Stamatios Kartalopoulos

Next Generation Intelligent Optical Networks

From Access to Backbone

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To my wife Anita for her love and support

Preface

Optical networks have been in commercial deployment since the early 1980s as a result of advances in optical, photonic, and material technologies. Although the initial deployment was based on silica fiber with a single wavelength modulated at low data rates, it was quickly demonstrated that fiber can deliver much more bandwidth than any other transmission medium, twisted pair wire, coaxial cable, or wireless. Since then, the optical network evolved to include more exciting technologies, gratings, optical filters, optical multiplexers, and optical amplifiers so that today a single fiber can transport an unprecedented aggregate data rate that exceeds Tbps, and this is not the upper limit yet. Thus, the fiber optic network has been the network of choice, and it is expected to remain so for many generations to come, for both synchronous and asynchronous payloads; voice, data, video, interactive video, games, music, text, and more.

In the last few years, we have also witnessed an increase in network attacks as a result of store and forward computer-based nodes. These attacks have many malicious objectives: harvest someone else's data, impersonate another user, cause denial of service, destroy files, and more. As a result, a new field in communication is becoming important, communication networks and information security. In fact, the network architect and system designer is currently challenged to include enhanced features such as intruder detection, service restoration and countermeasures, intruder avoidance, and so on. In all, the next generation optical network is intelligent and able to detect and outsmart malicious intruders.

This is the first book, to the best of my knowledge, which bridges two disjoint topics, optical networks and network security. It provides a comprehensive treatment of the next generation optical network and a comprehensive treatment of cryptographic algorithms, the quantum optical network, including advanced topics such as teleportation, and how detection and countermeasure strategies may be used. Therefore, we believe that this book differentiates from many others and presents a holistic approach to the treatment of secure optical networks, including fiber to the home (FTTH) and free space optical (FSO).

This book deserves my thanks and appreciation because it came into being after the persistence of Mr. Jason Ward, the expert "literal" eyes of Mrs. Caitlin Womersley, and the many management and production personnel of Springer US anonymous to me.

I hope that the next generation optical network will be intelligent, and when using wireless technologies at the edge, it will enable unlimited and secure communication multi-services with a single and portable device to anyone, anyplace, anytime at low cost.

Stamatios V. Kartalopoulos, Ph.D.

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Introduction

Optical technology and its applicability in communication networks has intrigued scientists and communications engineers alike. The reason is simple: fiber optic networks are the only ones that can transport at the speed of light a humongous amount of data in the unit of time.

Since the first optical protocol came into being, SONET/SDH has been proven for robustness, bandwidth transport and fast switching to protection. However, the transportable bandwidth and data was soon overrun by an unsaturated bandwidth appetite and new services. Within a decade or so, this led to a new optical network that was based on an optical and photonic technology known as dense wavelength division multiplexing (DWDM). The success of this optical network helped to solve the amount of transportable traffic, although at the same time it created a bottleneck at the network edge or access. Currently, different technologies are under development, and fiber is deployed at the access using an almost passive optical network (PON) technology suitable for fiber to the premises (FTTP). At the same time, new protocols have been developed to allow for a variety of payloads to be transported over the optical network.

As a consequence, the next generation optical network must be backwards compatible with traditional networks and also include nontraditional characteristic features and intelligence. Among these are protocol adaptability, future proofing, bandwidth elasticity, scalability, service protection, and security, both network and information. Security is an emerging topic in optical networks, and highly sophisticated algorithms and methods are under development and also under scrutiny to assure that they will not be outsmarted by sophisticated intruders.

This book provides a comprehensive treatment of the next generation intelligent optical networks, from access to the core where it also provides an insight into new protocols, connectivity management, and network security. Chapter 1 provides an introduction to telecommunications network from which the digital network evolved, which is described in Chapter 2. Chapter 3 describes the modern DWDM network and the technology that makes it possible. Chapters 4 and 5 provide a description of the next generation optical network, NG-SDH and OTN, and the new protocols that enable them to transport all known protocols mapped in a common payload envelope efficiently, reliably, and protectively. Chapter 6 describes the synchronization aspects of modern optical networks, and Chapter 7 describes the current issues with network and link performance, as well as methods for in-service and real-time performance estimation, BER, SNR, Q, and more. Chapter 8 describes the traffic management and control and wavelength management strategies that are needed by the multi-wavelength intelligent optical network of today and tomorrow. Chapter 9 describes network protection and service protection strategies as well as fault management. Network and information security is a growing concern of users, network providers, and government. As a consequence, we have enhanced this book with a thorough description of network security from the application/information layer to MAC and to physical layer. In this chapter, we review cryptographic methods including quantum cryptography and we describe detection methods and countermeasures. Finally, Chapter 11 provides a discussion on key issues of the next generation intelligent optical network such as protocol and service convergence, portability, security, backward compatibility and retrofitting, and more.

