DEVELOPMENT OF NEW CODE FOR OPTICAL CODE DIVISION MULTIPLE ACCESS SYSTEMS

By

HILAL ADNAN FADHIL
(0740810145)

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Hilal Adnan Fadhil
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LIST OF ABBREVIATIONS

ASE	Amplified Spontaneous Emission
AWG	Array Wavelength Grating
BER	Bit Error Rate
CDMA	Code Division Multiple Access
DCF	Dispersion Compensating Fiber
DWDM	Dense Wave Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
FBG	Fiber Bragg Grating
FFH	Fast Frequency Hopping
FWHM	Full Wave Half Maximum
FTTH	Fiber To The Home
Gbps	Gigabit per second
GF	Galois Field
IM/DD	Intensity Modulation/ Direct detection
LED	Light Emitting Diode
MAI	Multiple Access Interference
Mbps	Mega bit per second
MFH	Modified Frequency Hoping
MQC	Modified Quadratic Congruence
NRZ	Non Return to Zero
NDSF	Non Dispersion Shift fiber
OCDMA	Optical Code Division Multiple Access
ODLCs	Optical Delay Line Correlate's
OCC	Optical Orthogonal Code
OSNR	Optical Signal to Noise Ratio
OOK	On-Off Keying
QoS	Quality of Service
P2P	Point-to-Point

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P2MP	Point-to-Multipoint
PD	Photo Diode
PIIN	Phase Induced Intensity Noise
PIN	Positive Intrinsic Negative
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
RF	Radio Frequency
RD	Random Diagonal
SAC	Spectral Amplitude Coding
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SLD	Super Luminescent Diode
SPM	Self Phase Modulation
TDM	Time Division Multiplexing
TLS	Tunable Laser Source
WDMA	Wavelength Division Multiple Access
VoD	Video-on Demand

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PEMBANGUNAN KOD BARU UNTUK SISTEM CAPAIAN PELBAGAI PEMBAHAGIAN KOD OPTIKAL

