Hongxi Yin
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光码分多址通信网络

理论与应用

Optical Code Division Multiple Access Communication Networks

Theory and Applications

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Preface

The customized and service-orientated all-optical network can implement ultrahigh speed transmitting, routing and switching of data in the optical domain, and has the transparency to data formats and protocols which increases network flexibility and functionality such that future network requirements can be met. OCDMA technology is one of the promising technologies to implement all-optical networks, which has the potential to exploit the previously unmined bandwidth of optical fiber and take advantage of the predominance of radio CDMA, such as subscribers' flexible and effective sharing of the spectrum and time and space resources, and resisting jamming and eavesdropping.

OCDMA is a category of multiplexing and internetworking technologies that encodes/decodes signals through employing simple and cost-effective passive optical components (not requiring optical logic components) such that the signal multiplexing, routing and switching can be implemented smoothly. It has many advantages, such as asynchronous random access, simple management, flexible networking, good compatibility with WDM and TDM, suitable for bursty traffic, supporting multiple services and differentiated QoS, while providing some confidentiality of data transmission. It is a very important technology to implement optical access networks, metropolitan area networks and optical signal multiplexing and switching in backbone networks.

OCDMA has a twenty-year history from its first proposal and its first experimental demonstration in principle. However, since the information capacity demands were so much smaller and the development scale of communication networks was so limited in the past, the current higher functionalities of networks were not required. At the same time, WDM technology provided the transmission tunnels and wavelength switching for ultrahigh speed data, which could then meet the earlier demands of optical network functionalities. Therefore, OCDMA has remained outside the mainstream of optical communication research for a long time. However, at present, with the advent of the knowledge economy and the global reach of the Internet, the disharmony between the service provisions of transport networks and access networks is becoming a serious issue. Meanwhile, there exist many issues in data backbone networks, such as the electronic node bottlenecks, clumsy and low-efficient granularity of traffic, and so on.

To solve these current issues, it seems that the ability of WDM and TDM technologies is inadequate while, the high networking flexibility of OCDMA and the very good complementary properties of OCDMA with WDM and TDM are now recognized. Simultaneously, due to the rapid advancement of optical component technologies, all aspects of OCDMA technologies have become research hotspots, which should boost OCDMA development.

In this book, the first chapter introduces the evolution of optical communication systems and networks, and the status and role of OCDMA in optical communication systems and networks. The history of the main encoding/decoding theories and technologies, the composition and performance analyses of systems, and the network architectures and applications obtained are provided, including the published research results acquired by the research teams of the authors of this book and a number of newly proposed and improved schemes of existing technologies. The reader may wish to validate some of them through experiments.

In terms of the superposition behavior of optical signals, OCDMA can be categorized as either incoherent OCDMA or coherent OCDMA. Furthermore, incoherent OCDMA is mostly divided into one-dimensional temporally encoding OCDMA, spectral amplitude encoding OCDMA and two-dimensional wavelength-hopping/time-spreading encoding OCDMA, etc. The coherent OCDMA is mainly classified into spectral phase encoding OCDMA and temporal phase encoding OCDMA and so on.

In the second and third chapters we introduce the cardinality bounds, various constructions, performances and constructed examples of one- and two-dimensional codes. In the second chapter, we first give the definitions, the bounds on their cardinalities, diverse constructions and performance of the unipolar codes suitable for one-dimensional incoherent OCDMA. These codes include constant-weight symmetric OOCs, constant-weight asymmetric OOCs, variable-weight OOCs, prime codes, extended prime codes and modified prime codes, quadratic congruence codes, extended quadratic congruence codes and synchronous quadratic congruence codes, etc. Then the size, the generating methods and performances of the bipolar codes employed by spectral phase encoding and temporal phase encoding for the coherent OCDMA are discussed in detail. These bipolar codes encompass m-sequences, Gold codes, Walsh-Hadamard codes and the asymptotically optimal 4-phase codes. At the same time, after being modified, these codes can also be applied to the incoherent spectral amplitude OCDMA encoding. In addition, the combinations amongst these codes can be used to construct 2-D WH/TS codes that are well-suited for incoherent 2-D WH/TS OCDMA systems.

The third chapter describes the definition of 2-D WH/TS OCDMA codes, which can be applied to 2-D incoherent OCDMA networks, the constructions of

2-D incoherent OCDMA codes with OOC, PC, EQCC, OCFHC, m-sequence, Walsh-Hadamard codes, CHPC, etc., and the performance analysis of these codes. These two-dimensional WH/TS incoherent OCDMA codes include multiple wavelength optical orthogonal codes, PC/PC codes, PC/EQCC codes, OOC/PC codes, PC/OOC codes, OCFHC/OOC codes, B/U and B/B codes with the differential detection, MLEWHPC codes implementing multiple bit rates, multiple services and multiple QoS and so on.

