THREE LEVEL CODE DIVISION MULTIPLEXING IN RADIO OVER FIBER SYSTEM

By

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Chair : Makhfudzah binti Mokhtar, PhD
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Recently, broadband internet users and the demands for communications with high data rates and wide coverage networks have grown exponentially all over the world. Radio over fiber (RoF) system has been introduced to compete with the demands. It is basically a combination of radio waves and optical fiber links that facilitates wireless access in a range of applications such as Wi-Fi (IEEE 802.11), which is one of the Wireless Local Area Network (WLAN) standards. RoF technology can provide a solution for Wi-Fi that is suffering from relatively low data rates and high loss as the main advantages of this technology are large bandwidth, low attenuation losses, and low power consumption. Despite the benefits of this technology, it is suffering from low quality of signals due to the noise and limited number of users, as each user must be assigned a special carrier frequency. The signal impairments in RoF system, such as noise and distortion, tend to limit the dynamic range of RoF links. Therefore, Three Level Division Multiplexing (3LCDM) technique is chosen to be implemented over RoF system since it is one of the best multiplexing techniques that allows two users to share the same channel which double the capacity. Code division in the 3LCDM technique is achieved by compiling two data streams within the multiple levels instead of the wavelength bandwidth, and this doubles the bandwidth efficiency. In this study, the 3LCDM over RoF system is proposed in WLAN IEEE802.11 (Wi-Fi) to enhance the performance in terms of number of users and receiver sensitivity. OptiSystem software in cooperation with MATLAB was used for the simulation, which is only for the downlink transmission. In this study, the performance of the 3LCDM over RoF system was investigated with 2.4 GHz, 5 GHz, and the combination of 2.4 GHz and 5 GHz carrier frequencies. The results show that the system with the combination of 2.4 GHz and 5 GHz carrier frequencies can support 4 users at a maximum data rate of 2x 0.5 Gbps and 43 km fiber length without any amplifier. It was also found that the power penalty for this particular proposed model over the maximum distance was 0.8 dB for the best user and less than 3 dB for the worst user. The system also displayed better performance than the conventional RoF by around 8.65 dB. In this study, the

performance of the combination of 3LCDM over RoF over WDM for 8 users was also evaluated. By using the post-Dispersion Compensation Fiber (DCF), it was observed that the system at 2 x 0.5 Gbps for each carrier can achieve maximum distance of 57 km without using amplifiers. In addition, the performance of the worst user in 3LCDM-RoF-WDM system is better than that of the [50] in RoF over WDM system in terms of receiver sensitivity by around 7.94 dB. These findings prove the efficiency of the proposed 3LCDM-RoF and 3LCDM-RoF-WDM systems to be applied in Wi-Fi.

