A COMPARATIVE ANALYSIS OF AN OCDMA SYSTEM BASED ON SINGLE PHOTODIODE AND SPECTRAL DIRECT DETECTION SCHEMES

By

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LIST OF ABBREVIATIONS

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
FWHM	Full Wave Half Maximum
FTTH	Fiber To The Home
Gbps	Gigabit per second
GVD	Group velocity Dispersion
IM/DD	Intensity Modulation/ Direct detection
LED	Light Emitting Diode
MAI	Multiple Access Interference
Mbps	Mega bit per second
NRZ	Non Return to Zero
NDSF	Non Dispersion Shift fiber
OCDMA	Optical Code Division Multiple Access
ODLCs	Optical Delay Line Correlate’s
OSNR	Optical Signal to Noise Ratio
OOK	On-Off Keying
QoS	Quality of Service
PD	Photo Diode
PIIN	Phase Induced Intensity Noise
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
RF	Radio Frequency
SAC	Spectral Amplitude Coding
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SLD	Super Luminescent Diode
SPM	Self Phase Modulation

SPD	Single Photodiode Detection
SDD	Spectral Direct Detection
TDM	Time Division Multiplexing
TLS	Tunable Laser Source
WDMA	Wavelength Division Multiple Access
VoD	Video-on Demand

Satu Analisis Perbandingan Sistem OCDMA Berasakan Fotodiod-Tunggal Dan Skim Pengesanan Arah Spektrum

ABSTRAK

Kelebihan utama untuk menggunakan Kod Bahagian Optik Pelbagai Capaian (OCDMA) adalah kaedah akses tak segerak yang fleksibel, keselamatan yang dipertingkat dan penurunan gemalai. Sejak sedekad yang lalu, banyak teknik pengesanan telah dicadangkan bagi OCDMA, terutamanya untuk sistem OCDMA tidak jelas. Pemilihan pengesanan yang betul adalah sangat penting untuk pencapaian sistem yang baik dan skala rangkaian tinggi dengan kadar bit ralat rendah (BERs) kurang daripada 10^{-9}. Sistem OCDMA, bagaimanapun, secara amnya, mengalami pelbagai gangguan capaian (MAI) hingar yang berpunca daripada lain-lain pengguna secara serentak boleh meningkatkan kemungkinan berlakunya sedikit ralat. Untuk mengurangkan pembatasan ini, spektrum jerayun pengekodan (MPS) OCDMA digunakan sepanjang tesis ini. Kelebihan MPS-OCDMA berbanding sistem OCDMA biasa adalah, apabila menggunakan teknik pengesanan yang sesuai, MAI boleh sama sekali dibendung. Ini sama ada dapat mengurangkan kesan MAI atau meningkatkan pencapaian walaupun adanya MAI. Di dalam ini, teknik pengesanan langsung spektrum (SDD) dan fotodiod-tunggal mengesan (SPD) dikaji berdasarkan kod Berat Ganda Terubahsuai (MDW). Analisis prestasi teknik pengesanan yang disyorkan dilakukan melalui eksperimen penyelakuan yang menggunakan perisian Optisystem daripada OptiwaveTM. Selain itu, struktur kedua-dua teknik pengesanan adalah berdasarkan satu fotodiod bagi setiap pengguna berbanding dengan lain-lain teknik pengesanan penolakan. Analisis perbandingan menunjukkan bahawa teknik SPD adalah penyelesaian berkebolehan yang cekap untuk menghalang isyarat gangguan di dalam domain optik sebelum isyarat ditukar kepada domain elektrik. Untuk kod MDW pada kadar data 622 Mbps dan-kesilapan-kadar Bit (BER) 1×10^{-10}, keputusan menunjukkan bahawa SPD boleh menampung lebih daripada 60 pengguna aktif berbanding teknik SDD. Sebahagian daripada kerja tersebut juga dikhaskan untuk mengkaji kemungkinan penggunaan pelbagai jenis penapis optik (Optik Gaussian, filem nipis dan penapis Parut Gentian Braag (FBG)), format data yang berbeza (NRZ dan RZ). Akhir sekali, menggunakan teknik SPD bukan sahaja memberi pencapaian BER yang lebih baik daripada SDD, tetapi dapat digunakan untuk sejumlah besar pengguna pada penghantaran kadar berbilang dengan sumber cahaya yang menjimatkan kos dan untuk jarak penghantaran lebih panjang.

