PERFORMANCE CHARACTERISATION BETWEEN OPTICAL WIRELESS COMMUNICATION AND ULTRAVIOLET COMMUNICATION FOR INDOOR APPLICATION



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PERFORMANCE CHARACTERISATION BETWEEN OPTICAL WIRELESS COMMUNICATION AND ULTRAVIOLET COMMUNICATION FOR INDOOR APPLICATION



This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering Universiti Teknikal Malaysia Melaka

2022

DECLARATION

I declare that the thesis of Performance Characterisation Between Optical Wireless Communication and Ultraviolet Communication for Indoor Application is the result of my own work except for quotes as cited in the references.

UNIVERSITI (KA Signature

Author : IZZAH HAZIRAH BINTI ZAINAL

Date : 20 JUNE 2022

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

UNIVERSI MEL Signature Supervisor Name : TS DR ZAITON BINTI ABDUL MUTALIP

Date : 21 JUNE 2022

DEDICATION

I dedicate this thesis to the people who have been beside me throughout this journey which are my parents. I also dedicate this thesis to my siblings and friends who cheer me up when I feel down. This is for you.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

Wireless communication technologies become one of the biggest technology that are considered to be suitable for radio frequency in various type of applications including indoor application. This research studies is to know the suitability of wireless technology for indoor application to compliment 5G and 6G advancement. Two types of technology which are Optical Wireless Communication (OWC) and Ultraviolet Wireless Communication (UVC) are observed based on On-Off Keying (OOK) modulation technique. The power distribute by LED in fixed size room and various amount of LEDs are compared between those two technology. The minimum illuminance for OWC is 0.36lx while for UVC is 90lx. Bit Error Rate (BER) for both technologies are same which in the range of 10⁻⁹ that complement ITU-T standard. For eye diagram result, the eye pattern generated for both technologies are different in terms of eye opener. OWC is chosen to be the technologies that suitable for indoor applications due to its benefits. The ideas of this project is to make sure the safety and security of signal which are critical in optical and ultraviolet frequency communication.

ABSTRAK

Teknologi komunikasi tanpa wayar merupakan salah satu teknologi terbesar yang mempertimbangkan kesesuaian frekuensi radio dalam pelbagai jenis aplikasi termasuklah aplikasi di dalam kawasan tertutup. Penyelidikan ini dilakukan untuk melihat kesesuaian teknologi tanpa wayar yang boleh digunakan di kawasan tertutup bagi memenuhi kemajuan 5G dan 6G. Terdapat dua teknologi yang diselidik iaitu komunikasi optik tanpa wayar dan komunikasi ultraviolet. Keduanya akan dikaji menggunakan teknik modulasi kekunci tutup dan buka. Pengagihan kuasa yang dikeluarkan oleh LED dan diletak di dalam bilik yang mempunyai saiz sama akan dibandingkan untuk dua teknologi tersebut. Pencahayaan minimum yang di keluarkan bagi teknologi optikal adalah 0.361x manakala untuk komunikasi ultraviolet adalah 901x. Kadar ralat bit bagi kedua-dua teknologi adalah sama dimana ia berada dalam julat 10⁻⁹ yang ditetapkan dalam standard ITU-T. Bagi keputusan rajah mata, corak yang dikeluarkan untuk kedua-dua teknologi adalah berbeza dari segi bukaan rajah mata tersebut. Teknologi optik tanpa wayar dipilih sebagai teknologi yang sesuai digunakan di kawasan tertutup disebabkan oleh faedah yang ada pada teknologi tersebut. Cadangan projek ini adalah untuk memastikan keselamatan isyarat yang merupakan perkara penting untuk optik dan frekuensi komunikasi ultraviolet.

ACKNOWLEDGEMENTS

First and foremost, my most humble gratitude to our God, Allah S.W.T. Only with His blessings and perseverance that was bestowed upon me in making this undergraduate journey possible. My special gratitude and appreciations to my FYP main supervisor, Dr Zaiton Binti Abdul Mutalip who been an inspiration and mentor throughout my degree journey. Her guidance and encouragement in my research had refined my knowledge in the wireless technology and system engineering. My sincere gratitude to my family for their support, love and prayers throughout my degree journey. Words cannot express their sacrifices and support that had led me to what I am today. I am also very thankful to all my friends and colleagues who had contributed directly or indirectly in completing my thesis.

TABLE OF CONTENTS

Declaration	
Approval	
Dedication	
Abstract	i
Abstrak	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables ALAYSIA	vii
List of Figures	viii
List of Abbreviations	Х
List of Symbols	Х
اونيۇىرسىتى تېكنىكى مىلىسىيا ملاك	xi
CHAPTER 1 INTRODUCTION UNIVERSITI TEKNIKAL MALAYSIA MELAKA 1.1 Introduction	1
1.2 Objective	2
1.3 Problem Statement	3
1.4 Scope of Project	3
1.5 Sustainability	3
1.6 Report Structure	4
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	5
2.2 Optical Wireless Communication	5

9

		V
	2.2.2 Ultraviolet Communication	11
2.3	Modulation Technique	14
2.4	Past Research	16
CHA	APTER 3 METHODOLOGY	
3.1	Introduction	18
3.2	Overview of Project Implementation	18
	3.2.1 Flowchart	18
	3.2.2 Block Diagram	20
3.3	Simulation of Optical Wireless Communication	21
	3.3.1 Power Distribution	22
	3.3.2 Bit Error Rate and EbN0	24
	3.3.3 Bit Error Rate and Signal-to-Noise Ratio	25
	3.3.4 Eye Diagram for OOK Modulation	26
	AND THE PARTY OF T	
CHA	APTER 4 RESULTS AND ANALYSIS	
4.1	Introduction	28
4.2	Optical Wireless Communication	28
	4.2.1 Power Distribution	28
	4.2.2 Bit Error Rate	30
	4.2.3 Eye Diagram	31
4.3	Ultraviolet Wireless Communication	33

.3	Ultrav	iolet Wireless Communication	33
	4.3.1	Power Distribution	33
	4.3.2	Bit Error Rate	34
	4.3.3	Eye Diagram	36

CHAPTER 5 DISCUSSIONS

5.1	Introduction	37

5.2	Discus	ssion	37
	5.2.1	Power Distribution	37
	5.2.2	Bit Error Rate	39
	5.2.3	Eye Diagram	40

CHAPTER 6 CONCLUSION

6.1	Introduction	42
6.2	Conclusion	42
	6.2.1 Power Distribution	42
	6.2.2 Bit Error Rate	43
	6.2.3 Eye Diagram	43
6.3	Evaluation Performance	43
6.4	Future Work	44
6.5	Sustainability and Environmental Friendly	45
REFI	levier min in Sinces	46
APPI	ENDIX A1	50
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