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

PEMULTIPLEKSAN PEMBAHAGIAN KOD TIGA -TAHAP DALAM SISTEM RADIO ATAS GENTIAN

Oleh

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Pengguna internet jalur lebar dan permintaan komunikasi data berkadar tinggi dan liputan rangkaian yang luas kini telah berkembang dengan pesat di serata dunia. Sistem Radio melalui gentian (RoF) telah diperkenalkan untuk bersaing dengan permintaan tersebut. Pada dasarnya, ia adalah satu kombinasi gelombang radio dan pautan gentian optik yang memudahkan akses tanpa wayar dalam pelbagai aplikasi seperti Wi-Fi (IEEE 802.11) yang merupakan salah satu daripada piawaian Rangkaian Kawasan Setempat (LAN) tanpa wayar. Teknologi RoF mampu memberikan penyelesaian terhadap Wi-Fi yang mempunyai masalah kadar data yang rendah dan kehilangan yang tinggi berikutan beberapa kelebihan utama teknologi ini iaitu lebar jalur yang besar, kehilangan pelemahan yang rendah, dan penggunaan kuasa yang rendah. Walaupun memiliki beberapa kelebihan tersebut, teknologi ini mempunyai masalah signal berkualiti rendah disebabkan oleh bunyi bising dan jumlah pengguna yang terhad memandangkan setiap pengguna mesti diberikan frekuensi pembawa tertentu. Kelemahan signal dalam sistem RoF seperti bunyi bising dan penyelewengan menghadkan julat sambungan RoF yang bersifat dinamik. Oleh itu, teknik Pemultipleksan Pembahagian Kod Tiga Tahap (3LCDM) telah dipilih untuk digunakan ke atas sistem RoF memandangkan ia merupakan salah satu daripada teknik pemultipleksan terbaik yang membolehkan dua pengguna berkongsi saluran yang sama, dan ia mampu menggandakan kapasiti. Pembahagian kod dalam teknik 3LCDM Berjaya dicapai dengan menyusun dua aliran data dalam pelbagai tahap berbanding penggunaan lebar jalur panjang gelombang, dan ini menggandakan keberkesanan lebar jalur. Dalam kajian ini, 3LCDM melalui sistem RoF dicadangkan dalam WLAN IEEE802.11 (Wi-Fi) bagi meningkatkan prestasi dari segi jumlah pengguna dan sensitiviti penerima. Perisian OptiSystem yang bergabung dengan MATLAB telah digunakan untuk simulasi yang mana ini hanyalah untuk penghantaran downlink. Dalam kajian ini, prestasi 3LCDM melalui sistem RoF telah diperiksa menggunakan 2.4 GHz, 5 GHz dan kombinasi frekuensi pembawa 2.4 GHz dan 5 GHz. Keputusan menunjukkan bahawa

sistem yang memiliki kombinasi frekuensi pembawa 2.4 GHz dan 5 GHz mampu menanggung 4 pengguna pada kadar data maksimum 2x 0.5 Gbps dan jarak gentian sepanjang 43 km tanpa memerlukan apa-apa pembesar. Juga telah didapati bahawa penalti kuasa bagi model yang dicadangkan ini melalui jarak maksimum adalah 0.8 dB bagi pengguna terbaik dan kurang dari 3 dB bagi pengguna paling lemah. Sistem ini juga menunjukkan prestasi yang lebih baik berbanding RoF biasa dengan kadar 8.65dB. Dalam kajian ini, prestasi kombinasi 3LCDM-RoF melalui WDM bagi 8 pengguna juga telah dilnilai. Dengan menggunakan 'post-Dispersion Compensation Fiber' (DCF), telah diperhatikan bahawa sistem berkelajuan 2 x 0.5 Gbps untuk setiap pembawa boleh mencapai jarak maksimum 57 km tanpa menggunakan penguat. Malahan, prestasi pengguna paling lemah dalam sistem 3LCDM-RoF-WDM kelihatan lebih baik daripada prestasi pengguna sistem RoF melalui WDM dari segi sensitiviti penerima sebanyak kira-kira 7.94 dB. Kesemua dapatan ini membuktikan keberkesanan sistem 3LCDM-RoF dan 3LCDM-RoF-WDM yang akan diaplikasikan dalam Wi-Fi.

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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:

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- the research and the writing of this thesis were done under our supervision;
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LIST OF ABBREVIATIONS

3LCDM	Three Level Code Division Multiplexing
AM	Amplitude Modulation
ASK	Amplitude Shift Keying
BER	Bit Error Rate
BPSK	Binary Phase-Shift Keying
BS	Base Station
BW	Band Width
CS	Central Station
CWDM	Course Wavelength Division Multiplexing
DCDM	Duty Cycle Division Multiplexing
DCF	Dispersion Compensation Fiber
DD-MZM	Dual Drive Mach-Zehnder Modulator
DI	Delay Interferometer
DPSK	Differential Phase Shift Keying
DWDM	Dense Wavelength Division Multiplexing
EAM	Electro-Absorption- Modulator
EDFA	Erbium Doped Fiber Amplifier
EO	Electrical to Optical
FBG	Fiber Bragg Grating
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
IM	Intensity Modulation
ISI	Inter-Symbol Interference