A Comparative Analysis Of An ODMA System Based On Single-Photodiode And Spectral Direction Detections Schemes

ABSTRACT

The main advantages 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 detection techniques have been proposed for OCDMA, especially for incoherent OCDMA systems. Proper detection 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 originates from simultaneous users and severely increases the likelihood 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 techniques, the MAI can be totally suppressed. This either reduces the effect of the MAI or improves the performance even in the presence of MAI. In this thesis, spectral direct detection (SDD) and single-photodiode detection (SPD) techniques based on Modified Double weight (MDW) code, are investigated. The performance analysis of the suggested detection techniques are carried out through simulation experiments using *Optisystem* software from *Optiwave^{TM}*. Moreover, the structure of both detection techniques is based on one photodiode per user compared with other subtraction detection techniques. The comparative analysis shows that the SPD technique is a more capable solution for efficiently restraining interference signals in the optical domain before the signals are converted to the electrical domain. For MDW codes at a data rate of 622 Mbps and a BER of 1×10^{-10}, the results showed that SPD can support more than 60 active users than the SDD technique. Part of the work is also devoted to investigating the feasibility of utilizing different types of optical filters (optical Gaussian, thin film and Fiber Bragg Grating (FBG) filters), and different data formats non-return-to-zero (NRZ) and return-to-zero (RZ). Employing the SPD technique not only provided a BER improvement over SDD, but was used for a large number of users at multiple rates of transmission with cost-effective light sources, and for longer transmission distances.

CHAPTER 1

INTRODUCTION

1.1 Background

Optical fiber has been deployed very successfully in long-haul communications during the last two decades (Anas, S. B. A., M. K. Abdullah, 2009). These long-haul links serve as the backbones of intercontinental communication networks. The use of optical fiber enables transmission of huge data rate over distances of thousands of kilometers (Chen, X., J. Yao, et al., 2005; Glen, K., 2005). Conventional optical multiplexing techniques use either Time Division Multiple Access (TDMA) or Wavelength Division Multiple Access (WDMA) technologies to allocate bandwidth between multiple users, but both of these technologies suffer significant drawbacks when applied to local area networks (LANs) requiring a large number of users (Han, 2002; Prucnal, et al., 1986; Prucnal 2010). Moreover, the maximum transmission capacity for TDMA and WDMA depends on the total number of time slots and wavelength channels, respectively (Yin and Richardson, 2008).

Optical Code Division Multiple Access (OCDMA) is considered a promising technology for using all the optical bandwidth provided by the optical fiber more efficiently over a long-haul transmission distance (Prat, J.,2008; Hasoon, F. N., S. A. Aljunid, et al. (2007)]. It is a multiple access strategy in which the data bit stream of each user is encoded into an optical signal by assigning a unique code signature for each user to be transmitted randomly over a fiber-optic network at an arbitrary time (Kitayama, K.-I., X. Wang, et al., 2006). The advantages of OCDMA include the ability to operate asynchronously, enhancement of privacy, reduced network management, ability to support variable bit rates, and an increase in network capacity (Kavehrad, M. and D. Zaccarin, 1995; Shalaby, H. M. H., 2004). However, the successful implementation of an OCDMA system is dependent on the ability of each receiver to recover the desired data stream while rejecting interference noise introduced by other channels on the network (Smith, E. D. J., Gough, P. T., & Taylor, D. P., 1995). This noise is a consequence of the multiplexing technique itself and can severely limit the overall performance and capacity of the system. Therefore, to realize an optical network implementing OCDMA, a suitable detection technique is required at each receiver to remove unwanted noise while allowing the successful recovery of the desired data (Sahbudin, R. K. Z., Abdullah, M. K., Hitam, S., & Mahdi, M. A., 2008).