LIST OF TABLES

Table 2.1	Optical Spectrum	9
Table 2.2	Difference between VLC and IR	10
Table 2.3	Summary from past research	16
Table 3.1	Parameters	21
Table 4.1	Comparison between BER and SNR	31
Table 4.2	Comparison between BER and SNR for UVC	35
A LINE	NLAYSIA MELT	



LIST OF FIGURES

Figure 1.1	Optical spectrum	2
Figure 2.1	OWC schematic system	6
Figure 2.2	Schematic diagram NLOS ultraviolet for MIMO	11
Figure 2.3	The visualisation of single scattering event	13
Figure 2.4	a) directed LOS b) NLOS c) diffuse link.	14
Figure 3.1	Flowchart of the project	19
Figure 3.2	Block diagram of the project	20
Figure 3.3	Parameters	22
Figure 3.4	Lambertian formula	22
Figure 3.5	Center luminous	23
Figure 3.6	Simulation of probability error	24
Figure 3.7	Bit error rate	24
Figure 3.8	Bit error rate vs EbNOL MALAYSIA MELAKA	25
Figure 3.9	Simulation of BER and SNR	25
Figure 3.10	BER vs SNR	25
Figure 3.11	Parameter for eye diagram	26
Figure 3.12	Impulse response system	26
Figure 3.13	Plotting eye diagram	27
Figure 4.1	Power distribution for 1 LED	28
Figure 4.2	Power distribution for 2 LEDs	29
Figure 4.3	Power distribution for 4 LEDs	29
Figure 4.4	Error rate performance against SNR for 1-LED	30

Figure 4.5	Error rate performance against SNR for 2-LEDs	30
Figure 4.6	Error rate performance against SNR for 4-LEDs	30
Figure 4.7	Eye diagram for 1-LED	31
Figure 4.8	Eye diagram for 2-LEDs	31
Figure 4.9	Eye diagram for 4-LEDs	31
Figure 4.10	Binary eye diagram for 1-LED	32
Figure 4.11	Binary eye diagram for 2-LEDs	32
Figure 4.12	Binary eye diagram for 4-LEDs	32
Figure 4.13	Power distribution for 1-LED	33
Figure 4.14	Power distribution for 2-LEDs	33
Figure 4.15	Power distribution for 4-LEDs	33
Figure 4.16	Error rate performance against SNR for 1-LED	34
Figure 4.17	Error rate performance against SNR for 2-LEDs	34
Figure 4.18	Error rate performance against SNR for 4-LEDs	34
Figure 4.19	Eye diagram for 1-LED	36
Figure 4.20	Eye diagram for 2-LEDs	36
Figure 4.21	Eye diagram for 4-LEDs MALAYSIA MELAKA	36
Figure 5.1	a)c)e) OWC; b)d)f) UVC	38
Figure 5.2	a)c)e) OWC; b)d)f) UVC	39
Figure 5.3	a)c)e) OWC; b)d)f) UVC	40
Figure 5.4	Visualisation of transit time	41

LIST OF APPENDICES

Appendix A1

Coding in MATLAB



50

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless devices are increasing day by day because of its user friendly which consumer can access real-time information other than it can helps in reducing the usage of cables. WiFi is something everyone know and people cannot live without it. Device connectivity provides ecosystems in which one device can act as an entry point to others. Using the system's continuous data gathering, a device may collectively function to deliver insights to users. IoT solutions have the potential to enhance business verticals while also influencing other elements of our everyday lives such as health, safety, productivity, and entertainment [1]. Optical wireless communication (OWC) is known to have wide bandwidth and license-free frequency spectrum as shown in [2]. OWC suitable for radio frequency in many applications including indoor application. The optical spectrum is described as electromagnetic radiation with wavelengths from 10nm and frequencies range from 300 GHz to 3000 THz. Ultraviolet communication (UVC) is included under OWC but with difference bandwidth and omni-directional links with low background noise [3].



Figure 1.1: Optical spectrum

Because of the low signal attenuation at low carrier frequencies, the signal that need to be transmit may pass through opaque obstacles such as walls and it diffract on it. Even though the carrier frequency might be low it has smaller bandwidth and consequently data speeds [1]. Increasing the carrier frequency and reducing the wavelength can make better bandwidth and data rates across a shorter connection range with less penetration and diffraction.

1.2 Objective

The project is focus on exploring the performance of optical wireless communication and ultraviolet communication by using On-Off Keying modulation schemes. Optical Wireless Communication OWC is known to have license-free unregulated wide bandwidth to serve ultra-high transmission rate while ultraviolet wireless communication UVC has large spectrum than optical spectrum. Indoor application has obstacles that can cause data loss for optical wireless communication OWC since it need point to point system. Ultraviolet wireless communication UVC is band that is virtually noiseless compared to optical wireless communication OWC so it can be enable more secure communication at once it will transmit the data faster and stable. On-Off Keying OOK modulation will be used in the project by using MATLAB software to compare the performance both system in the same environment and to analyze which wireless communication is suitable for indoor application.

1.3 Problem Statement

Due to the rapid expansion in wireless technology, optical wireless communication OWC and ultraviolet wireless communication UVC become uprising promising technology. Optical wireless communication OWC break in the optical line of sight Line-of-sight (LOS) link that can be major cause loss of data. When it comes to indoor application, it has lot of obstacles including smokes, furniture, etc. It does have some of suitable link configuration for both application such as line-of-sight LOS, non line-of-sight Non line-of-sight (NLOS) and diffuse link. Even though ultraviolet wireless communication UVC channel response have different behavior for different room size, it also had harmful effect if human expose for too long. Between optical wireless communication OWC and ultraviolet wireless communication UVC which one is more suitable to use for indoor application?

1.4 Scope of Project

The scope of project is to simulate both optical wireless communication and ultraviolet wireless communication based on on-off keying configuration. Then the performance in terms of bit error rate, transmission power, environmental noise measurement and signal-to-noise ratio are evaluated. The size of room is fix to 4x4x4 and used LED as the transmitter. Based on the performance characterization, the suitability of the system for indoor environment will be proposed

1.5 Sustainability

This project is considered to be a green technology because the component used which is LED in the project is one of the efficient lighting source and consumed less electricity compared to the normal fluorescent light. optical wireless communication and ultraviolet wireless communication system are compatible to the radio frequency wireless technology in many applications. Based on the vision of IR4.0, both system can help to overcome the spectrum crunch in radio frequency Radio Frequency (RF) communications. This helps to meet the growing demand for high-speed communication links between consumer electronics, sensors and the infrastructure. The project has commercial value especially in the communication and data transmission field as it offers high- speed wireless communication as a complementary solution for overcrowded RF and WIFI system.