It is my hope that this book will excite and stimulate the interest of the reader in the exciting Next Generation Intelligent Optical Network and it will aid in the development of robust, efficient, and cost-effective systems and networks that will help develop and offer novel services, cost-efficiently and securely.

Stamatios V. Kartalopoulos, Ph.D.

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Chapter 1
Communication Networks

1.1 Analog and Digital Transmission

The transmission of analog electrical signals over twisted pair copper cables emulates the acoustic voice signal within a narrowband between 300 and 3,400 Hz within a 4,000 Hz frequency band; the unused spectrum 0–300 and 3,400–4,000 Hz provides a guardband and also a useful sub-band for out-of-band signaling.

As demand for service increases, the analog signal, being subject to attenuation and electromagnetic interference, is difficult to multiplex with other signals reliably and cost-efficiently. However, if the analog signal is converted to digital, then the multiplexing problem is greatly simplified at the small expense of better engineered trunk lines. Based on this, the analog signal is periodically sampled at 8,000 samples per second [1, 2], and each sample is converted to eight bits via a coder-decoder (CODEC) using a nonlinear digital pulse coded modulation (PCM) method, Fig. 1.1. Thus, the signal is converted to a continuous 64 Kbps digital signal, known as digital service level 0 (DS0), Fig. 1.2. Having converted the analog signal to digital PCM, many signals can be multiplexed by upping the bit rate accordingly, based on an established digital hierarchical network [3, 4]. Thus, 24 DS0s are multiplexed to produce a digital service level 1 (DS1) signal at 1.544 Mbps and other higher data rates, Table 1.1.

Up to the 1970s, the established digital hierarchy was sufficient to meet the communication bandwidth demand and service needs, if one also considers regulations that did not allow to mix services such as voice and video despite the fact that video over DS1 lines and the videophone had already been demonstrated. However, this was a decade where personal computers and the Internet were in embryonic phase and phone service in the United States was dominated by the old American Telephone and Telegraph Corporation or AT&T; it was the era when the POTS telephone device was permanently connected on the wall and it was also the property of the phone service provider.

At about the beginning of the 1980s, a need for integrated digital services over the same loop came about, but these services were by far close to the services we have today: the equivalent of two voice channels and a subrate 8 Kbps to a total of 144 Kbps. However, at the time this was a radical loop technology and several experiments were (successfully) demonstrated that eventually led to what is known as ISDN (integrated services digital network) and to DSL (digital subscriber line) [5–11].

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* The content of this book is intended to have illustrative and educational value and it should not be regarded as a complete specification of Next Generation Networks or any protocol described herein. The information presented in this book is adapted from standards and from the author's research activities; however, although a serious effort has been made, the author does not warrant that changes have not been made and typographical errors do not exist. The reader is encouraged to consult the most current standards recommendations and manufacturer's data sheets.

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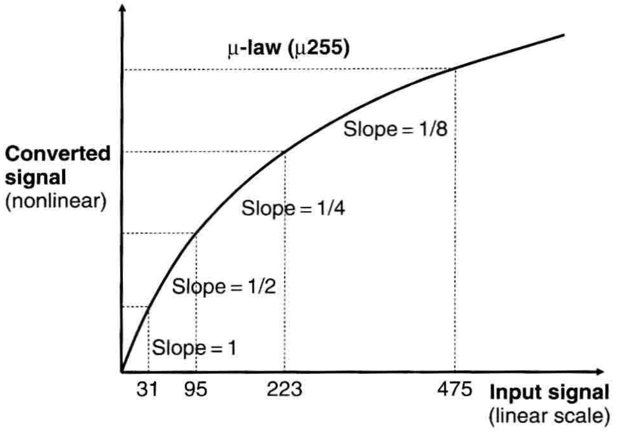

Fig. 1.1 Transfer function for converting linear binary to digital PCM code according to a weighted (nonlinear) curve known as μ-law (in Europe, a similar transfer function is used known as α-law)

Since then, microelectronics have demonstrated an exponential increase in transistor density, antennas have been miniaturized, displays have become ultrathin with very high resolution, novel modulation methods have been deployed, printed circuit technology and packaging have been advanced, and batteries with extended life have been miniaturized. As a consequence, the initial portable or mobile phone that was based on analog signal (AMPS) is slowly being replaced by digital transmission techniques that support voice, data, and low-resolution video.

