PERFORMANCE ANALYSIS OF DIFFERENT DETECTION TECHNIQUES IN SAC-OCDMA SYSTEMS

by

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LIST OF ABBREVIATIONS

1-D	One Dimensional
2-D	Two Dimensional
3D	Three Dimensional
APD	Avalanche Photodiode
BER	Bit Error Rates
CDMA	Code Division Multiple Access
dB	Decibel
DW	Double Weight
EDW	Enhanced Double Weight
FBG	Fiber Bragg-Grating
HD	High Definition
LAN	Local Area Network
LASER	Light Amplification by Stimulated Emission of Radiation
LED	Light Emitting Diodes
MAI	Multiple Access Interference
MDW	Modified Double Weight
MFH	Modified Frequency Hopping
MQC	Modified Congruence Code
NRZ	Non Return to Zero
OCDMA	Optical Code Division Multiple Access
ONU	Optical Network Unit
PIIN	Phase Induced Intensity Noise
PIN	Positive Intrinsic Negative
PON	Passive Optical Network
PRBS	Pseudo Random Binary Sequence
RZ	Return To Zero

SAC	Spectral Amplitude Coding
SLD	Superluminescence Diode
SMF	Single Mode Fiber
SNR	Signal To Noise Ratio
TDMA	Time Division Multiple Access
WDM	Wavelength Division Multiple
WDMA	Wavelength Division Multiple Access
ZCC	Zero Cross-Correlation

LIST OF SYMBOLS

B	Bandwidth (bps)
e	Electron's Charge (C)
K	Number of user
K_b	Boltzmann's Constant (JK^{-1})
K_B	Number of user in basic matrix
N	Code length
N_B	Code length at basic matrix
P_{sr}	Received Power (dB)
$\Re$	Responsivity
R_L	Receiver Load Resistor (Ω)
T	Absolute Receiver Noise Temperature (K)
w	Code Weight
λ_c	Cross-correlation
Δ_V	Linewidth (Hz)

Penganalisaan Pencapaian Teknik Pengesanan Berbeza Di Dalam SAC-OCDMA Sistem

ABSTRAK

Sistem Bahagian Kod Optik Capaian Berganda (OCDMA) merupakan satu pilihan yang terbaik kerana ia adalah pemprosesan optik secara keseluruhan, rangkaian sistem yang ringkas, kecekapan jalur lebar serta sistem komunikasi yang selamat. Salah satu dari sistem pengekodannya ialah Pengekodan Amplitud Spektral OCDMA (SAC-OCDMA) yang hebat. Skop kajian ini bertumpu kepada SAC-OCDMA di mana baru-baru ini ia mendapat perhatian yang luas berdasarkan prestasi yang mantap, fasa tidak sensitif dan peruntukan lebar jalur yang fleksibel. Justeru itu, sasaran kajian adalah menganalisa dan mengkaji pencapaian kod sistem SAC-OCDMA dengan silang korelasi iaitu Enhanced Double Weight (EDW) dan Modified Double Weight (MDW) menggunakan setiap teknik pengesanan terus, teknik pengesanan penolakan AND dan teknik pengesanan penolakan pengubahsuai-AND. Analisis dijalankan secara teori dan simulasi menggunakan perisian Optisystem Versi 7.0 dengan merujuk kepada parameter berdasarkan standard ITU-T G.652. Hasil penganalisaan menunjukkan bahawa dalam mengurangkan kadar ralat bit (BER) serta menghapuskan gangguan capaian berganda (MAI) dan hingar intensiti berpunca fasa (PIIN), penggunaan teknik pengesanan ideal memberi kesan yang lebih besar dari menggunakan jenis kod yang tepat. Untuk 100 orang pengguna, didapati bahawa BER untuk kod MDW yang menggunakan teknik pengesanan penolakan AND dan teknik pengesanan penolakan pengubahsuai-AND adalah masing-masing 1×10^{-12} dan 1×10^{-43}. Manakala, BER untuk kedua-dua kod EDW dan MDW yang menggunakan teknik pengesanan penolakan pengubahsuai-AND adalah masing-masing 1×10^{-20} dan 1×10^{-43}. Di samping itu, pencapaian teknik pengesanan penolakan pengubahsuai-AND adalah lebih baik dari teknik pengesanan penolakan AND dan teknik pengesanan terus. Keberkesanan sistem SAC-OCDMA dalam penghantaran jarak jauh menggunakan hanya satu Diod Pemancar Cahaya (LED) dan satu penguat optik turut difokus. Teknik pengesanan penolakan pengubahsuai-ANDadalah lebih baik dari teknik pengesanan penolakan AND untuk penghantaran jarak jauh. Bagi kualiti servis (QoS) pada BER 1×10^{-18}, teknik pengesanan penolakan pengubahsuai-AND membolehkan jarak penghantaran 46.98% lebih jauh dari teknik pengesanan penolakan AND ketika menggunakan kod MDW manakala 24.21% jarak yang lebih jauh apabila menggunakan kod EDW. Oleh itu, dapat disimpulkan bahawa kriteria utama dalam mengurangkan MAI dan PIIN serta mengoptimumkan sistem dengan lebih berkesan adalah melalui penggunaaan jenis pengesanan yang ideal.