1.6 Report Structure

This report consists of five (5) main chapters. Chapter 1 is introduction where it is more to describe about this project that includes introduction of the project, objectives, problem statement, scope, sustainability and summary of the project. Chapter 2 is literature review that involved with the background research of application. Next, methodology is explained in chapter 3 that includes technical design of electronic component and coding that use in this project. In chapter 4, there are results and discussion on outcome of the project. Last chapter which is chapter for conclusion and suggestion on how to improve and added in the project.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains more on how the project is needed by the user to utilise in their work. Some research on the component specifications is made to complete the job successfully. Other than that, this chapter needs to consider how the initiative will aid in the improvement of user performance.

2.2 Optical Wireless Communication

Optical wireless communication OWC is light that transmits from one point to another in free space or it also called Free Space Optics (FSO) [4]. Wireless communication is essential and has become part of our lives where it helps to connect people all around the world through the internet and devices. Light can transmit data faster and efficiently through the air rather than through glass with a greater incident angle. Optical wireless communication OWC has benefits, including people who can use it for free without any license. It is not dangerous to humans since it does not emit any harmful light. Unfortunately, optical wireless communication OWC have stringent alignment requirements and severe weather-related impacts [5]. Data will be interrupted if there is an obstacle in front of the receiver because it is sensitive to shadow and has limited by front-end photodiode capacitance. Figure 2.1 below shows the structure of OWC system where it includes a laser that generates a light source and transmits it to atmospheric channel before filtering the signal in telescope.



Figure 2.1: OWC schematic system

There is much more application that OWC can be used in such as indoor, outdoor, underwater, industry and airport. The history started with the first telegraph and electrical telegraph developed in 1830s by Samuel Morse to use for long distance communication [6]. After years of invented new technology, it has few types of communication technology based on its suitability. Under OWC itself, it has different communication such as; [7]

i. Satellite communication

Satellite communication has the big role to transmit signal all over the world and designed specifically to use in telecommunications including TV, radio broadcasting, planes and ships. It is also used for military purposes or as military weapon. They are in charge of providing these services to a certain location of the planet. The satellites' power and bandwidth are determined by the preferred footprint size, the complexity of traffic control protocol methods, and the cost of ground stations.

ii. Infrared communication

Infrared (IR) is a form of information transmission that uses light that is invisible to the naked eye. This indicates that it is located between microwaves and visible light on the electromagnetic spectrum. To receive the light beam, infrared communication requires a transmitter and a photo receiver [7]. Because any disruption to the light will prevent the photo receiver from receiving it, IR can only work when there is a clear line of sight.

iii. Broadcast radio

An omnidirectional antenna broadcasts a sent signal over a large coverage area in a broadcast radio channel. A directional transmitting antenna is used in a point-to-point radio channel to focus the wave into a small beam that is directed toward a single receiving location. In either instance, a remote receiving antenna picks up the sent electromagnetic wave and converts it to an electric current [8].

iv. Microwave communication

Antennas can focus microwave signals in the same way that a laser beam concentrates light into a narrow beam. Signals are sent straight from the source to the receiver. The range of a reliable microwave signal does not extend much beyond the visible horizon. Cities would be crisscrossed by microwave transmissions transmitting crucial signals if microwave signals were visible to the naked eye. Any type of data that can be communicated over telephone wires or coaxial cables can be transmitted as efficiently over a microwave circuit as it can over the wires and cables it supplements.

اونيوم سيتي تيڪنيڪل مليسيا ملاك^{، w. wi-Fi}

Wi-Fi internet is a wireless electronic network with a low power consumption. These can be found in nearly every shopping mall, restaurant or even in public places. A physical wired network is, in essence, connected to a router. As a result, low-power wireless network is created. It is possible to join a variety of devices to the local network using this method. However, criminals and hackers have been known to target public wireless internet connections. As a result, it is critical that both users and providers implement password security measures when connecting to these networks [9].

vi. Global Positioning System (GPS)

The Global Positioning System (GPS) is a space-based radio navigation system that consists of a constellation of satellites that broadcast navigation signals and a network of ground stations and satellite control stations that monitor and regulate the system.

GPS attracted a wide range of users throughout the world by providing a system that overcame the constraints of several existing navigation technologies [9].

Indoor application become much crucial as an outdoor application since most of the work happen either at home or office. OWC-based indoor positioning functionality is also in great demand. The method to accept the signal has generated much interest, where multiple transmitters are used and positioning information is provided by estimating the channel gain of each transmitter [8]. Before apply communication technology for indoor application, OWC has some types of communication types of depending on the distance.

• Ultra-short range: for nm/mm distance of communication.

AALAYSIA

- Short range: Wireless body area network (WBAN) and wireless personal area network (WPAN) and bluetooth which do not need to consume too much power and low in data transfer.
- Medium range: when the data transmits between two points and usually used for wireless local area networks (WLANs).
- Long range: suitable for inter-building connection since it can transmit data faster than short range communication.
- Ultra-long range: used for space communication such as inter-satellite [9].

2.2.1 Visible Light Communication

Due to the revolution of IR 4.0, everyday devices such as TVs, microwaves, refrigerators, and cars will be linked 24 hours a day and cause of demanding even more resources, either from the devices themselves or from the accompanying network infrastructure [10]. In other literature, to increase the power distribution in a room [11] used five optical attocells and improve most of the area of room. When the technology of Light Emitting Diode (LED) was developed, most researchers chose LEDs to send signals since they are ideal because they are not dangerous to humans when exposed for long periods. In the optical spectrum range, visible light has the most LED colours with a different range of frequency and wavelength.

VLC used white LEDs to provide a minimal cost combines lighting and communication features [12]. Compared to LEDs, lasers with core wavelengths of 850 nm, 1310nm, and 1550 nm may easily attain a greater transmission data rate but have a much smaller beam diameter [13]. When there are a lot of other devices that use wire- less communication, larger bandwidth is needed to transmit signals, even for high- speed frequencies. Other than focusing more on indoor applications, other researchers fixate on the outdoor application where it can be used in military based for surveillance and traffic light signals [14].