LANs	Local Area Networks
LPF	Low Pass Filter
MZM	Mach-Zehnder modulator
NRZ	Non Return to Zero
OBPF	Optical Band Pass Filter
OCDM	Optical Code Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing
OOK	On-Off Keying
OSSB	Optical single sideband
PM	Phase Modulator
PMD	Polarization Mode Dispersion
PRBS	Pseudo-Random Binary Sequence
PSK	Phase Shift Keying
QPSK	Quaternary-phase-shift keying
RF	Radio Frequency
RoF	Radio over Fiber
RZ	Return to Zero
SCM	Sub-Carrier Multiplexing
SIR	Signal-to-Interference Ratio
SSMF	Standard Single Mode Fiber
WDM	Wavelength Division Multiplexing
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Nowadays, information technology systems are growing rapidly due to the increasing demand for cell phones and broadband internet, which require many base stations (BS) to satisfy the demands. Thus, the world has moved towards Radio over Fiber (RoF) systems that offer an economic advantage because of their low attenuation and wide bandwidth characteristics. Meanwhile, Wireless Local Area Network (WLAN) technology was available to support Mbps data transmission rates and provide fixed data network expansion. The WLAN standard-IEEE 802.11, which is known as Wi-Fi, can offer up to 54 Mbps for IEEE 802.11a and g standards functioning at 2.4 GHz and 5 GHz. However, they do not provide the type of mobility that is required. Wi-Fi (IEEE 802.11) is suffering from the problems of complex installation, high loss, and comparatively low bit rate [1].

In these circumstances, RoF offers a potential solution for mobility and compensates for the limitations of many technologies. It is a technology where radio frequency (RF) signals are utilized to modulate light and then transmitted over an optical fiber. The modulated signals are distributed from a central station to base stations. Most operations of signal processing, including multiplexing, encryption, RF generation, and modulation, take place in the central station, which makes the base station simple and cost-effective. RoF technology can provide ultra-wide bandwidth and dynamic resource allocation. RoF technology is also characterized by immunity to radio frequency interference, low attenuation loss, and reduced power consumption [2]. However, RoF suffers from a limited number of users and poor quality of signals due to the noise.

Therefore, multi-carrier transmission techniques can be used over RoF communication systems in order to increase the number of users and enhance the signal quality. One of the multiplexing techniques that can be used over RoF is Wavelength Division Multiplexing (WDM) which sends many signals through the same optical link. WDM can raise the broadband system by overcoming problems that affect the efficiency of RoF system performance, but the use of spectrum is not optimized in WDM. Another technique is Orthogonal Frequency Division Multiplexing (OFDM) that can improve signal RF transmission performance and provide high data rate transmission. However, it is still limited for short distances and adds complexity to the system. In addition, the combination of Sub-Carrier Multiplexing (SCM) and WDM over RoF system has been implemented as a solution for the continuous demand of bandwidth. This combination provides high spectral efficiency and less complicated receiver (base station) but it is sensitive to Polarization Mode Dispersion (PMD) [3]. Optical Code Division Multiplexing (OCDM) is also applied over RoF system to

improve spectral efficiency [4]. However, OCDM needs huge bandwidth and suffers multiple access interference (MAI) which can produce noise degrades the transmission performance [5, 6].

Another multiplexing technique that has a potential to improve the performance if it is designed over the RoF system in Wi-Fi is Three-level code division multiplexing (3LCDM). This technique which is developed by Mokhtar et al. (2004) has the ability to support two users in one channel containing both Non Return to Zero (NRZ) and Return to Zero (RZ) line codes [5]. Code division in 3LCDM technique is achieved by combining two data streams within the multiple levels instead of the wavelength bandwidth which leads to double the bandwidth efficiency. Thus, 3LCDM is selected in this study to be designed and implemented over RoF system to be applied in Wi-Fi application.