Performance Analysis of Different Detection Techniques In SAC-OCDMA Systems

ABSTRACT

Optical Code Division Multiple Access (OCDMA) system is a perfect choice for satisfying high communication demand because of the all-optical processing, simplified network control, bandwidth efficiency and security of such system. One of the coding schemes of OCDMA is the Spectral Amplitude Coding OCDMA (SAC-OCDMA). This study focused on the SAC-OCDMA system, which recently received increasing attention because of its robust performance, phase insensitivity and flexible bandwidth provisioning. This study aimed to analyze the performance of SAC-OCDMA system's codes with cross-correlation, particularly Enhanced Double Weight (EDW) and Modified Double Weight (MDW) codes, by using direct detection technique, AND subtraction detection technique as well as modified-AND subtraction detection technique. Theoretical and simulation analyses using Optisystem Version 7.0 software were performed with reference to the parameters in the ITU-T G.652 standard. Analysis results show that the use of an ideal detection technique is more efficient than using the right type of code in reducing bit error rates (BERs) as well as eliminating multiple access interference (MAI) and phase induced intensity noise (PIIN). At 100 users, the BERs of the MDW code with the AND subtraction detection technique and modified-AND subtraction detection technique are 1×10^{-12} and 1×10^{-43}, respectively. Whereas, the BER of EDW and MDW codes that utilized the modified-AND subtraction technique are 1×10^{-20} and 1×10^{-43} respectively. The performances of EDW and MDW codes present different outcomes depending on the parameter analyzed. The modified-AND subtraction detection technique shows better performance than AND subtraction and direct detection techniques. The effectiveness of a SAC-OCDMA system in long-distance transmission with only single Light Emitting Diode (LED) and one optical amplifier was also verified. In long-distance transmission, the modified-AND subtraction detection technique exhibits a better performance than the AND subtraction detection technique. For the same quality of service at a BER of 1×10^{-18}, the modified-AND subtraction detection technique allows 46.98% and 24.21% longer transmission distance than the AND subtraction detection technique with MDW code and EDW code, respectively. Hence, the ideal type of detection should be the focus in SAC-OCDMA systems to reduce BER, MAI and PIIN furthermore, optimize the system greatly and effectively.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The communication requirement indeed has become increasingly demanding. A current Cisco forecast projects the growth of global internet traffic by a factor of four between 2009 and 2014, and video-rich services will be the most prevalent cause of the traffic. Advanced Internet video such as Three Dimensional (3D) video and super High Definition (HD) video, are projected to increase 23-fold, whereas video communications traffic, e.g., video calling and video conferencing, will increase by 7-fold. By 2014, 66% of mobile data will comprise video traffic (Cisco, 2011). Emerging applications such as Ultra HD video and free viewpoint video will continue to push bandwidth requirements even further.