ABSTRAK

Perdebatan utama bagi penggunaan sistem capaian pelbagai pembahagian kod optikal adalah fleksibiliti dalam kaedah capaian asinkron, peningkatan keselamatan dan keunggulan penyahgredan. Dalam beberapa dekad yang lalu, banyak kod telah dicadangkan dalam OCDMA, terutamanya bagi Pengkodan Amplitud Spektral. Semua kod yang dicadangkan mempunyai korelasi silang maksimum nilai satu atau lebih daripada satu. Pilihan kod yang tepat sangat penting bagi prestasi sistem yang baik dan skalabiliti rangkaian yang mempunyai kadar ralat bit yang rendah (BERs) iaitu kurang dari 10^{-9}. kebiasanya, OCDMA mengalami gangguan akses yang pelbagai iaitu Multiple Access Interferance (MAI) noise daripada pengunaan serentak yang boleh menyebabkan kesilapan bit. Bagi mengurangkan masalah ini, pengkodan spectral amplitude (SAC) OCDMA digunakan dalam tesis ini. Gangguan MAI dapat disekat dengan teknik pengesanan yang sesuai merupakan kelebihan SAC-OCDMA berbanding pengunaan OCDMA yang biasa. Ia bertindak mengurangkan kesan gangguan Mai ataupun memperbaiki prestasi walaupun dengan kewujudan MAI. Sumbangan penting kod ini adalah gangguan MAI dapat disekat dan sekaligus prestasi system dipertingkatkan dengan korrelasi rentangan yang sifar antara turutan kod. Jujukan kod keseluruhan dibahagikan kepada dua bahagian: kod dan segmen data. Jujukan kod kod ini mempunyai nilai sifar dan pembolehubah persilangan hubungkait pada segmen data dan segmen kod masing masing. Peningkatan prestasi kod RD membuktikan kaedah pengesahan spectral direct. Pengiraan berdasarkan teori dan experimen stimulasi telah di jalankan. Jarak, nilai bit, input kuasa dan penjarakan chip adalah parameter-parameter yang digunakan dalam stimulasi. Di dapati kegunaan kod RD telah mepertingkatkan prestasi berbanding kod SAC yang berlainan seperti Hadamard, Hadamard, Modified Quadratic Congruence (MQC), dan Modified Frequency Hopping (MFH) dengan membandingkan keputusan teori dan stimulasi yang diambil dari komersial sistem optical stimulator "optisystem™". Dengan panjang OCDMA yang tidak terhad teknologi Fiber-To-The Home (FTTH) menunjukkan cara ideal untuk mempastikan kemajuan rangkaian di masa depan menepati peningkatan kehendak pelanggan dan perniagaan untuk jangka rangkaian yang pantas dan aplikasi panjang gelombang yang tinggi. Terdapat empat aspek yang telah dikaji dalam kajian ini. Pertama sekali, semua aspek penting kod yang sedia ada termasuk kelebihan dan kelemahan dibincangkan. Cara pemisahan dicadangkan untuk membentuk famili kod baru iaitu RD kod. Korrelasi rentangan yang kurang baik, teknik pengesanan terbaru diperkembangkan berdasarkan pengesanan terus spectra dan di bandingkan dengan teknik pengesanan yang di laporkan. Skim sebegini membolehkan kegunaan turutan yang tidak terhad pada peringkat kolerrelasi rentangan jadi membolehkan pembentukkan kod family yang panjang. Kesan gangguan disebabkan fasa atau dikenali phase-induced intensity noise (PIIN), gangguan pendek atau dikenali short noise, dan gangguan haba atau thermal noise dianggap serentak untuk analisis prestasi. Prestasi sistem di bandingkan dengan sistem yang di laporkan dan di kategorikan dengan merujuk kepada nisbah isyarat kepada gangguan iaitu signal to noise ratio (SNR), kesilapan nilai bit iaitu bit error rate (BER) dan juga keberkesanan kuasa iaitu effective power (P_{sr}). Didapati bahawa keadah pengesanan baru berdasrkan kod famili RD dapat menyekat gangguan kuasa intensity serta mambaiki prestasi sistem dengan ketara dibandingkan dengan sistem yang di laporkan. Selain dari membaiki prestasi BER, RD juga dpat digunakan untuk pengguna yang ramai di nilai siaran yang berlainan dengan punca cahaya yang berpatutan dan jarak siaran yang panjang. Ketiga, stimulasi software untuk sistem SAC OCDMA dengan famili RD dijalankan dengan mengunakan sistem optikal komersial "otisystem™ver.7,0". Keputusan stimulasi menunjukkan bahawa kod RD lebih sesuai untuk siaran FTTH akses pada rangkaian. Akhirnya, experimen untuk membuat dan mengkategori kod RD dengan LED dan Fiber Rig Laser sebagai punca optic untuk sistem OCDMA dibingcangkan. Berat sistem mestilah besar atau sama dengan tiga, dan sistem menjadi kurang selamat pengunaan teknik pengesanan spectra terus adalah antara kekurangan kod RD.

