UNIVERSITI PUTRA MALAYSIA

NEW MULTIPLEXING TECHNIQUE BASED ON RETURN-TO-ZERO DUTY-CYCLES

MOHAMED FAISAL ABDALLA ELHAG

FK 2007 87

NEW MULTIPLEXING TECHNIQUE BASED ON RETURN-TO-ZERO DUTY-CYCLES

By

MOHAMED FAISAL ABDALLA ELHAG

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science

November 2007

DEDICATION

To my parents who have supported me patiently all the time
To my lovely wife and my beloved son Ahmed
To my family with love

Thank you.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirement for the degree of Master of Science

NEW MULTIPLEXING TECHNIQUE BASED ON RETURN-TO-ZERO DUTY-CYCLES

By

MOHAMED FAISAL ABDALLA ELHAG

November 2007

Chairman: Associate Professor Mohamed Khazani bin Abdullah, PhD

Faculty: Engineering

The ever increasing demand for higher speed data transmission is now accelerated more than ever, derived by the requirements of new applications that require very high bandwidths. The huge amount bandwidth available on transmission links such as optical fibers is shared by multiple users using multiplexing techniques. Although commercially available multiplexing techniques help utilizing transmission bandwidth, they are yet to exploit the full bandwidth available due to the speed bottleneck imposed by electronics. To better utilize the transmission bandwidth and release the electronic bottleneck this study proposes a multiplexing technique based on different Return-to-Zero (RZ) duty-cycles. Different users are assigned different RZ duty-cycles. These RZ signals modulate a Continuous Wave CW laser carrier before being multiplexed together using passive couplers. The resulting multiplexed signal forms a multilevel step-down signal. This feature enables channel demultiplexing to be performed electronically at single user baud rate, which is very economic. In this thesis the system design is developed and implemented in the optical domain.

Theoretical study of the system limitations is also presented. Due to cost, time, and flexibility constraints, OptiSystems and MATLAB simulators are used in the design and implementation of the proposed technique and to evaluate the performance of the system under different configurations. The system's performance is investigated back-to-back and after transmission over Standard Single Mode Fiber (SSMF). The system tolerance to signal impairments is investigated. The impairments considered in this study are the dispersion, fiber nonlinearities and amplifier noise. The system tolerance to chromatic dispersion is found to be very poor compared to Time Division Multiplexing (TDM) systems. To reduce the effect of dispersion the study proposes a synchronization technique that gave four times improved dispersion tolerance. The use of dispersion compensating techniques is also recommended as they completely eliminate the dispersion effect. The system is affected by two main nonlinear effects; Self Phase Modulation (SPM) and Stimulated Brillouin Scattering (SBS). Simulation results investigation showed that dispersion pre-compensation reduces the SPM effect and raises the maximum power limit set by this nonlinear phenomenon. This thesis makes two primary contributions. First, this thesis introduces the theory and working principle of the duty-cycle division multiplexing technique which is both economic and less complex than conventional multiplexing techniques. Second, the thesis evaluates the performance of the proposed technique for different design configurations and signal impairments.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