With the present need for communication with vast bandwidth requirement, the Optical Code Division Multiple Access (OCDMA) emerges as the alternative solution. Meanwhile, with the implementation of incoherent processing which offers a low cost design, the Spectral Amplitude Coding (SAC) coding scheme, also known as SAC-OCDMA, provides a new perspective of effective and less expensive communication network that provides an excellent performance (Kakaeea et al., 2013; Yanget al., 2013).

1.2 Multiple Access Techniques

The combination of optical signal processing that provides enormous capacity of bandwidth with the Code Division Multiple Access (CDMA) technique creates the OCDMA system. OCDMA is a method that performs encoding and decoding using an optical signature code for the selection of a desired signal that allow different users to share the same bandwidth (Sabbagh & Kakhki, 2014). This system is secure since only the intended user with the correct code can recover the user-specific optically encoded signal (Irfan Aniset al., 2009; Sahuguede et al., 2010). In comprehending the multiplexing transmission and multiple accesses that support multiple simultaneous transmissions in the same time slot and frequency band, OCDMA proves to be a good choice for multiple access systems compared with other conventional multiple access techniques such as Time Division Multiple Access (TDMA) and Wavelength Division Multiple Access (WDMA).

Users of the WDMA technique are allocated with a specific wavelength slot by dividing the available optical bandwidth into fixed wavelength channels that are shared concurrently by different users (Hisham et al., 2004). Although WDMA can be used as a degree of design freedom with respect to routing and wavelength selection, WDMA add a further dimension to network functionality. The fundamental issue regarding WDMA is the limited number of useable wavelengths (Wei et al., 2000). Another issue that constrains WDMA performance is the wavelength granularity which limits the handling of traffic on the optical channel of the wavelength path. This constraint can be overcome by OCDMA because OCDMA uses a band of wavelengths in a form of codewords. OCDMA can accommodate more users by offering a larger number of channels than WDMA (Wei et al., 2000). OCDMA can offer same virtual topology as

WDMA, but with much simpler network configuration and a vastly facilitated and decentralized network operation and management system than WDMA (Chen et al., 2008; Fei et al., 2004; Li et al., 2004). Besides, the OCDMA system does not need an in-field Wavelength Division Multiple (WDM) multiplexer or individual wavelength filters at the Optical Network Unit (ONU) as required in WDMA virtual Point-to-Point (P2P) topology over the physical tree architecture (Fouli & Maier, 2007).