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ABSTRACT

The main arguments for using Optical Code Division Multiple Access (OCDMA) are the flexibility of an asynchronous access method, increased security and graceful degradation. Over the last decade, many codes were proposed for the OCDMA, especially for Spectral Amplitude Coding (SAC). Proper code selection is very important for good system performance and high network scalability with low bit-error rates (BERs) of less than 10^{-9}. OCDMA systems, however, generally, suffer from multiple access interference (MAI) noise which originated from other simultaneous users severely increases the likelihood of occurrence of bit errors. To mitigate this limitation, spectral amplitude coding (SAC) OCDMA is used throughout this thesis. The advantage of SAC-OCDMA over conventional OCDMA systems is that, when using appropriate detection technique, the MAI can totally be suppressed. This either reduces the effect of MAI or improves the performance even in the presence of MAI. This work proposed algorithms for designing a new code with variable cross-correlation properties for the SAC-OCDMA system, namely, Random Diagonal (RD) code. The overall code sequences are divided into two parts: code and data segments. These codes sequences having zero and variable cross-correlation at data segment and code segment, respectively. The significant contribution of this code is the suppression of MAI and improved system performance by guaranteeing zero cross-correlation at data segment between code sequences. Spectral direct detection technique is proved, which improves the performance of the RD code. The study is carried out using a theoretical calculation, and simulation experiment. The simulations are carried out using various design parameters namely; distance, bit rate, input power and chip spacing. By comparing the theoretical and simulation results taken from the commercial optical systems simulator "Optisystem^{TM}", it is shown that utilizing RD code considerably improves the system performance compared with other SAC codes such as Hadamard, Modified Quadratic Congruence (MQC), and Modified Frequency Hopping (MFH) codes. Given the almost unlimited bandwidth of OCDMA, Fiber-To-The Home (FTTH) technology is seen as an ideal way of "future-proofing" networks in light of the ever-increasing consumer and business demand for faster networks and higher-bandwidth applications. Four aspects are tackled in this research. Firstly, a comprehensive discussion takes place on all important aspects of existing codes from advantages and disadvantages point of view. Splitting algorithm is proposed to construct the new code families namely RD code. The existing code families are being challenged by several problems such as poor cross correlation properties, a rather restricted number of available code sequences, complicated and time consuming code construction. To overcome the stated problems, RD code families are used throughout this stage. Secondly, a new detection technique based on spectral direct detection is developed and compared to the reported detection techniques. Such a scheme allows using sequences with less strict in-phase cross correlation constraints, thus allowing much larger code families to be constructed. For the performance analysis, the effects of phase-induced intensity noise (PIIN), shot noise, and thermal noise are considered simultaneously. The performances of the system compared to reported systems were characterized by referring to the signal to noise ratio (SNR), the bit error rate (BER) and the effective power (P_{sr}). Numerical results show that, the new detection scheme based on the RD code families can suppress the intensity noise power, and improve the system performance significantly compared to the reported systems. Employing RD code not only provide to have a better BER performance than other codes, but was able to be used for a large number of users at different rates of transmission with cost-effective light sources, and for longer transmission distances. Thirdly, a software simulation for SAC OCDMA system with the RD families using a commercial optical system, "Otisystem^{TM} Ver. 7.0" is conducted. Simulation results show that the RD code is very much suitable for a point-to-point FTTH transmission in an access network. Finally, an experimental test to generate and characterize the RD code using the light emission diode (LED) and Fiber Ring Laser as optical sources for OCDMA systems is discussed. The limitations of the RD code should be highlighted in this thesis; these limitations are considered the main disadvantages of the RD code, which are: the system weight should be greater or equal to three; and using the spectral direct detection scheme the overall system is considered less secure compared with other SAC-OCDMA detection schemes.

CHAPTER 1

INTRODUCTION

1.1 Background

Code Division Multiple Access "CDMA" has been widely used in modern satellite and mobile communication systems. The transmitted information is encoded into a pseudo-noise waveform according to a signature spreading sequence. The bandwidth of the encoded signal is much greater than the data rate. In CDMA, the signals from different users overlap in both time and frequency. A receiver can only decode the signal from a transmitter if it has the same signature sequence as the transmitter. All signals from other users remain noise-like after the decoder in the receiver, and are called the Multiple-Access Interference (MAI) because they corrupt the desired signal. Compared to the more conventional multiple access Frequency-Division (FD) or Time-Division (TD) schemes, this relatively new multiple-access scheme has many advantages, such as: a) Asynchronous transmission; b) Interference rejection; c) Scalability; and d) Security.