TEKNIK PEMULTIPLEKS BARU BERASASKAN KITAR-TUGAS KEMBALI-KE-SIFAR

Oleh

MOHAMED FAISAL ABDALLA ELHAG

November 2007

Pengerusi: Profesor Madya Mohamed Khazani bin Abdullah, PhD

Fakulti: Kejuruteraan

Peningkatan permintaan kepada transmisi data berkelajuan tinggi semakin cepat hari ini, dimangkinkan oleh keperluan aplikasi-aplikasi baru yang memerlukan lebarjalur yang sangat besar. Jumlah lebar jalur yang besar dalam talian transmisi seperti fiber optic dikongsi oleh beberapa pengguna menggunakan teknik pemultipleks. Walaupun teknik pemultipleks yang sedia ada secara komersil membantu perkongsian lebar jalur, ianya belum lagi dapat mengeksploitasi keseluruhan lebar jalur yang ada disebabkan oleh had-had peranti elektronik. Untuk menggunakan lebar jalur transmisi dengan lebih baik, dan menyelesaikan masalah had-had elektronik, kajian ini mencadangkan satu teknik pemultipleks berasaskan kitar-tugas kembali-ke-sifar di mana pengguna yang berbeza diberikan kitar-tugas yang berbeza. Isyarat-isyarat kembali-ke-sifar memodulasi pembawa laser dengan gelombang berterusan, sebelum dimultipleks bersama menggunakan pemasang pasif. Hasil isyarat yang telah dimultipleks membentuk isyarat banyak aras menapak ke bawah. Sifat ini membolehkan penyahmultipleks isyarat dilakukan secara elektronik pada kadar baud pengguna tunggal, yang mana sangat menjimatkan. Dalam tesis ini rekabentuk sistem dibangunkan dan digunakan di dalam domain optik. Kajian secara teori berkenaan had-had sistem juga dibentangkan disini. Perisian simulasi OptiSystems dan MATLAB digunakan dalam merekabentuk dan implementasi teknik yang dicadangkan dan menilai prestasi sistem di bawah konfigurasi-konfigurasi berbeza. Prestasi sistem diselidik secara ‘back-to-back’ dan juga selepas transmisi melalui ‘Standard Single Mode Fiber’ (SSMF). Toleransi system terhadap kesan-kesan buruk fiber diselidik. Kesan-kesan buruk fiber yang dikaji di sini adalah Pencapahan Kromatik, Kesan-tak-linear fiber, dan hingar pembesar. Toleransi sistem terhadap Pencapahan Kromatik didapati sangat teruk berbanding Sistem Pemultipleks Pembahagi Masa. Untuk mengurangkan kesan ini, teknik penyegerakan diperkenalkan dan dapat meningkatkan toleransi sebanyak 4 kali ganda. Penggunaan teknik Kompensasi Pencapahan Kromatik juga digalakkan kerana ianya menghapuskan kesan ini dengan lengkap. Sistem ini di pengaruhi oleh dua Kesan-tak-linear yang utama iaitu Modulasi Fasa Sendiri dan Perawakan Broullin Teruja. Dari keputusan simulasi, didapati kompensasi-awal Pencapahan Kromatik mengurangkan kesan Modulasi Fasa Sendiri dan meningkatkan had kuasa maksimum yang ditetapkan oleh fenomena tak-linear ini. Tesis ini memberi dua sumbangan utama. Pertama, tesis ini memperkenalkan teori dan prinsip kerja pemultipleks pembahagi kitar-kerja, yang mana menjimatkan dan kurang kompleks berbanding teknik konvensional. Kedua, tesis ini menilai prestasi teknik yang dicadangkan ini untuk konfigurasi rekabantuk dan pemburuk isyarat yang berbeza.

ACKNOWLEDGEMENTS

I would first wish to acknowledge the infinite debt that I owe to Allah and Prophet Mohammed SAWS. I also wish to thank Allah for His tender compassion and mercy, His everlasting love and goodness, His unmerited favor and blessings, and His perfect peace. Without any and all of these gifts, this thesis would have been impossible.

I am also eternally indebted to my supervisor Assot. Prof. Dr. Mohamed Khazani for all the help, guidance and expertise, provided by him throughout this study. I really appreciate all the valuable time he has spent in helping me with his valuable knowledge and new ideas about this research. I have been very fortunate to have him as my supervisor and it would take more than a few words to express my sincere gratitude. I would also like to recognize the invaluable help that was freely and generously given to me by D. Ahmed Fauzi Abass and D. Raja Shamsul Azmir.

I would sincerely like to thank all my parents for being there at all times and for their support and encouragement with my research. Last but not least, I would like to thank my wife for all her effort and support.

I certify that an Examination Committee has met on 20th of November 2007 to conduct the final examination of MOHAMED FAISAL ABDALLA on his Master of Science thesis entitled "NEW MULTIPLEXING TECHNIQUE BASED ON RETURN-TO-ZERO DUTY-CYCLES" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Sudhanshu Shekhar Jamuar, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Adzir Mahdi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ahmed Fauzi Abas, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Rosly Abdul Rahman, PhD
Associate Professor
Faculty of Science
Universiti of Technology Malaysia
(External Examiner)

HASANAH MOHD GHAZALI, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 29 January 2008

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of **Master of Science**. The members of the Supervisory Committee were as follows:

Mohamed Khazani bin Abdulla, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Raja Shamsul Azmir, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ahmed Fauzi Abass, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 21 February 2008

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MOHAMED FAISAL ABDALLA ELHAG

Date: 8th of December 2007

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

Tables **Page**

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Historical Background

Throughout the 1960s and 1970s, there were many investigations of transmission through waveguide structures (microwave and optical) to overcome the major limitation set by coaxial cables. In the 1966, K.C. Kao and G.A. Hockham demonstrated the feasibility of transmitting information coded into light signals through a glass fiber. Four years latter, Corning Glass Works announced the development of the optical fibers with attenuation of 20dB/km. However, fabrication of pure glass that can carry the light signals without loss was successful only in the 1970s in Bell Laboratories. The general trend worldwide has been to introduce developments which have increased the system span and the data rate through the enhancement to the power budget and reduction in the detrimental effects of fiber properties. Subsequently, single-mode fiber was developed, which has less loss and support for higher data rates. For early commercial 850nm systems, typical fiber attenuation was 3-5dB/km with repeater spacing in the range of 5-10km. The benefits associated with single mode fiber (significantly lower attenuation and dispersion) spurred the development of technologies to manufacture both fiber and semiconductor devices to enable long span transmission in the second transmission window around the 1300nm region. By 1980, single mode optical fibers were being produced with the associated losses approaching the theoretical minimum around the 0.4dB/km in the 1300nm region. The combination of lower attenuation and negligible dispersion in single mode fibers at this wavelength was particularly attractive as it led to the prospect of receiver spacing as long as 30km approximately for 140Mbit/s systems. The first 1300nm single mode fiber systems were installed around 1983. However it was not clear if they could be upgraded to operate at higher data rates while maintaining the same repeater spacing. Fortunately, improvement in the transmitters and receivers removed any concerns before such systems were developed and installed in the mid 1980s. The development of the 1550nm window laser transmission began to enhance the transmission spans of laboratory systems at around the same time. Further increases to the system span became possible when optical amplifiers were used to increase link lengths.