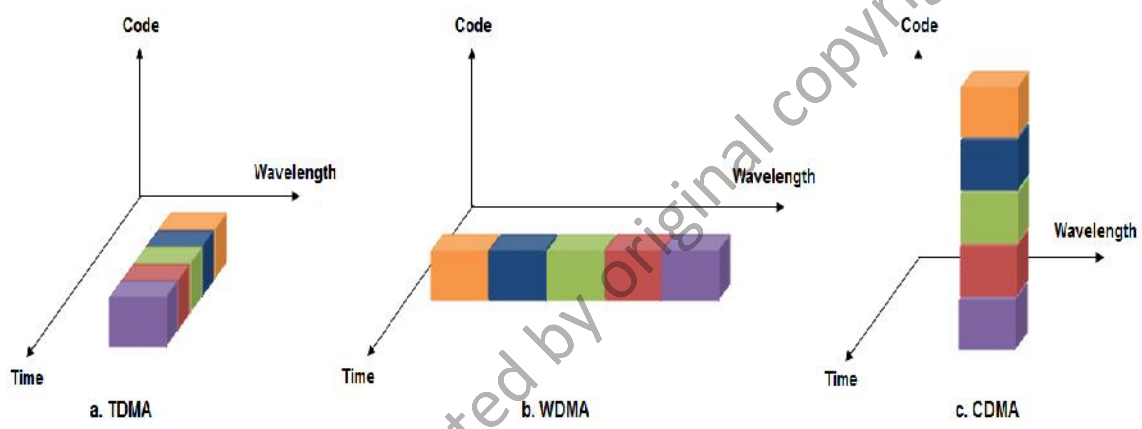

Figure 1.1: Various multiple access systems; (a) TDMA, (b) WDMA, (c) CDMA

Users are allocated with a precise time slot in TDMA. The performance of TDMA is restricted by the time-serial nature of technology. TDMA prevents the utilization of statistical multiplexing gain, which is significant at high data traffic (Zhuo et al., 2010). Compared with TDMA, OCDMA supports bursts and asynchronous network traffic (i.e., IP traffic nature) without time synchronization between communicating nodes, resulting in a simplified network functionality and management (Yin & Richardson, 2009). OCDMA is attractive because of its dynamic capacity and flexible bandwidth management, supporting random access protocols and superior security (Hernandez et al., 2012; Karbassian & Ghafouri-Shiraz, 2009). The asynchronous transmission in OCDMA is a more simplified access control to the medium than TDMA (Ghafouri-Shiraz & Karbassian, 2012).

The OCDMA system can supports a larger number of users than TDMA and WDMA systems, especially the multi-dimension OCDMA systems (Ghafouri-Shiraz & Karbassian, 2012). The performance of the OCDMA system is better than that of WDMA and TDMA systems (Fakidis et al., 2013; Sari et al., 2000). New TDMA and WDMA users reduce the free and guaranteed bandwidth, thus requiring bandwidth allocation (Ghafouri-Shiraz & Karbassian, 2012). Unlike WDMA and TDMA systems, new OCDMA users do not reduce bandwidth or time allocation of other users, thus making it simpler to employ than WDMA and TDMA systems (Maneekut et al., 2012; Moeneclaey et al., 2001).

1.3 Performance of the OCDMA System

Though many coding schemes exist in the OCDMA system, the performance of the system is dependent on the characteristic and specification of each coding scheme. The performance of the coding schemes is evaluated by Bit Error Rates (BER). While the OCDMA system serves the multiple access purpose, Multiple Access Interference (MAI) becomes its main constraint. Besides, the Phase Induced Intensity Noise (PIIN), which consequently increase BER, limits the performance of the system. Thus, a number of studies had been conducted to minimize the said constraints and to enhance the performance of the OCDMA system.

Many methods can be applied to achieve excellent performance. First, a suitable coding scheme is necessary. Coding schemes are differentiated by the type of optical sources, detection scheme, and coding technique applied in each system design. A suitable coding scheme can be utilized either by pulse amplitude coding, pulse phase coding, spectral amplitude coding, spectral phase coding, spatial coding or by wavelength hopping time spreading.

Employing a specific code to the coding scheme can also boost the performance of the OCDMA system. Many codes of different types and properties are generated to eliminate the MAI noise and to suppress PIIN effects. Not all codes can be used in each coding scheme. Each of the coding schemes utilizes different optical sources, detection scheme, and coding technique. Codes are built with properties that fit in a certain coding scheme. Codes can be characterized by its code dimension, which may either be One Dimensional (1-D) or Two Dimensional (2-D) (Hongxi Yin & David, 2009). Code properties include the code length, cross-correlation, and code weight. Cross-correlation, code length, and the complexity of the code become the main issues of code's development that needs to be solved.

Another way to maximize the performance of the OCDMA system is by utilizing a suitable and notable detection technique. Depending on the type of coding scheme and code applied, an ideal detection technique can be exploited. One of the main problems faced by OCDMA is cross-correlation. Cross-correlation influences the detection technique that recovers the intended signal. Cross-correlation increases the interference noise affecting the system, which can degrade the SAC-OCDMA system's performance. Many types of detection techniques can be applied to filter out the noise. Examples of detection techniques are direct detection technique (Abdullah et al., 2008; Rashidi et al., 2010) and subtraction detection technique that include complementary subtraction detection technique (Miyazawa, Sasase, & Yoo, 2007), AND subtraction detection technique (Aljunid et al., 2007; Sahbudin et al., 2008), NAND subtraction detection technique (Nasim Ahmad et al. 2012) and modified-AND subtraction detection technique (H. M. R. Al-Khafaji, Aljunid, & Fadhil, 2011; Hamza M. R. Al-Khafaji, Aljunid, & Fadhil, 2012).