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The past decade has witnessed significant developments in the area of optical networking. Advanced technologies such as Dense Wavelength Division Multiplexing (DWDM), optical amplification, optical path routing (wavelength cross-connect), Wavelength Add-Drop Multiplexer (WADM), and high-speed switching have found their way into the Wide-Area Networks (WANs), resulting in a substantial increase in the telecommunications backbone capacity and greatly improved reliability (Govind 2002). At the same time, enterprise networks almost universally converged on 10 Gbps fast Ethernet architecture. Although they are improvements compared to 56 kbps dial-up lines, they are unable to provide enough bandwidth for emerging services such as Video-on-Demand (VoD), interactive gaming, or two-way video conferencing (Mukherjee, Kramer et al. 2003; Glen 2005). Therefore, the need to search for a new and versatile approach that is cost effective with more than enough bandwidth to accommodate end-user data-rate intensive applications is necessary.

One approaches that by implementing CDMA, which has been proven effective in the wireless regime. The optical version of CDMA, called Optical CDMA (OCDMA), is expected to inherit many of the advantages of the wireless version with the added value of the huge bandwidth of fiber optic systems. Because of its unique features, OCDMA is gaining increased attention in the research community, which is indicated by the increased number of publications in different conferences and journals papers. Because On-Off Keying (OOK) is used in the transmitters of the OCDMA scheme, the function of a receiver is to detect the presence of the pulse train from the desired user. Various receiver structures have been proposed in the literature. The most straightforward one (Santoro and Prucnal 1987) is an optical matched filter built with tapped optical delay lines, followed by an ultra-fast photodetector (PD). The response time of the PD is required to be less than, or equal to, the pulse width, which is usually very short. (Hossam 1998) proposed the chip-level receiver and showed that it is the optimal receiver for this OCDMA scheme. These different receiver structures have been compared in (Zahedi and Salehi 2000).

(Tancevski and Andonovic 1994) proposed the wavelength-hopping/time-spreading scheme. In this scheme, the pulses are spread both in time and frequency. In other words, each pulse has a different carrier wavelength. They extended the prime

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code to a two-dimensional code that has zero off-peak auto-correlation and maximum cross-correlation equal to one. The code also has good cardinality. Many researchers have investigated the feasibility of implementing OCDMA systems (J.F.Huang and Hsu 2000; Yu, Shin et al. 2000; Kim, Park et al. 2003; Gnauck et al 2004; Yang, J.F.Huang et al. 2004). Compared to traditional electrical CDMA schemes, OCDMA systems have the advantage that various types of radio signal can be multiplexed in the optical domain. Furthermore, high processing gains can be obtained using conventional broadband optical devices.

1.2 Optical Multiplexing Techniques

Multiple access techniques are required to meet the demand for high-speed and large-capacity communications in optical networks, which allow multiple users to share the fiber optic bandwidth. There are three major multiple access approaches: each user is allocated a specific time slot in Time-Division Multiple Access (TDMA) and a specific frequency (wavelength) slot in Wavelength Division Multiple Access (WDMA). Both techniques have been extensively explored and utilized in optical communication systems (Charlet 2004; T. Ohara, H. Takara et al. 2004; Turkiewicz 2004; Yoshikane et al. 2004). Alternatively, Optical Code Division Multiple Access (OCDMA) (Shah, 2003; Wang X. , Wada, Miyazaki, & Kitayama, 2006; Ycn-Chun, Chia-Chu, Hen-Wai, & Jingshown, 2008; Zhang, 2002) is receiving increasing attention due to its potential for enhanced information security, simplified and decentralized network control, and increased flexibility in the granularity of bandwidth that can be provisioned. In OCDMA, different users whose signals may be overlapped both in time and frequency share a common communications medium; multiple-access is achieved

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by assigning different, minimally interfering code sequences to different transmitters, which must subsequently be detected in the presence of Multi-Access Interference (MAI) from other users. Figure 1.1 shows a schematic illustration of bandwidth allocation in TDMA, WDMA and CDMA.