Range	Spectral Category	Frequency	Wavelength
IR	Far Infrared (FIR)	0.3-20THz	1-0.015nm
IR	Near Infrared	214.3-394.7 THz	1400-760nm
Visible Light	Red	394.7-491.8 THz	760-610 nm
Visible Light	Orange	491.8-507.6 THz	610-591nm
Visible Light	Yellow	507.6-526.3 THz	591-570nm
Visible Light	Green	526.3-600 THz	570 - 500 nm
Visible Light	Blue	600 - 666.7 THz	500-450 nm
Visible Light	Violet	666.7-833.3 THz	450-360 nm
UV	Ultraviolet	50-1071 THz	400-280 nm

Table 2.1: Optical Spectrum

Туре	VLC	IR
Data Rate	>100Mb/s	4Mb/s or 16Mb/s
Distance	several meters	Max 3 meters
Wavelength	380nm-780nm	850nm
Noise source	Sun and others	Ambient light
Environmental	Visible and safe	Invisible and safe for low power

Table 2.2: Difference between VLC and IR

Chaabna et.al [15] proposed Visible Light Communication (VLC) research using trilateration technique and solar cell that are known as passive components. Based on his paper, trilateration technique are used to accomplish exact target which can be applied to different application such as human tracking. VLC also possible to use in automotive communications via the use of LED-based two outputs lights, and maybe even in flights to give high-speed Internet access [12].

$$H(f) = \hat{A}H_L, i \exp -j2p f dT_L + H_d \frac{\exp -j2p f dT_d}{1 \quad \overline{f_c}}$$
(2.1)

Based on the equation 2.1 used for channel model of VLC, channel gain by using LOS propagation is denoted by HL and Hd is diffuse signal gain. T in the equation is delay based on LOS item and lastly fc is cutoff frequency of diffuse channel [16]. When compared to radio frequency, visible light has the benefit of having a larger spectrum of wavelengths. Set of rules governing the allocation of frequencies are difference in each place for different types of uses including content broadcasts on AM and FM radio stations [10]. Table 2.2 shows difference RF and VLC technology [17].

2.2.2 Ultraviolet Communication

Ultraviolet is known as natural source from the sun. It does not need point to point system, unlike OWC and has the advantage of anti-electromagnetic interference and disadvantages with multi-path fading and interference [18]. People may find a mix of manufactured ultraviolet (UV) sources. According to the theory of black-body radiation or in simple words, radiation produced by heated object will emit ultraviolet light [19]. The sun transmits a mixture of wavelengths into space, ranging from infrared to ultraviolet. NLOS is commonly used in research paper since it is more suitable with ultraviolet communication. Researchers developed high-performance of UV by using LED and susceptible sensors that received UV signal more accurate [20]. UV light have solar-blind band around 200-300 nm [18].

Based on gathering information through journals, books and papers, they focus more to outdoor application and use the Poisson channel with transmit power constraints. Based on research made by Patmal, he used UVC and VLC to make comparison on wavelength division multiplexing and enable multiple wavelength to send data in the same medium. UV-A LED used in his paper compared to other UV types since UV-A has low path loss with wavelength of 365nm [19]. In the other literature, they used single and double scattering using NLOS propagation. The Monte Carlo technique is used in modelling risk to generate random values.



Figure 2.2: Schematic diagram NLOS ultraviolet for MIMO

Based on Figure 2.2 [21], OOK modulation technique is used, and two transmitters will transmit the data from one point to another. Next, to detect light from the transmitter, the photo-multipliers' receivers are used, and it will convert Alamouti code to the linear space-time blocks. One of the difficulties in developing UV communication systems is the significant effect of radiation scattering parameters, which are influenced by the condition of the atmosphere, on the properties of these systems. The development of successful UV communication tools necessitates the development of a complete model representation of the transmission channel, optical transmitter, an optical receiver.

A variety of well-known mathematical models take into account in detail versions of NLOS UV channels with varied geometry, as well as their interactions [22]. Below are types of ultraviolet light from the least harmful to most harmful [23]:

- UV-A (320nm-400nm): Safe to use and least harmful.
- UV-B (290nm-320nm): Dangerous to human. It can cause skin cancer and other health problem.
- UV-C (100nm-290nm): The most dangerous. In food, air and water, it is often used as a disinfectant because it can kills germs.

High-temperature surfaces, such as the Sun, emit ultraviolet radiation in a continuous spectrum, while atomic excitation in a gaseous discharge tube emits a discrete spectrum of wavelengths. The majority of UV energy in sunlight is absorbed by oxygen in the Earth's atmosphere, which produces the lower stratosphere's ozone layer [24]. UVA radiation makes up nearly all of the ultraviolet that reaches the Earth's surface.

[25] used Monte Carlo simulation that is commonly known as the Monte Carlo Method or multiple probability simulation, is a mathematical technique for estimating the consequences of an uncertain event. The researcher studies the analysis method for single and double scattering events specifically for non-line-of-sight (NLOS) ultraviolet (UV) communication systems. Consider the transmitter and receiver configuration in the Cartesian coordinate system presented in Figure 2.3. For NLOS UV channels, the author presents a mathematical framework for analysing single and double scattering occurrences. A simple fixed uniform sample of the photon path with a modest step size is impracticable since a photon can travel a long distance before scattering.



2.3 Modulation Technique

Some researchers implemented OWC by setting up a post-equalization circuit to shift low pass frequency response effects. Modulation schemes they chose to use are single carrier modulation Single Carrier Modulation (SCM) by using OOK and multi carrier modulation Multi Carrier Modulation (MCM). The primary purpose is to increase the high frequency and bandwidth. They use experimental techniques to analyze the output and use red Moonstone Tri-color power LED. They did not provide any analysis regarding the modulation. Still, they successfully proved that using post-equalization with different gains will expand data rate and decrease the bit error rate (BER) at once.

Most researchers used LEDs as the source of light since they are highly efficient, generate minimum heat, and have a low risk of harmful chemicals [14]. LED is an ideal component for both OWC and UVC as data transmitters for indoor applications. Un-fortunately, LEDs used in the system offer low modulation bandwidths that will limit the achievable data rate. There is also some new modulation to solve the technical issue and can be used for a future generation [26] but these new modulation formats involve complicated and costly transmission system. The optical transmission system will be more feasible and efficient if advanced modulation formats can reduce the com- plex portion of the system while simultaneously achieving higher bit rates and spectral efficiency using relatively reduced optoelectronic components count.



Figure 2.4: a) directed LOS b) NLOS c) diffuse link.

