central office location of a carrier with individual users.

The physical network topology that best supports traffic demand is generally different for different parts of the optical networking structure presented in Figure 1.1. It could vary from mesh (deployed in the core and edge networks), to ring

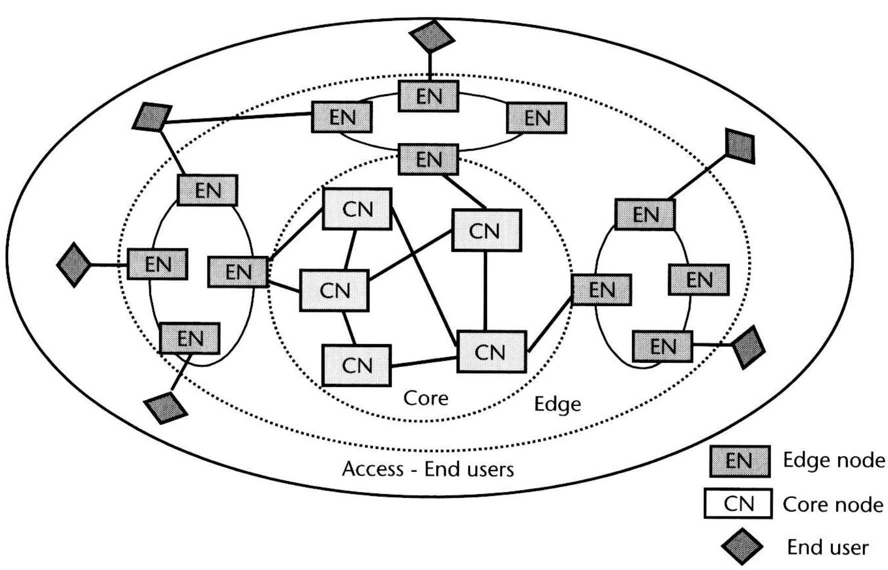

Figure 1.1 Optical networking structure.

(deployed in all portions of a global network), or to star topology (deployed mostly in an access network). From the optical transmission engineering perspective, the optical network configuration is just a mean to support an end-to-end connection via the lightwave path. Therefore, optical transmission engineering is related to the physical layer of an optical network, and takes into account the optical signal propagation length, characteristics of deployed optical elements (fibers, lasers, amplifiers, and so forth), the impact of the networking topology and bandwidth distribution, the characteristics of the signal that need to be delivered from the source to destination, and the quality of services (QoS) requirements.

In this book we will introduce the fundamentals of optical transmission system engineering by assuming that a digital electrical signal carries information that enters and exits the optical transmission system. The term "digital" is related to the waveform at the input of the optical transmission system. We assume that it is an electrical signal with two discrete levels, which occupy a specified time slot. The lower level is recognized as the logical space, or zero (0) bit, while the upper level is recognized as the logical mark, or one (1) bit. The bits are aligned along the time coordinate and form a data stream, which is characterized with the corresponding bit rate. The bit rate is expressed in bits per second, which means that it measures a number of bits, either 0 or 1, occurring during a second-long time interval. In practice, that number is very high, and bit rate is expressed in units such as kilobit per second (Kbps), megabit per second (Mbps), and gigabit per second (Gbps).

The ultimate goal of proper optical system engineering is to deliver the information bandwidth from one physical location to the other in the most economical way, while achieving required QoS. This can be done by establishing the most favorable relationship between a number of variables that characterize the signal and different impairments (such as noise, nonlinear effects) within a specific transmission scenario. The scope of the optical transmission system engineering is to understand how to minimize the effect of different impairments, learn how to allocate system margin to cope with remaining destructive effects, and how to make trade-offs between different design parameters to achieve the goal mentioned above.

1.2 Optical Transmission System Definition

The simplest optical transmission system is a point-to-point connection that utilizes a single optical wavelength, which propagates through an optical fiber. The upgrade to this topology is deployment of the wavelength division multiplex (WDM) technology, where multiple optical wavelengths are combined to travel over the same physical route.

The WDM has proven to be a cost-effective means of increasing the bandwidth of installed fiber plant. While the technology originally only served to increase the size of the fiber spans, it gradually became the foundation for optical networks. In an optical networking scenario, different signals are transported over arbitrary distances, while the wavelength routing can take a place at specified locations. The WDM technology is sometimes named with different prefixes—dense-WDM (DWDM), course-WDM (CWDM), or ultra-dense-WDM (UDWDM)—used to reflect a specific multiplexing technique used.