1.4 Problem Statements

The effect of MAI is a main concern in the SAC-OCDMA system. MAI affects the entire system as multiple active users and overlapping chips emerge in the code sequence. The overlapping chips will corrupt the data of the intended user, thus increasing BER. As a result of MAI, PIIN is generated at the mixed phase incoherence of overlapping signals on the same spectra of input light sources. MAI consequently evolves as the predominant factor in degrading the performance of the system by damaging the data and increasing the noise. The SAC-OCDMA system has two main issues, namely, the extraction of clean data by the intended user and reduction of the PIIN effect (Shalaby, 2012; Yen, 2012).

Therefore, the new code sequences, detection, system design, effect of channel spacing, or utilized data format types are explored to identify the effective way to eliminate MAI noise and to suppress PIIN noise. Theoretically, the PIIN noise can be reduced at the optical layer. Although the overlapping chip can be subtracted by subtraction detection to clean the signal from unwanted noise and then eliminate MAI, PIIN noise is still present and continues to affect the system.

Accordingly, one of the approaches of the SAC-OCDMA application is the types of detection implemented for the intended user to extract the actual signal that is free from MAI and PIIN noises. Each subtraction detection and direct detection has pros and cons. Subtraction detection is the detection that is suitable for codes that have cross-correlation of $\lambda_c = 1$. At the decoder side, the signal is split into

i. A branch that the received signal is identical to the transmitted signal

ii. A branch that usually has the logic element dependent on the type of subtraction detection applied

Both branches are then fed to the subtractors that will subtract the cross-correlation. The advantages of this detection are:

i. The usage of most of the chips is allowed, which can increase the signal's received power

ii. The shorter code can be manipulated (codes that have cross-correlation are usually much shorter than those that do not have cross-correlation)

Whereas, the disadvantages are:

i. The number of filters needed depends on the number of code weights in the code sequence

ii. High system cost; two sets of filters are used followed by two sets of corresponding photodetectors

Though many subtraction detection techniques claim that they can suppress the MAI effect, results still showed high BER, which indicate that MAI and PIIN noises still severely affect the system. By contrast, direct detection is the only detection technique that allows the decoding process for the clean detection of the non-overlapping signal. The advantages of direct detection are

i. The signal extracted is theoretically free from MAI and PIIN

ii. The system is less complex because no subtraction process is involved.

The disadvantages are

i. If the code used has cross-correlation, the received power of a signal will be lost from the neglected overlapping chip because the code tends to have many overlapping chips

ii. If the code used does not have cross-correlation, the code must be considerably long to accommodate many users, avoiding the overlapping of chips and affecting bandwidth efficiency

In eliminating MAI, the detection scheme should be able to suppress or eliminate completely all overlapping data. Hence, controlling the power level of the signal is crucial. This concept is applied in the modified-AND detection, which has the main objective of producing sufficient power to entirely eliminate overlapping signals. In a well-designed SAC-OCDMA system where MAI is eliminated and PIIN is addressed, users can successfully communicate asynchronously regardless of network traffic and number of active users (Evgenii, 2005).

The evolution of the development of the code has improved in terms of its simplicity, number of code weight (w), code length (N), and other code properties. In incoherent SAC-OCDMA systems, the codewords are in binary (0, 1) sequences of unipolar encoding that subsequently denote the absence and presence of the light signal, respectively (Djordjevic & Vasic, 2003; Wei et al., 2000; Yin & Richardson, 2009). The number of the code dimension depends on the type of coding scheme applied. 1D code is applied for pulse amplitude coding, pulse phase coding, spectral amplitude