As shown in Figure 2.4, propagation for indoor application, both LOS and NLOS can be used for VLC and UVC technology. Line of sight LOS is where the light distributed from the ceiling to the whole room with minimum dispersion. LOS is much preferred for indoor application due to its high efficiency rather than non line of sight NLOS which has multiple dispersion distributed in a room. It is suitable for high speed hot spots for indoor applications even though the data rate is limited. A diffuse link has more advantages since it has more than one path, but it also limits the achievable bit rates [27].



2.4 Past Research

Author	Title	Parameters
	Indoor optical wireless	Wavelength transmitters $= 1550.12$ nm,
	communication system with	Radiation power = 7 dBm,
[8]	continuous and simultaneous	Bandwidth photodiode= 2.5GHz,
႞၀႞	positioning	Modulation= On-Off Keying,
		Bandwidth Mach Zender modulator= 10GHz,
		Achieved data rate= 2.5 Gb/s
	Virtually Imaged Phase	Modulation= On-Off Keying
	Array (VIPA)	Data rate= 12.5 Gb/s
		Scanning field of view= 3.440 x 7.90
[13]		Wavelength= 1500 nm to 1600 nm
		$BER=3.8 \rightarrow 10^{-3}$
	MALATSIA	Maximum output power= 7mW
4		Minimum output power= 1mW
S.W.	Simulation and experimental	Power=1mW
E	research on the Alamouti	Wavelength= 265nm
-	code for ultraviolet	Solar filter transmitter= 0.2
[21]	communication	Data rate transfer= 100kbps
	Aluce	Number of samples= 80
		Sampling rate of ADC= 8MHz
5	Via Junio Lais	BER when Tx is $240 = 10^{-0.8}$
	A study on Ultraviolet	Modulation= Quadrature Amplitude
	Optical wireless	Noise voltage $(UV) = 14mV$
[10]	communication	$BER=3.8 \rightarrow 10^{-3}$
[17]	employing WDM	Data rate 16-QAM= 64Mbps
		Configuration = LOS
		Distance = 1.5m
	Novel Indoor Ultraviolet	Modulation= On-Off Keying
	Wireless Communication:	$Room = 5 \rightarrow 5 \rightarrow 3m$
	Design Implementation,	Wavelength $= 280$ nm
[22]	Channel Modeling,	Bandwidth $= 20$ MHz
[23]	and Challenges	Responsivity = 0.6 A/W
		Received power = 69.26nW
		Mean excess delay = 9.23ns
		RMS delay = 0.43 ns

Table 2.3:	Summary	from p	oast researc	h
------------	---------	--------	--------------	---

Author	Title	Parameters	
	Optical Wireless	Room size = $10 \rightarrow 10 \rightarrow 3m$	
	Communication Based	Min average error (TRIP)= 0.61m	
[20]	Indoor Positioning	Min average error (OBRIP)= 0.81m	
[28]	Algorithms: Performance	Standard deviation= 3.04m	
	Optimisation and		
	Mathematical Modelling		
	Implementation of	Modulation= On-Off Keying	
	Visible Light	Room size= $5 \rightarrow 5 \rightarrow 3 m$	
[20]	communications for	Max illuminance (1-LED)= 568 lx	
[29]	Indoor Applications	Max illuminance (4-LED)= 852.8 lx	
	MALAYSIA	Delay (1-LED)= 1.85ns	
A		Delay (4-LED)= 2.58ns	
EKN	KA	Min SNR (1-LED)= 30dB	
TI		BER (1-LED)= 0.01739	
1º		Data rate (1-LED)= 61.24	
	anna -	Data rate (4-LED)= 38.69	
5	كنيكل مليسيا ملا	BER (4-LED)= 0.003720	
		Min SNR (4-LED)= 18dB	
Ur	Design of Indoor	Modulation = On-Off Keying	
[20]	Wireless Communication	$BER = 10^{-7}$	
[30]	System Using LEDs	Distance = 2.5m	
		Data rate = 115200 bps	
	Bandwidth and BER	Bandwidth= 0.0868 to 0.562	
[31]	Improvement Employing	Data rate= 30Mb/s	
	a Pre-Equalization	Received power = 3.3dBm	
	Circuit with White	FOV= 300	
	LED Arrays in a	Signal to Noise Ratio (SNR)= 69.0	
	MISO VLC System	$BER=5 \rightarrow 10^{-17}$	

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter focuses more on how the flowchart outlines the related works involved in this project, the specification, parameters and tools used in this project. It also explains the workflow planning based on the produced Gantt chart.

3.2 Overview of Project Implementation

3.2.1 Flowchart

Based on the flowchart Figure 3.1 it shows the procedure that will be carried out in this project is searching and collecting suitable information based on the project including from websites, journal and books. Next, the parameters that will be used in the project are decided such as the size of room and power radiated by LED. After that, the illuminance in a room is determine by using MATLAB. OOK modulation is chosen as modulation to run the performance of both technologies. OOK modulation is a carrier signal with a certain amplitude is transmitted. LED is chosen to be the source of light in the project. The LED could be easily modulated for communication due to its short response time Logic 1 is set when there is a signal transmit and when there is no signal

takes place, the logic will become 0. Basically, the OOK modulation program will have the input for speed transmission for the data, transmission power, bit error rate BER, signal to noise ratio SNR and eye diagram for each technology. The next step continue when the range of bit error rate is within 10⁻⁹. The output for OWC need to be analyze. After analyze the output for OWC using the same modulation, UVC performance is evaluate with the same parameter. After run the simulation, the result for both wireless technology will compare and the best application will be proposed for indoor application.



Figure 3.1: Flowchart of the project

3.2.2 Block Diagram

Block diagram in Figure 3.2 shows the visual illustration of a wireless communication system. The transmitter part is section where information is convert to signal form. First, the data start to collect information and goes into modulator. Modulator function to modulate information signal and goes into the driver. LED is the main part in transmitter to transmit signal and direct towards the receiver. An information signal is transmitted through a channel. The bandwidth in Hz or the data rate in bits per second are commonly used to measure the capability of a channel for delivering information. Channel can be in vacuum, atmosphere or water as the medium.

In receiver part, the incident optical signal is captivated by receive optics and focus on photo detector. In photo detector, the signal form transmitted from LED is convert to electrical form. The next step, the electrical form enter into amplifier to amplifies the signal and increase SNR before go in demodulator to estimate of input signal. By comparing the transmitted and received bit sequences and calculating the amount of mistakes, the BER is determined in BER calculator.