1.2 OCDMA Networks

A typical optical network utilizing the OCDMA approach with a star coupler is shown in Figure 1.1. OCDMA is an access strategy in which the data bit stream of each user is encoded into an optical signal by assigning a unique code signature for each user with very low cross-correlation functions in order to optimize the discrimination between the correct sequence and interference. However, implementing OCDMA systems in which the user's data shares the optical channel means the system can exploit the encoding and decoding technique with a unique code signature for each user, which is the most important issue for implementing such system. The encoder of each transmitter represents each 1 bit by sending a signature sequence; however, a binary 0 bit is not encoded and is represented using an all-zero sequence. Since each bit is represented by a pattern of lit and unlit chips, the bandwidth of the data stream is increased.

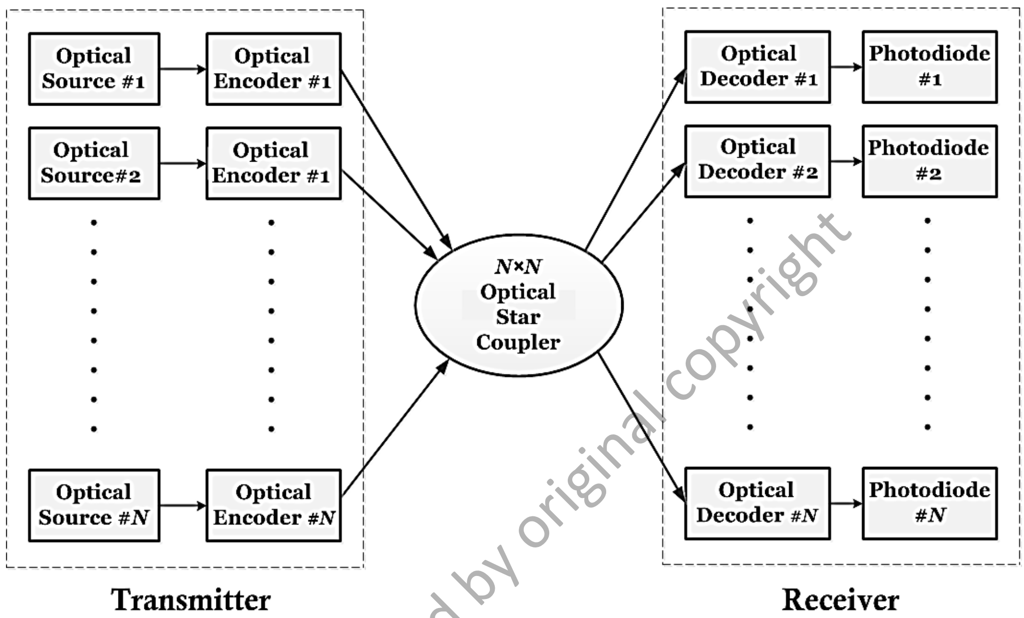

Figure 1.1: A Schematic Diagram of a General OCDMA System (Prucnal, P. R., 2005).

As shown in Figure 1.1, the OCDMA encoded data is sent to an $'N \times N'$ known as a star coupler (in a local area network), or a $'1 \times N'$ coupler (in an access network), and broadcast to all nodes. The crosstalk between different users sharing the common fiber channel, known as Multiple Access Interference (MAI), is usually the dominant source of bit errors in an OCDMA system. The OCDMA technique, which allows multiple users to share the same transmission media by assigning different optical codes to different users, is an attractive candidate for next generation broadband access networks due to its unique features of allowing fully asynchronous transmission with low latency access, as well as enhanced confidentiality (Kitayama, Wang et al. 2006; Kataoka 2009). In addition, since the data is encoded using pseudo-random optical codes during transmission, it also has the potential to enhance confidentiality in the network (Leaird, Jiang et al. 2005; Wang, Wada et al. 2006). OCDMA systems have a number of possible inherent advantages in comparison to alternate multiplexing techniques such as TDMA and WDMA in terms of flexible allocation of channels, ability to operate asynchronously, enhancement of privacy, reduced network management, ability to support variable bit rates, and an increase in network capacity. Moreover, new OCDMA users will not reduce the bandwidth or time allocation for other users, thus making it simpler to employ than WDMA or TDMA systems. (Kitayama, Wang et al. 2006). Therefore, OCDMA is considered a sufficient optical approach that enables the necessary bandwidth to accommodate a large number of user data rate with intensive applications at a cost-effective rate (Yoshikane, N. and e. al., 2004).