In the fourth chapter, the operational principle of OCDMA optical encoding and decoding, and a large number of implementing schemes and techniques are illustrated, which include one-dimensional incoherent fixed and tunable optical encoders and decoders with time encoding, two-dimensional incoherent wavelength-hopping/time-spreading fixed and tunable optical encoders and decoders, the spectral-amplitude incoherent optical encoders and decoders, the incoherent 2-D bipolar/unipolar optical en/decoders and the coherent spectral-phase and temporal-phase optical en/decoders, etc.

The fifth chapter presents the existing and representative analysis approaches of system performance with the different receiver models that have been proposed in references, and shows a large number of simulating results on system performance. These systems include one-dimensional incoherent OCDMA systems with the correlation receiver models and the chip-level receiver models, two-dimensional incoherent OOK-OCDMA communication systems, the spectral amplitude encoding incoherent OCDMA system based on fiber-optic Bragg gratings, and the spectral phase encoding and the temporal phase encoding coherent OCDMA systems. These analysis methods are very helpful for the analysis and design of OCDMA systems.

In the last chapter, OCDMA network architecture, primary research results on OCDMA local area network protocols and applications of OCDMA technologies are detailed, focusing on OCDM/WDM hybrid multiplexing, the interconnections of OCDMA networks with OTDM networks and WDM networks, OCDM/WDM hybrid networks, the architectures of OCDMA LANs, the primarily random access protocols of OCDMA LANs, optical packet switching networks with optical code labels, data transmission confidentiality provided by OCDMA networks, and some other applications of OCDMA. This content has very important reference value for OCDMA network design and for further advancement of the research on OCDMA applications.

Many advantages of OCDMA technology and novel demands for coming optical network functionalities make OCDMA technology very promising from an application perspective. After a long period of neglect, OCDMA has become a research hotspot in optical communication technologies in recent years, making great progress. However, in order to push forward the application of OCDMA technology, great efforts are still required by researchers in the OCDMA community. This book systematically presents OCDMA optical coding/decoding theory and implementation techniques, systems and networks, which adequately reflect the current global research results on OCDMA theory and experiments. It is a valuable textbook or reference book for postgraduates majoring in telecommunication to obtain a well-knit theoretical foundation and for engineering technicians in the fields of R&D and management of optical fiber communications.

The authors regret any omissions or errors, and reader comments or suggestions will be warmly welcomed.

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Hongxi Yin

Contents

1 Introduction

1.1 Developments and Applications of Optical Fiber Communication Systems and Networks

1.1.1 Optical Fiber Communication Systems

Optical fiber communication is a communication approach to transport information from one point to another using light as a carrier and optical fibers as transmission media. In ancient times, in order to speed up information transmission, people learned how to use optical signals, such as smoke signals, semaphores, etc., to communicate. However, the utility of these methods was very limited. In the early 1960s, American physicists invented the ruby laser[1], and the proposals for optical communication via dielectric waveguides or glass optical fibers to avoid degradation of the optical signal by the atmosphere were made almost simultaneously in 1966 by Kao and Hockham[2] and Werts[3]. Initially the optical fibers exhibited very high attenuation (i.e., 1000dB/km) and were therefore not competitive with the coaxial cables which they were to replace (i.e., 5 to 10dB/km). In 1970, the Corning Company in America manufactured a fiber-optic with attenuation of 17dB/km, and the optical fiber losses at 1310 nm wavelength were reduced to 0.3dB/km[4] in 1974. In 1977, the field trial of the first commercial use of the multimode fibers between two telephone offices in Chicago 7000 meters distant was made successfully[5].

As the transmission media of communication, optical fibers have many advantages[6].

(1) Enormous communication capacity. In general, the capacity of communication depends on the carrier frequency. The higher the carrier frequency, the larger the available transmission bandwidth and thus the greater information capacity of the communication systems. The optical carrier frequencies in the range of 10^{13} to 10^{16} Hz (generally in the near infrared around 10^{14} Hz or 10^{5} GHz) can yield a far greater potential transmission bandwidth than metallic cable systems (i.e., coaxial cable bandwidth up to around 500 MHz) or even millimeter wave radio systems (i.e., system currently operating with modulation bandwidths of 700 MHz). Furthermore, introducing wavelength division multiplexing (WDM)[7] even more bandwidth in the fiber-optic can be utilized. Thus, many orders of magnitude are gained with optical fibers.

(2) Low transmission loss. The attenuation or transmission losses in optical fibers are very low, in contrast with that in the best metallic cable. Optical fibers have been fabricated with losses as low as 0.2 dB/km. With the advances of technology of fiber-optic manufacturing, optical fibers with lower attenuations will be made and they will facilitate the implementation of communication links with extremely long repeater spacing (long transmission distances without intermediate electronics), thus further reducing both communication system cost and complexity.

(3) Small size and weight. Optical fibers have very small diameters, which are often no greater than the diameter of a human hair. Even when such optical fibers are covered with protective coatings they are far smaller and much lighter than corresponding copper cables. Fiber-optic cables need little layout space and they are very convenient to transport and construct.