1.2 Evolution of Multiplexing Techniques

Multiplexing signals, switching multiplexed signals, and demultiplexing signals are the key functions required to construct telecommunication networks. The multiplexing techniques evolved from electrical multiplexing and moved recently to optical multiplexing. It started with electrical frequency division multiplexing (FDM), then electrical time division multiplexing (TDM), followed by the optical frequency multiplexing which is known as wavelength division multiplexing (WDM) and now the trend is to use optical time division multiplexing (OTDM). The first multiplexing technique used was the FDM which was developed for analog telephone transmission [1]. In the middle of the 20th Century, telephone networks used FDM to carry several voice channels on a single physical circuit. In Single-sideband modulation schemes, 12 voice channels would be modulated onto carriers spaced 4 kHz apart. The composite signal, occupying the frequency range 60 – 108 kHz, was known as a group. In turn, five groups can be multiplexed by a similar method into a supergroup, containing 60 voice channels. In long distance systems, supergroups were multiplexed into mastergroups of 300 voice channels (Europe) or 600 (AT&T Long Lines L-Carrier) for transmission by coaxial cable or microwave. After the transition from analog to digital communication, the electrical TDM was introduced specially after the great improvement in electronics and switching circuits. TDM was a synchronous technique invented during World War II to encrypt transatlantic radio conversation between Churchill and Roosevelt [2]. In 1962, engineers from Bell Labs had developed the first T1 Channel Banks, which combined 24 digitized voice calls over a 4-wire copper trunk between Bell central office analogue switches. A channel bank sliced a 1.544 Mbit/s digital signal into 8,000 separate frames, each composed of 24 contiguous bytes. Each byte represented a single telephone call encoded into a constant bit rate signal of 64 Kbit/s. Channel banks used a byte's fixed position (temporal alignment) in the frame to determine which call it belonged to. Bell Labs research projects conducted in the late sixties introduced the Asynchronous Time Division Multiplexing which later served as a base for asynchronous transfer mode (ATM) networks. Plesiochronous Digital Hierarchy (PDH) was developed as a standard for multiplexing higher order frames. PDH created larger numbers of channels by multiplexing the standard Europeans 30 channel TDM frames. This solution worked for a while; however PDH suffered from several inherent drawbacks which ultimately resulted in the development of the Synchronous Digital Hierarchy (SDH).

The simplest optical transmission system is a point-to-point connection that utilizes a single optical wavelength, which propagates through an optical fiber. The light wave paths are the foundation for lower bandwidth services between two end users. The light wave path can be considered as a super highway that aggregates the traffic of smaller speed subways. In this case multiplexing techniques is used to aggregate smaller bandwidths before it is wrapped in the super highway fiber.

By the time the optical communication technology matured, a number of proprietary networking solutions were already developed. During the first ten years of installation in the UK inland network, the step following initial trials was to produce complete proprietary systems from manufacturers whose terminal equipment was designed to operate over only one specific design of optical fiber. Subsequently, standardization activities resulted in a number of international standards to develop optical networks. SONET (synchronous optical network) is a standard developed by American National Standards Institute (ANSI) for optical networking in North America. International Telecommunications Union Telecommunications Sector (ITU-T) developed a slightly different standard that is called synchronous digital hierarchy (SDH). SONET/SDH standards specify how to access single-mode optical fiber using standard interfaces and how to multiplex the digital signals using synchronous TDM. These standards specify the rate hierarchy and interfaces for data rates from 51.84Mbps to 9.95328Gbps [3]. The next milestone was the development of wavelength division multiplexing (WDM), which increased the capacity of a fiber significantly.