1.3 Problem Statement

The effect of MAI is considered a main challenge in an SAC-OCDMA system that faces the practical implementation of an OCDMA system. Generally, SAC-OCDMA systems are limited by the MAI that results from other users transmitting at the same time and on the same common channel (Zahedi, S. and J. A. Salehi, 2000). Furthermore, there are other noises arising from the physical effect of the system design itself, such as Phase-Induced Intensity Noise (PIIN), (Yoshino, M., S. Kaneko, et al., 2008) where the PIIN is related to the MAI due to the overlapping (cross-correlation function) of the spectra from different users (Wei, Z., H. M. H. Shalaby, et al., 2001; Wang, X. and K. Kitayama, 2004). The overlapping chips will corrupt the data of the intended user, thus increasing the BER.

PIIN is related to MAI owing to the overlapping of the spectrum from different users. However, although PIIN is caused by MAI, the suppression of MAI in conventional subtraction detection techniques will not suppress PIIN as the electrical subtraction can only filter out the unwanted data, not PIIN that has already occurred at the photo-detector (Aljunid, S. A., R. A. R, et al., 2004). Therefore, PIIN severely restricts the data transmission rate of each user, impairs the communication quality, and limits the capacity of incoherent SAC-OCDMA systems. Hence, mitigating the PIIN effect is considered the main issue for incoherent SAC-OCDMA systems. (Galli, S. Menendez, R., Narimanov, E. & Prucnal, P., 2008).

Many detection techniques have been proposed in SAC-OCDMA systems such as complementary subtraction techniques (Zahedi, S. and J. A. Salehi, 2000), spectral direct detection (SDD) (Abdullah et al, 2008), and single photodiode detection (SPD) techniques, (AL-Khafaji H. M. R., 2013). Subtraction detection is detection that is suitable for codes that have ideal cross-correlation. However, the subtraction technique suffers from various limitations such as that the number of filters needed depends on the number of code weights in the code sequence; and there is a high system cost as two sets of filters are used followed by two sets of corresponding photodiodes. Moreover, results show that the BER is still high, even though the MAI effect has been suppressed.

SDD is considered the only detection technique that allows the clean detection of the non-overplaying signal. The advantages of SDD are twofold:

i- The filtered signal is absolutely free from MAI and PIIN.

ii- The system is considered cost effective as no subtraction process is involved.

The main limitation of using the SDD technique is that when the code used does not have zero cross correlation, then the received signal will be lost from the neglected chip because the code tends to have many overlapping chips.

Previous studies have indicated that the SPD technique is distinguishable from other detection schemes due to its capability to mitigate both PIIN and MAI in the optical domain. The advantages of SPD are as follows:

i- Restraining interference signals in the optical domain before the signals are converted to the electrical domain.

ii- The system is less complex, as only a single photodiode is utilized instead of two photodiodes as in typical subtraction techniques.

iii- The reduction in the number of photodiodes reduces the amount of optical-to-electrical conversion, and the generated shot noise.

However, other detection techniques have several limitations on system performance (for example, low signal-to-noise ratio, short transmission distance, the number of accommodated users is limited, and complexity). Therefore, in this research, both SDD and SPD techniques which are based on single photodiodes without complex receiver circuitry will be investigated for SAC-OCDAM systems.

MAI can, in theory, be removed when using code with fixed in-phase cross-correlation (Abd, T. H., S. A. A., Hilal A. Fadhil, and M. A. Rashid, 2012). Therefore, an intelligent design of code sequence is necessary to eliminate the effect of MAI in SAC-OCDMA systems (Hasoon, F. N., S. A. Aljunid, et al., 2007; Wei, X. and H. G. Shiraz, et al., 2001). For example, long code length (e.g., prime codes) limits the addressing flexibility of the codes. Long sequences are considered disadvantageous in their implementation, since very wide bandwidth sources are required. (Djordjevic, I. B., B. Vasic, et al., 2004; Kavehrad, M. and D. Zaccarin 1995; Kostinski, N., K. Kravtsov, et al., 2008;). In this work, Modified Double Weight (MDW) codes are focused in this analysis, owing to their motivating properties to eliminate the effect of MAI and suppress the PIIN, such as in (Aljunid, S. A., et al., 2006).