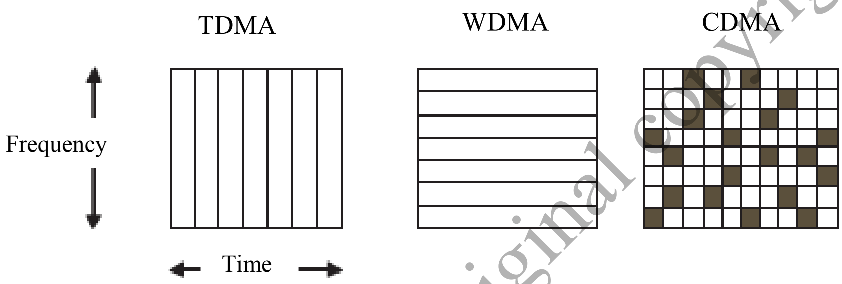

Figure 1.1 Schematic Illustration of Bandwidth Allocation in TDMA, WDMA, and CDMA Optical Networks (Chen 2007)

CDMA derives from Radio Frequency (RF) spread spectrum communications, originally developed for military applications due to an inherent low probability of intercept and immunity to interference, and more recently for commercial RF cellular radio applications (R. L. Peterson, R. E. Ziemer et al. 1995; Proakis 2005). CDMA is now becoming the dominant multiple access technique in RF wireless networks. Since RF-CDMA works with typical carrier frequencies in the ~1 GHz range and bit rates on the order of ~100 kbps, current electronic technologies can easily provide coding and long temporal code (~1000 chips) for each bit, which is critical to support a large number of potential users (Shah 2003). In addition, the Bit Error Rate (BER) requirement is usually not so strict for RF-CDMA. In contrast, the need to perform encoding and decoding for OCDMA poses one immediate challenge both because of the optical carrier frequency and the much higher bit rate of ~Gbps per user, which already approaches the limit of electronic processing. Therefore, innovative all-optical processing technologies are needed. In addition, the challenges for OCDMA also come

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from critical requirements that are routinely required in optical communication systems. These requirements include: extreme high Quality of Service (QoS) (BER at 10^{-9} or below), large capacity (tens or hundreds of users, total capacity up to ~40 Gbps or above), and long distance (kilometers to ~100 km for Local Area Networks (LAN) and Metropolitan Area Networks (MAN)).

Several different OCDMA detection schemes have been proposed (Tancevski & Andonovic, 1994b, 1996; C.C. Yang, 2005; Yun & Dimyati, 2009), based on different choices of sources, coding schemes, and detection. Significant progression of OCDMA research has been achieved worldwide in recent years (Galli, Menendez, Narimanov, & Prucnal, 2008; Gupta & Saxena, 2007; Huang Jen-Fa, Yang, & Huang, 2009; Wang X. et al., 2006). OCDMA schemes may be classified according to the choice of coherent versus incoherent processing, coherent (mode-locked pulses) versus incoherent (e.g., Amplified Spontaneous Emission (ASE) and Light Emitting Diode (LED)) broadband optical source, and encoding method (time domain versus frequency-domain, amplitude versus phase). Schemes based on incoherent processing (summing of optical powers) and broadband incoherent sources are generally the easiest to implement, but offer relatively poor performance. Figure 1.2 shows the conceptual OCDMA network diagram for many of the OCDMA approaches. On the transmitter side of an OCDMA system, an OCDMA encoder is used to encode the input data bit stream into an optical signal depending on the signature sequence that is distinct for each user on the system. This encoded signal is multiplexed with the signal generated from all other users, and it is redistributed to each user using the same fibers. At the receiver side, an OCDMA decoder uses a matched filter that corresponds to the signature sequence of the desired user. Depending on the technology of choice, this decoder optical signal is then passed into a direct detection photo-detector (e.g., InGaAs PIN, and Ge APD) or a differential

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