Figure 3.2: Block diagram of the project

3.3 Simulation of Optical Wireless Communication

The parameters used for the simulation is as Table 3.1. The size of room is fixed to 4x4x2 meter with three LED conditions. For the first room, it only has one LED while for the second room will have two LEDs and the last room have four LEDs to observe the power distribution in the room.

Туре	Parameters	Value		
	Number of LED	1/2/4		
	Power radiated by each LED	1W		
Transmittan	Angle of Irradiance	70		
Transmitter	1 LED	(2.5,2.5)		
	2 LED	(2.5,1.5) and (2.5,3.5)		
	4 LED	(1.25, 1.25), (1.25, 3.75), (3.75, 1.25) and		
ST		(3.75,3.75)		
Receiver	Photodetector Responsivity	1A/W		
E	Room Size	$4 \rightarrow 4 \rightarrow 2 \text{ m}^3$		
Others	Bit Rate	$200 \rightarrow 10^6$		
	Number of bits	$1 \rightarrow 10^3$		
	Background Noise	202 → 10 ⁻⁶		
	Electron Charge	$1.6 \rightarrow 10^{-19}$		
اونىۋەر سىت ئىكنىكا مايسىا ملاك				

Table 3.1:	Parameters
------------	------------

The output measurement for this project is to determine the BER to observe the performance of data channel when the signal transmit. When the signal transmits from one point to another, BER is the way to check how much error the data have after its done transmitting. Then, SNR is calculated to observe the difference between the received signal and the noise floor. For data networks, the best SNR that need to achieve is 20dB and above [32]. For this project, the parameters used above is use for both technology of optical wireless and ultraviolet communication. The only changes that need to change is parameter of each LED use in the project.

3.3.1 Power Distribution

It is necessary to run and get a graph of power distribution in a room as the first phase of this project by using MATLAB software after determining the values that will be used in this project.

```
%parameter
q = 1.6e-19;
                    %electron charge
Ib = 202e-6;
                    %background noise
N0 = 2*q*Ib;
                      %noise spectral
R = 1;
                      %photodetector responsitivity
Po = 1;
Tbs = 1;
M = 100000;
Rb=200e6;
                        %bit rate
Tb=1/Rb;
                      %bit duration
sig_length=1e3;
                    %number of bits
nsamp=10;
                      %samples per symbol
Tsamp=Tb/nsamp;
                      %sampling time
                        %signal to noise ratio in dB
EbN0=1:1:12;
SNR=10.^(EbN0/10); %SNR
Rate=zeros(1,length(EbN0));
              Figure 3.3: Parameters
```

Figure 3.3 shows the parameters are declared on the first part of coding using proper language. The photo detector responsivity is set to 1W for each LED and the number of samples per symbol is set to maximum 10. Semi angle half power of 30^o is declared and used in the Lambertian equation order of emission as theta. For ultraviolet communication technology, the semi angle half power change from 30^o to 70^o based on the data sheet for UV-LED. The parameter changes in order to simulate power distribution, bit error rate and eye diagram is LED parameters. In practical work, by monitoring the luminosity while rotating the receiver, Lambertian orders of the LED and receiver can be obtained.



Figure 3.4: Lambertian formula

The centre luminous intensity and declaration on the size of room are code in Figure 3.5. Both parameters not vary even though the number of LED change. The position of LED is set based on x-axis and y-axis. When one LED is use in a room, LED need to be at the centre of ceiling which is (2.5,2.5). The distance between transmitter and receiver is constant to 1 meter in each room.

%Center luminous intensity I0=0.73; I0_total=60*60*I0; % room dimension in metre lx=4; ly=4; lz=2; %the distance between source and receiver plane h=1; % position of LED1 XTrans1=2.5; YTrans1=2.5;



3.3.2 Bit Error Rate and EbN0

EbN0 is define by signal to noise ratio per bit where

$$E_b = \frac{E_p}{2} \tag{3.1}$$

Based on equation 3.1, Eb represent the average energy per bit and Ep is the peak of energy transmit by the signal. In Figure 3.6, the average transmitted of optical power is the first equation to find in order to get the noise variance or standard deviation.



Figure 3.7 is instruction to do the random signal by using uniformly distributed pseudorandom integers with maximum range is 10. For BER calculation, the error define between OOK modulation and threshold equation.



Figure 3.7: Bit error rate

The semilogy for theory part of BER versus EbN0 is written before grid on the graph command. Figure 3.8 is to grid the graph based on instruction set by the user. The instruction includes the label for x-axis and y-axis. Other than that, before generate the code, the equation for theoretical part is written in order to develop reference graph in the result.



Figure 3.8: Bit error rate vs EbN0

3.3.3 Bit Error Rate and Signal-to-Noise Ratio

Figure 3.9 shows algorithm to simulate BER and SNR. The similar command for SNR are used to find the BER and SNR graph. The only difference is either we can used additive white Gaussian formula that denote by AWGN in the command or uniformly distributed random numbers multiplied by standard deviation.



Figure 3.10 is where the equation for the theory section is used in semilogy command before the probability curve between BER and SNR executed. X axis labeled as Signal-to-Noise Ratio and Y axis labeled Bit Error Rate.

```
[err, ber]=symerr(x_inp,x_out);
Rate(dB)=Rate(dB)+ber;
end
Rate(dB)=Rate(dB);
figure;
semilogy(EbN0,Rate,'b-*');
hold on;
semilogy(EbN0,qfunc(sqrt(10.^(EbN0/10))),'r-X','linewidth',2);
xlabel( 'Signal-to-Noise Ratio (SNR)')
ylabel( 'Signal-to-Noise Ratio (SNR)')
ylabel( 'Bit Error Rate (BER)')
title('Simulation OOK-NRZ transmission over noise');
legend('BER simulation')
grid on;
```

Figure 3.10: BER vs SNR

3.3.4 Eye Diagram for OOK Modulation

When it comes to binary OOK systems, another significant alternative BER measurement is the eye diagram. There are two forms of noise that might influence system performance; amplitude noise and temporal jitter [33]. Amplitude noise is the most common type of noise. Typically, the shape of the eye is expanded and deformed due to restricted bandwidth and wavelength limitations. Noise and timing jitter is added to this broadened and distorted eye shape to create more problems further.