1.4 Research Objective

The objectives of this study are as follows:

1- To analyze the performance of MDW code in the family of SAC-OCDMA based on SPD and SDD techniques.

2- To clarify the efficiency of SPD and SDD techniques using different types of optical filters, data formats and dispersion compensating fiber (DCF).

3- To compare the performance analysis of both detection techniques based on various data rates and fiber lengths.

1.5 Scope of the Project

To investigate the performance of an SAC-OCDMA system utilizing SPD and SDD techniques, four approaches were followed in this thesis:

i- The first approach is to design a system using different type of optical filters, such as uniform Fiber Bragg Grating (FBG), optical Gaussian, and thin film filters.

ii- The second approach is to investigate the system using different types of data formats (Return to Zero (RZ) and non-return to zero (NRZ))

iii- The third approach is to investigate the system performance under a Dispersion compensating fiber (DCF) and ideal dispersion FBG filter.

iv- The fourth approach is to compare and analyze the system using SPD and SDD techniques under multiple data rates, received optical power, and BER.

1.6 Thesis Outline

This thesis is composed of five (5) chapters and is organized as follows:

i. Chapter 1 presents the overview and problem statement that clarifies the driving force and motivating aspect, together with objectives and thesis layout.

ii. Chapter 2 describes the literature review for OCDMA communication systems. It describes the high level transceiver architecture, with discussions on the different modulation techniques and spreading methods as well as different types of detection techniques.

iii. Chapter 3 gives a detailed explanation of the investigation of the transmission performance of an OCDMA system based on SPD and SDD techniques. Also, it proposes different approaches used in order to enhance the system performance.

iv. Chapter 4 discusses the results and the performance analysis of the proposed detections systems.

v. Chapter 5 concludes the thesis by summarizing the most important ideas, conclusions, contribution and future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The interest in OCDMA has been steadily growing during recent decades and this trend is accelerating due to the optical fiber penetration in the first-mile as a pragmatic solution for residential access. In this chapter, a background on the necessary fundamental used to enable OCDMA system compilation is provided. The flow for the rest of this chapter is as follows. A brief introduction is provided in section 2.2. Section 2.3 studies the incoherent OCDMA systems. Section 2.4 introduces the construction of incoherent SAC-OCDMA codes based on Modified Double Weight (MDW) code. Following that, section 2.5 discusses the detection techniques used for an incoherent SAC-OCDMA system. The mathematical model in terms of signal-to-noise (SNR) ratio is derived based on the reported detection techniques. Generally, this chapter provides in detail about the fundamental concepts of OCDMA systems.

2.2 Multiplexing Technologies

To enable flexible bandwidth allocation and possibility of enhanced security within these networks (LAN, WAN and MAN), OCDMA techniques accomplish this by enabling multiple users to broadcast across a shared fiber through optically encoded transmission. In order to make full use of the available bandwidth in optical fibers and to satisfy the bandwidth demand in future networks, it is necessary to multiplex low-rate data streams onto optical fiber to accommodate great number of subscribers. There is a need for technologies that allow multiple users to share the same frequency. Currently, there are three common types of multiple access systems (Prucnal, P. R. (2005) :

- Wavelength Division Multiple Access (WDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

Optical fiber offers vast amount of bandwidth for multiple access operations, permitting many users to simultaneously communicate on the same transmission medium. Furthermore in FTTP networks, the downstream traffic is often broadcast to all users and the upstream traffic from each individual user is collected and combined through some multiplexing techniques onto a single strand of fiber before reaching the carrier's central office. Figure 2.1 illustrates three different multiple access approaches: Time division multiple access (TDMA), Wavelength division multiple access (WDMA) and Code division multiple access (CDMA). These approaches are often considered to make the system bandwidth available to the individual user. Traditional fiber optic communication systems use either TDMA or WDMA schemes to allocate bandwidth among multiple users. Unfortunately, both present significant drawbacks in local area systems requiring large number of users (Charlet, G., 2004; Zaccarin, D. and M. Kavehrad, 1994).