1.2 Problem Statement

Wi-Fi (IEEE 802.11) is suffering from the problems of complex installation, higher loss, and relatively low data rate. In these conditions, Radio over Fiber (RoF) provides a potential solution to compensate the limitations of many technologies as it is characterized by immunity to radio frequency interference and low attenuation loss [1]. However, RoF suffers from a limited number of users and poor quality of signals due to the noise. Based on the system of conventional RoF reported by Shuvodip Das and Ebab Zahir [50], the RoF system with 10 GHz and 15 GHz carrier frequencies can support only two users at 2.5 Gbps maximum data rate. The system also encounters a certain amount of deviation in the optical spectrum at both receivers due to the nonlinear effect. In addition, the system of RoF over WDM reported by Sainawi and Ismail [34] uses two wavelengths and two carrier frequencies to support only two users at 1Gbps of data rate. Noted that the conventional RoF system and RoF over WDM system were simulated with using optical amplifiers that add more cost to the systems. Therefore, this study aims to address such issues by applying 3LCDM as a multi-carrier transmission technique over RoF and over RoF-WDM in WLAN IEEE802.11 without using any amplifier. The 3LCDM which was developed by Mokhtar et al. (2004), was chosen since it has the ability to support two users in one channel containing both Non Return to Zero (NRZ) and Return to Zero (RZ) line codes. Code division in the 3LCDM technique is achieved by compiling two data streams within the multiple levels instead of the wavelength bandwidth, and this doubles the bandwidth efficiency. In RoF, the electrical carrier frequencies of 2.4 GHz and 5GHz are chosen since these frequencies are from the bands that are broad enough to be useful for Wi-Fi needs, as well as they are considered the highest and widest bands available within the boundaries of economics and technology. Furthermore, there is a lack of studies on 3LCDM technique and it has not yet been implemented over RoF system. Thus, a combination of 3LCDM technique and RoF system for the first time has been introduced in this work to enhance the reliability and double the capacity of the conventional RoF system.

1.3 Research Objectives

The main aim of this proposed research is to develop the 3LCDM over RoF system for Wi-Fi application at 2.4 GHz and 5GHz carrier frequencies in order to improve the data rate, number of users, and signal quality in the RoF system. To achieve this, these specific objectives are derived to:

1. Design the 3LCDM over RoF system with 2.4 GHz, 5 GHz, and the combination of 2.4 GHz and 5 GHz carrier frequencies.

2. Analyze the optimal tradeoff between data rate and fiber length for the designed 3LCDM over RoF system.

3. Evaluate the performance of the designed system of 3LCDM over RoF for four users at the maximum data rate.

4. Design and evaluate the performance of the combination of 3LCDM-RoF over WDM.

1.4 Scope of the Study

This study demonstrated modeling and designing of 3LCDM over RoF system, then simulation and analysis of this design. It also discussed the principle work of the system. To achieve the objectives, the work was done by using OptiSystem software and MATLAB. This study is within the scope of radio over fiber system and multiplexing techniques. For the relevant literature reviews, it includes theoretical aspects of RoF system and some related multiplexing, modulation and line coding techniques. In addition, analysis for the work based on relevant design parameters. The performance evaluation is in terms of the achieved Bit Error Rate (BER), receiver sensitivity, and the number of users that can be served.

1.5 Research Method

In this study, the proposed of 3LCDM-RoF model was designed using 2.4 GHz and 5 GHz carrier frequencies and Dual-Drive Mach-Zehnder modulator (DD-MZM) as an optical modulator. The methodology that used in designing 3LCDM over RoF system involves familiarization with the OptiSystem software, understanding designed samples, designing system, generating components and simulation objects, running the simulation, analyzing the data and evaluating the results. OptiSystem software was used for simulation for downlink transmission only. The software was used to design, test, evaluate and simulate any type of optical link in the transmission layer of optical networks [7]. Its capabilities can be simply extended with the accumulation of user components and interfaces to a variety of broadly used tools. OptiSystem has a

MATLAB component that provides the facility of calling MATLAB within its environment to integrate different components or models into the software. Thus, we used the optical signal format that OptiSystem generate and co-simulated that signal to be launched into the MATLAB workspace. In this study, the performance of 3LCDM over RoF system was evaluated by analyzing the results obtained from OptiSystem software and co-simulated with MATLAB.

1.6 Thesis Organization

This thesis is laid out in five chapters, where a brief background about the study is provided by chapter one. The problem statement, the objectives, and the scope of the work have also been covered. Chapter two reviews the literature, which includes principles of several multiplexing techniques and an overview for RoF systems. In chapter three, the methodology of the study is covered by showing detailed diagram of the proposed system as well as highlighting the steps to achieve the purpose of the study. Then chapter four discuss the results and achievements that related to the proposed system by considering bit error rate as the main performance parameter. Finally, the conclusions as well as some suggestions for future work are drawn up in chapter five.

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LIST OF PUBLICATIONS

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