The first part in Figure 3.11 is to plot eye diagram, the parameters for impulse response which to normalize delay spread and equation for delay rms. The multipath signal of a wireless communications channel is measured by delay spread. Delay spread is to differentiate between the time of arrival of the earliest signal and the time of arrival of the next multipath signal.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 3.12 shows algorithm to clarify the transmitter filter and the channel delay in system impulse response command window.

```
%% filter
pt=ones(1,nsamp);
c=conv(pt,h);
delay=find(c==max(c));
```

Figure 3.12: Impulse response system

Lastly for Figure 3.13 shows command window where randi command is used to get random binary signal. Then pulse shaping for transmitter and return convolution of vectors used to gain the channel output without noise and smooth than when randn command is used in the coding. The 'randn' command returns a number chosen randomly from the usual normal distribution.

> OOK=randi([0 1],1,sig_length); Tx_signal=rectpulse(OOK,nsamp); channel_output=conv(Tx_signal,h); figure; eyediagram(channel_output,200,2*Tb);

Figure 3.13: Plotting eye diagram



CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter discusses on the results gathered and analysis of the results of coding by using MATLAB. The findings of the study will be explained in detail for further understanding.

4.2 Optical Wireless Communication

4.2.1 Power Distribution



Figure 4.1: Power distribution for 1 LED



Figure 4.2: Power distribution for 2 LEDs



Figure 4.1 to Figure 4.3 shows the power distribution for 1, 2 and 4 LEDs. Based on the power distribution when there is one LED, two LEDs and four LEDs in a room, the graphic depicts of the space, and it can see that the highest illumination is seen at the top of the room, where the lighting is high, and that it is observed to be 2628 for a single LED, 2638.88 for a pair of LEDs, and 2634.5 for a four-LED configuration. When comparing the middle of the room to the corners, the core has greater illumination since the light is evenly dispersed. Even though the number of LED are difference for each room, the illumination(lx) do not have much difference which in the range of 500 lx. It can be used in normal office work, PC work, study library, groceries, show rooms, laboratories, check-out areas, kitchens and auditoriums.

4.2.2 Bit Error Rate



Figure 4.4: Error rate performance against SNR for 1-LED



Figure 4.6: Error rate performance against SNR for 4-LEDs

Figure 4.4 to Figure 4.6 shows the error rate performance with SNR for those three conditions of LED, the lowest performance is when there is 4 LEDs in a room while the best performance is when there is 1 LED. Bit rate of 200MHz for all three arrays are set up. From the table below, it can be observed that the value of the BER decreases with the increase of the SNR. This is because large SNR will generate a small BER, and thus it will result in good performance. Between Figure 4.4 to Figure 4.6 its shows when there are 4 LEDs in a room it will lead to weak performance.

Array	Bit Error Rate	Signal to noise ratio
1 LED	0.2573	1
I-LED	0.0001	12
2 LED	0.57407	1
2-LED	0.04674	12
	0.77663	1
4-LED	0.31923	12

Table 4.1: Comparison between BER and SNR

4.2.3 Eye Diagram



Figure 4.9: Eye diagram for 4-LEDs

From the eye diagram result in Figure 4.7 to Figure 4.9, the highest amplitude is 3.04596 while the lowest amplitude is -3.53607 for 2-LED configuration. Based on the eye diagram waveform in this MATLAB, the signal are overlap and not smooth since the software run for random bit that used randn as instruction in command window.



Figure 4.10: Binary eye diagram for 1-LED



Figure 4.11: Binary eye diagram for 2-LEDs



Figure 4.10 to Figure 4.12 shows eye diagram when the coding change from random integers to random binary integers. Based on the observation to get better and smooth simulation eye diagram, binary bit need to add in the coding. The impact of multipath propagation on OOK–NRZ transmission with a standardized delay spread (DT) of 0.5 for both coding is highly visible, with fluctuations in signal amplitude according to preceding pulses being easily visible and number of channel taps is 300. For the Figure 4.7 until 4.9, randn command is used which will distribute random numbers normally while for Figure 4.10 until 4.12 randi command is used to generate binary bit.

4.3 Ultraviolet Wireless Communication

4.3.1 Power Distribution



Figure 4.13: Power distribution for 1-LED



Figure 4.15: Power distribution for 4-LEDs

Figure 4.13 to Figure 4.15 shows power distribution for ultraviolet technology based on the simulation run in the MATLAB, the illuminance radiated by LED for this technology are much wider than optical technology. Logically, the power distribution are much wider when there are more LED in a room because one LED has its own power dissipated value and field of view. When one UV LED is present in a room, the minimum illuminance is 90.451x. The peak illuminance is 21001x, which is appropriate utilization for performance of visual tasks of low contrast and very small size for prolonged periods of time. Based on the results in Figure 4.13 to Figure 4.15, the maximum is 30001x. In order to assure comfort to the user, UV LED can be used in bigger

4.3.2 Bit Error Rate



Figure 4.16: Error rate performance against SNR for 1-LED



Figure 4.18: Error rate performance against SNR for 4-LEDs

The results in Figure 4.16 to Figure 4.18 show the simulation in this technology and wireless optical technology have no difference since the parameters do not change. Same as OWC when there is one LED in a room, the simulation part is nearer to the theoretical part. For Figure 4.16 has higher quality of signal than Figure 4.18. When the signal is strong, the likelihood of mistake is lower since low BER requires a high SNR. When there is more LEDs in a room, the possibilities of performance to transmit signal is decreasing. It is because when there are more LEDs in a small room,

the overlapping of signal might occur and it can breach the signal. The solution to prevent previous case from happening is by identify the angle of view.

Array	Bit Error Rate	Signal to noise ratio
	0.2643	1
I-LED	0.0001	12
2 I ED	0.5814	1
2-LED	0.0444	12
	0.7852	1
4-LED	0.3246	12

Table 4.2: Comparison between BER and SNR for UVC

Table 4.2, the comparison between BER and SNR is recorded based on results generated in MATLAB software. The pattern shows when there are 4 LEDs in the room, the error rate is higher than when there are 2 LEDs and 1 LED. Apparently the higher the SNR, the lower would be corresponding of BER. For instance, when there is 1 LED in a room, the lowest SNR has bigger error rate than when the SNR is 12. It shows the hypothesis is accepted but when the comparison happened between 1 LED and 4 LED, the error rate is much higher than error rate for 1 LED.

تيكنيكل مليسيا ملا UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.3.3 Eye Diagram



Figure 4.19: Eye diagram for 1-LED



UNIVERSIT Figure 4.21: Eye diagram for 4-LEDs AKA

Figure 4.19 to Figure 4.21 shows the eye diagram gained through MATLAB software, the results generated for 1, 2, and 4 LEDs are the same. There is no difference in transmitted and received signal happen when used ultraviolet LED which shows it is better to use to transmit signal. Difference from optical wireless communication, which produces a contrast eye diagram. The better received signal must be in rectangular pulse and it has no noise in the generated signal. Because sampling practically anywhere and save directly at the transition boundaries, it would provide the proper values. The rectangular pulse is insensitive to timing problems.