(4) Immunity to electromagnetic interference and high signal security in transmission. Optical fibers, which are made of glass, or sometimes of a plastic polymer, are electrical insulators and therefore free from electromagnetic interference (EMI). They can be used in electromagnetic hazardous environments and don't need to be shielded from electromagnetism. Cross interference among several distinct optical signals doesn't occur when they simultaneously transmit in different fibers in the same fiber-optic cable. Furthermore, the optical signals in optical fibers generally don't radiate outside so that it is highly secure for the information to be transmitted in it, except possibly for hostile attack.

(5) Rich resource and potential low cost. The raw material used to manufacture the fiber-optic is silicon dioxide and it is abundant in nature, unlike copper. Moreover, the technology to fabricate optical fibers has matured so that the cost for manufacturing optical fibers has been reduced continuously.

Because optical fibers have so many aforementioned advantages and the technologies of manufacturing optical devices and optical fiber systems have been improved and matured, a flourishing period has come in the development, research and applications of optical fiber communication systems. So far, the developments of optical fiber communication have proceeded through four generations[8]. The first generation optical fiber communication systems used short wavelength at 0.85 μm and multimode fibers which used material based on quartz and whose diameter was 50 μm and whose loss was 4 dB/km. The light source was a light emitting diode (LED) made from III-Vs semiconductor compound, alloys of gallium arsenide (AlGaAs), and the optical detector was a p-i-n (PIN) photodiode or Si avalanche photodiode (APD). The first generation optical fiber communication systems were mainly used in the links among central offices and transmitted digital signals with less than third-level (E3) of PCM (pulse code modulation).

The second generation optical fiber communication systems used long wavelength with 1.31 μm single-mode fibers whose loss had been reduced from 4 dB/km to 0.5 dB/km. LEDs made from III-Vs semiconductor, the quarternary alloy InGaAsP, or laser diodes (LD) were used as light sources and InGaAs-PIN/GaAs-FETs were used as optical detectors. The second generation was suitable for being used in the links among central offices with the bit rate of 140 Mb/s or long-haul links with the high bit rate of 400 – 565 Mb/s and distance could achieve 40 km without repeaters.

The third generation optical fiber communication systems uses dispersion-shifted single-mode fibers with wavelength of 1.55 μm, with loss reduced to 0.2 dB/km. They can be used in long-haul telecommunications or submarine long-span telecommunications with a high bit rate of 2.5 Gb/s and a InGaAsP LD light source or a distributed feedback (DFB) LD.

The fourth generation optical fiber communication systems use nonzero-dispersion single-mode fibers with the wavelength of 1.55 μm and WDM, using optical amplifiers such as erbium-doped fiber amplifiers (EDFAs), and Raman amplifiers used to increase the transmission distance. The data rate per wavelength is in the range 2.5 Gb/s to 10 Gb/s.

The scheme of optical fiber communication system is shown in Fig. 1.1. The schematic diagram of a wavelength division multiplexing system is shown in Fig. 1.2.

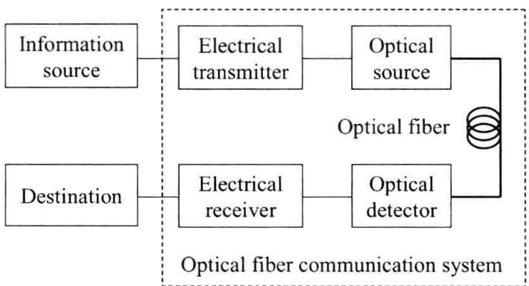

Figure 1.1 Optical fiber communication system

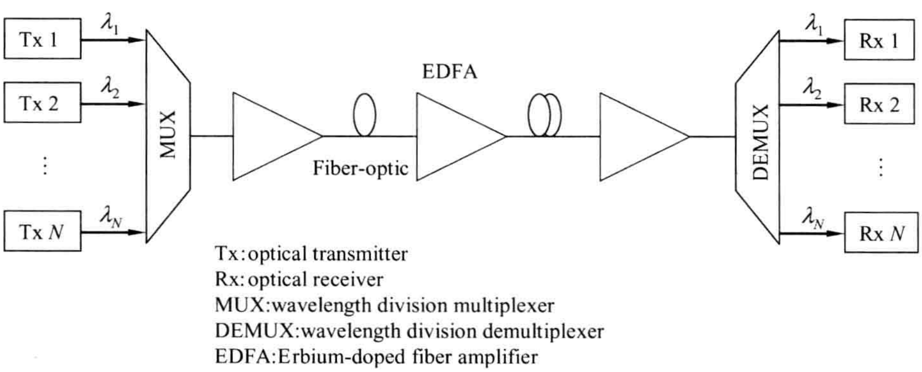

Figure 1.2 Schematic diagram of wavelength division multiplexing system