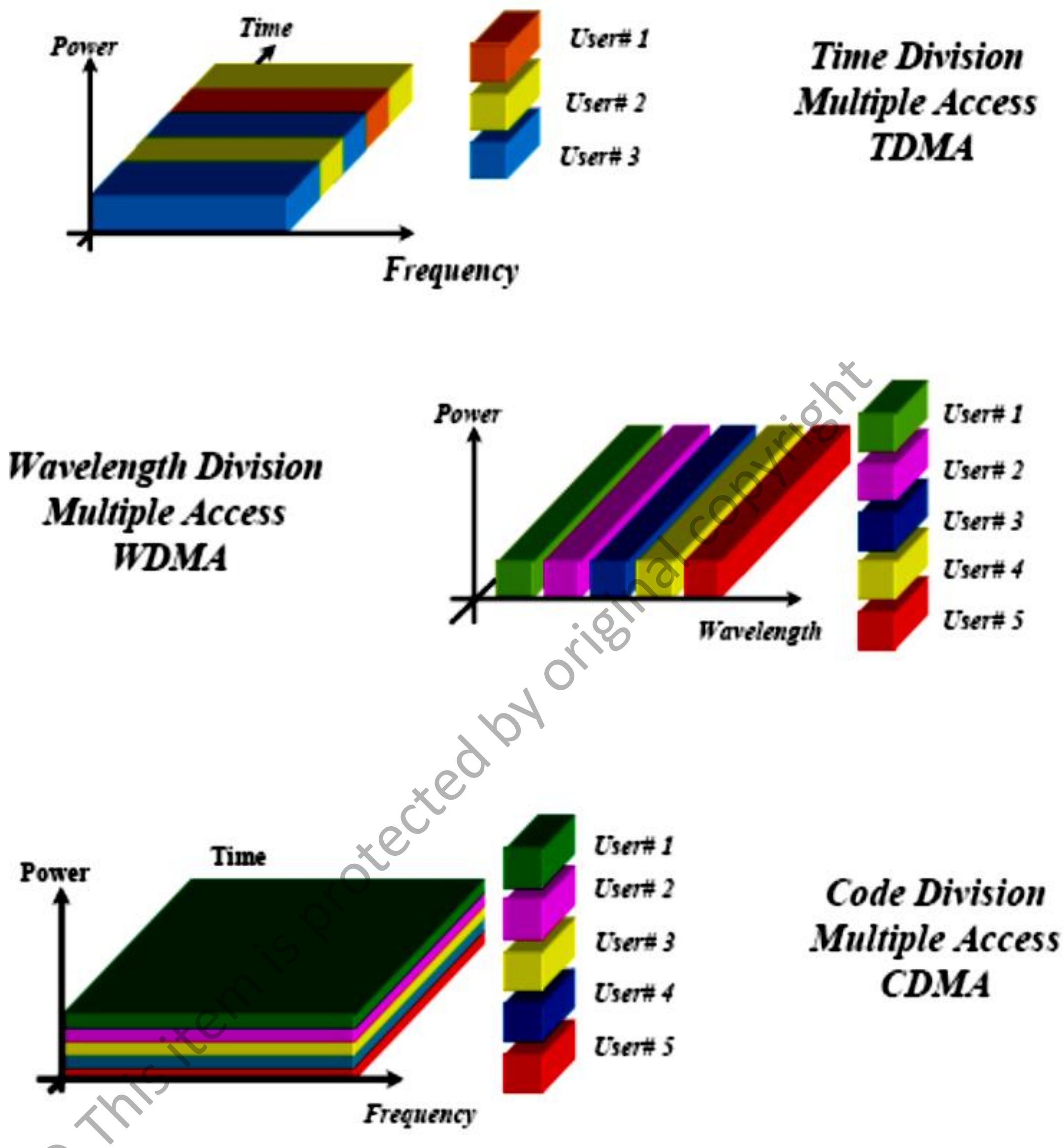

Figure 2.1: Multiple Access Schemes (Proakis, J. G. 2005).

2.2.1 Time Division Multiple Access (TDMA)

TDMA system allows a user to access the common transmission medium by assigning each user a designated time slot and by multiplexing lower bit rate data streams from all users to a higher bit rate data stream (Proakis, J. G.,2005), which means each