These incredible advancements over just three decades have opened an appetite for new services and more bandwidth that the traditional communication network was running short in bandwidth capacity. At about the same time, in the 1970s, a new transmission medium became available, the optical fiber based on silica. This medium, being highly purified and with a highly controlled refractive index profile in its core, was able to transport optical signals at unprecedented data rates

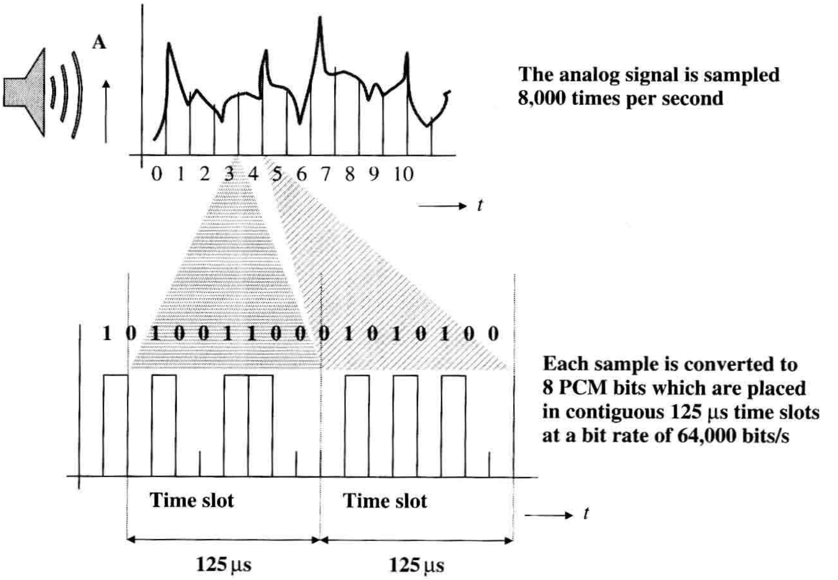

Fig. 1.2 The analog signal is sampled 8,000 times per second, and each sample is converted to eight PCM bits placed in 125 μs concatenated time slots to generate 64 Kbps (DS0)

Table 1.1 Bit rates in the legacy telecommunications non-optical network

Facility	United States	Europe	Japan
DS0/E0	64 Kbps	64 Kbps	64 Kbps
DS1	1,544 Kbps		1,544 Kbps
E1		2,048 Kbps	
DS1c	3,152 Kbps		3,152 Kbps
DS2	6,312 Kbps		6,312 Kbps
E22		8,448 Kbps	
			32,064 Kbps
E31		34,368 Kbps	
DS3	44,736 Kbps		
DS3c	91,053 Kbps		
			97,728 Kbps
E4		139,264 Kbps	
DS4	274,176 Kbps		
			397.2 Mbps

and distances without amplification. With the first optical transmission demonstration, it was immediately realized that fiber optics is a disruptive technology and the future of telecommunications will be exciting and it will allow for services that could be found in science fiction only. Today, videophones, teleportation effects, remote surgery, online banking, and many more futuristic services convince us that "the future is here, now".

The rapidly changing information and communications technologies have summoned World Economic Forums at a high level to negotiate on trade agreements in an effort to set the trade rules in Internet, mobile telephony, video formatting, music formatting, communication technology and networking, security, and other technological developments.

1.2 Breaking the Traffic Barrier

Data traffic has exceeded voice traffic and it is in an explosive path as a result of an abundance of new data services that are offered over the access network. One part that has contributed to this explosive increase in data traffic is emerging wireless, wired, and optical technologies and new techniques that in their own way have increased the accessible bandwidth; digital wireless access technology has enabled Mbps and optical access Gbps allowing for multiplay services, voice, data (IP, Ethernet), and music and video (broadcasting and interactive, streaming, and real time). Another part that contributed to data traffic explosion is new end devices (or gadgets) that have taken advantage of advances in hybrid microelectronics, display technology, RF technology, miniaturized batteries, and advanced packaging; end devices are versatile, pocket size, and affordable. Finally, a third part that has contributed to this explosion is an aggressive pricing model that appeals to very young and to mature customers and a revenue-flow model that satisfies the service providers. One can also add a fourth contributor, an aggressive competitive environment so that every 3 months or so a new gadget becomes available that is smaller, more versatile, more capable, and at lower cost. Thus, the old paradigm of having the same telephone for several years has changed, and telephones have become a perishable commodity so that one may go through few generations in a single year as a result of an appetite for new services and capabilities that cause a bandwidth aggregation which can only be accommodated by high bandwidth access networks.

In addition to high bandwidth demand, many new data services demand quality of service (QoS), reliability, availability and real-time deliverability comparable with that of the legacy public digital synchronous network, as well as bandwidth elasticity, and bandwidth on demand, which only the next generation network can provide.