The development of the erbium-doped fiber amplifiers (EDFA) in the late 1980s and early 1990s was a major milestone in the development evolution of optical fiber. A major advantage of EDFAs is that they are capable of amplifying signals at many wavelengths simultaneously. This advantage spurred the deployment of the WDM technique which dramatically brought down the cost of long haul transmission systems and increased their capacity. WDM systems with EDFAs were deployed in the mid 1990s and are today achieving capacities in the order of Tbps over a single fiber. WDM first became available during the 1980s when Deutsche Telecom, for example, introduced the technology into their BIGFON metropolitan networks [4]. Among the earliest WDM systems deployed were the AT&A's four wavelength long-haul system in 1995 and IBM's 20 wavelength MuxMaster metropolitan system in 1994. By 1996, WDM fiber pipes were being extensively installed followed within two years by a few primitive OADMs with frozen paths. Today, dynamically switchable OADMs are commercially available.

Dense wavelength division multiplexing (DWDM) was the next evolutionary step which increased the capacity of fiber to terabits. DWDM that corresponds to the superimposition of optical signals at different wavelengths closely spaced at 100 GHz or less on each fiber, becomes, as a matter of fact, the unavoidable solution, not only for a capacity increase at lower cost, but also for switching and routing in the optical domain.

In recent years people realized that optical networks are capable of providing more functions than just point-to-point transmission. Major advantages are to be gained by incorporating some of the switching and routing functions that were performed by electronics into the optical part of the network. This trend led to what is known as all optical networks.

The key network elements that enable optical networking are the optical add/drop multiplexer (OADM) optical cross-connect (OXC) and wavelength routers. The OADM and optical cross-connect technology are seen as a viable option in the large network optical nodes. Specially, when the digital cross-connectors are unable to scale to higher port-density and higher speed interface requirements at affordable costs, or in general, when the optical/electrical/optical conversion would be unnecessary and questionable.

DWDM with more than 160 channels, OADM with more than 32 channels, and wavelength-selective cross-connects (WSXC) with 32 × 32 input-to-output ports are currently in commercial use. Wavelength-interchanging cross-connects (WIXC) will become available soon, as the first industrial tunable lasers and wavelength converters are already proposed on the market.

The deployment of all optical networks however is also limited and constrained with other challenges. The two main constraints on system length were and still are power budget and time budget. The first of these is a simple function of transmitter power, receiver sensitivity, insertion losses and fiber attenuation, whereas the second is a more complicated function of the fiber dispersion and optical source characteristics. The standard single mode fiber which compromises most of the installed base at present is designed to have zero chromatic dispersion centered on the loss minimum in the 1300nm window. This gives the advantage of simultaneously relaxing the system constraints due to power budget and chromatic dispersion. However in the third telecommunication window 1500nm, single mode optical fiber now exhibits a typical attenuation of 0.17-0.2dB/km, half the value of that in the 1300nm window. In principle this should enable doubling the system length for power budget limited systems. However the main penalty associated with using this wavelength is that the chromatic dispersion of standard single mode fiber is high and can become a severe system constraint. This may be avoided by the installation of dispersion shifted fibers or by using dispersion compensating techniques. In addition to previous constraints there is the nonlinear effect of optical fiber research, however, researchers are working to turn this constrain to the benefit of the optical system. One result of these efforts is the development of Raman amplifier. Nonlinearity is also being utilized in optical routing in all optical networks. Nowadays, low nonlinearity fibers, dispersion management on fibers, lasers with high wavelength stability over years, new tunable light sources, new erbium-doped amplifiers, distributed Raman amplifiers, semiconductor amplifiers and gates, wavelength converters, couplers, space-switches, and wavelength division multiplexers offer new solutions.

1.3 Problem Statement

Fueled by the seemingly inexhaustible human appetite for more bandwidth per user and, by the new requirements that are far less predictable than they have been before, the bandwidth utilization moved ever forward. Before the invention of optical fiber the transmission medium has always been the scarcest resource. In an effort to make the most efficient use of this resource, various technologies have been developed so that multiple users can be supported in the same transmission medium. This concept is called "multiplexing". The most commonly used multiplexing techniques in communication systems are time division multiplexing (TDM), code division multiplexing (CDM), frequency division multiplexing (FDM), and wavelength division multiplexing (WDM). In TDM different users are located different time slots. This method was proved to be efficient but the electronic devices used in multiplexing and demultiplexing become a bottleneck from exploiting the available transmission bandwidth. In OCDM, each user's data is associated with a different code, which allows multiple users with more efficient bandwidth sharing. However, the broad spectrum signals used, made the signal less tolerant to some of the transmission line impairments especially the dispersion. In WDM each user uses a carrier with a different wavelength. This technique suffers low spectral efficiency due to the wide range of wavelengths used. Moreover, it is limited to the available EDFA band and it’s costly. Existing techniques are either limited by electronics speed or by spectral inefficiency. These problems are solved in the duty-cycle multiplexing technique by releasing the electronics bottleneck and more efficiently utilizing the spectrum at a lower cost.

1.4 Objectives

The major objective of this thesis is to introduce a new multiplexing technique that overcomes the time and spectral efficiency limitations on existing multiplexing techniques.