CHAPTER 5

DISCUSSIONS

5.1 Introduction

Based on the previous chapter, the data accumulated for two technologies are compiled. This chapter discusses on the results gathered and analysis of the results. The findings of the study will be explained in detail for further understanding.

5.2 Discussion UNIVERSITI TEKNIKAL MALAYSIA MELAKA

5.2.1 Power Distribution

Both results in Figure 5.1 shows differences in the distribution of illuminance based on number of LEDs in a room and the characteristics of LEDs. 1 LED for OWC, the minimum illuminance is 1.526lx and when the coordinate of room is (2.5,2.5), the peak illuminance is 494.67lx. The more the number of LEDs in a room, the more the value of illuminance since there is more LEDs in a room. Both technologies have intense illuminance and are evenly dispersed throughout the room based on the results. When there are 4 LEDs in a room, the minimum illuminance radiated by LED is 560lx which, according to the standard, can be used for everyday office work and houses. However, it also may cause some risk since the average illuminance for four LEDs is 18251x which is suitable more for detailed drawing work, very detailed mechanical works, electronic workshops, testing, and adjustments. It still can be use for house or office but it may cause uncomfortable to user since it can make their eyes tired due to strong exposure to light. The difference for OWC when there are 4 LEDs, the average of illuminance is 13001x which is suitable to use for everyday drawing work, detailed mechanical workshops, and operation theaters in hospitals.



e) Power distribution for 4-LED

f) Power distribution for 4-LED

Figure 5.1: a)c)e) OWC; b)d)f) UVC

5.2.2 Bit Error Rate

The bit error rate is a good factor for evaluating data networks' effectiveness. The crucial parameter for transmitting data from one point to another, either through wireless or cable telecommunications is how many errors will occur in the data at the output port. While in optical communication, bit error rate refers to the receiver's ability to generate a maximum of one error for every 10⁻⁹ bits of data transmitted. Based on the Figure 5.2 when there is one LED in a room, the simulation result is nearer to the theoretical part while when there are more LEDs in a room, the simulation part become farther than theoretical analysis. It shows the more LEDs in a room, the performance become weak. It does not mean when there are more LEDs, it can bring benefits to user. For example, there are 4 LEDs in a room, it will cause collision of transmitter, confusion to the receiver and it may cause more error because of overlap signal. There is no significant difference between both technologies since the parameters used are constant and not affected by the LEDs.



Figure 5.2: a)c)e) OWC; b)d)f) UVC

5.2.3 Eye Diagram

Eye patterns for OWC and UVC are different based on the eye-opener. Both technologies generate exemplary eye diagram since it has less noise and precise shape. The eye diagram for serial communication would be two parallel lines with the almost negligible simultaneous rise and fall times. The slope happened to be smaller in the UVC part since the slope represents the sensitivity to the timing error. The better eye diagram should look like a rectangular wave-like eye diagram generated by UVC. If the eye-opener is small, it can lead to an increase in data error. It happens when the actual time error represents an increasing amount of the cycle as the bit rate increases. The analysis made to decide which eye diagram is suitable for indoor application shows that UVC is better for detecting the signal quality.



e) Eye diagram for 4-LED

f) Eye diagram for 4-LED

Figure 5.3: a)c)e) OWC; b)d)f) UVC

UVC is better in performance since the transit time between previous point to the next point is shorter than in OWC. Transit time is the time it takes for the information to go from the source to the next destination, whereas the response time is the time between the end of a query to a computer system and the start of a response. In order to know the better performance based on eye pattern, the eye diagram need to have smaller slope or closed to rectangular pulse. For instance, is when the system has bigger transit time, the LED will become dim before it to be turn on or off. Figure 5.4 shows the visualisation of two different type of transmit time applied in the modulator.



CHAPTER 6

CONCLUSION

6.1 Introduction

The project and results between optical wireless communication and ultraviolet communication are conclude in this chapter. To obtain reliable outcomes, certain parameters are set for both technologies. We should be able to determine which technology is best for LED power distribution, bit error rate, and eye diagram based on the data. The improvement that can be apply in the project are listed in future work section.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

6.2 Conclusion

6.2.1 Power Distribution

Based on the power distribution results for both technologies, there are differences in distribution radiated by LED. For OWC, the maximum peak of illuminance is 2628 is when there is one LED in a room, and for UVC has the same value as owc. When there are 4 LEDs in a room, for OWC it becomes 83.839 lx while UVC is 1612.36 lx. It happened since the LED use for both technologies has different power radiated based on the datasheet of LED. Based on the visualization of the graph, UVC is better in distributed light in a room since it has greater illuminance. The illuminance might

differ when there is more than one LED; for instance, when there are 4 LEDs placed at different magnitudes in a room, the illuminance becomes wider. When the illuminance value is 500lx, user can use for everyday office work or house use.

6.2.2 Bit Error Rate

From the results generated in MATLAB, there is no difference between graphs for OWC and UVC since the parameter used are the same for both technologies. The difference occurs when the number of LEDs in a room changes from one to two or four. When there is one LED in a room, the simulation graph is similar to the theoretical part, but the difference in the bit error rate value. Based on ITU-T standard, the minimum the acceptable bit error rate is 10^{-9} , and since our results are in the range of ITU standards, it shows that this project is suitable for indoor application.

6.2.3 Eye Diagram

The eye diagram for OWC shows the transmitted and received signal. It shows the effect of multipath propagation on OOK–NRZ signaling with a normalized delay spread DT of 0.4, where variations in signal amplitude due to preceding pulses can easily be seen It is intuitive to see that for a given severity of channel-induced distortion, higher data rates will cause further variation in signal amplitudes. While for UVC, the transmitted and received signals are similar.

6.3 Evaluation Performance

Based on the simulation results that we get in chapter 4 and 5, Optical Wireless Technology is chosen for the most suitable technology to be used in indoor applications even though ultraviolet shows better performance in eye diagram. The other factor need to consider including safety and risk when user will be exposed in certain period of time. For instance, in office environment, workers need to stay in close spaces for at least 9 hours. If ultraviolet LED is used, it might cause tiredness to the workers and risk their health.

Visible light LED is safer to use since it has a low risk to the humans when they are being exposed to the LED for a long time. OWC LED also is much cheaper since user just need one LED that can transmit signal and distribute light while ultraviolet LED only transmit data. When user choose to use ultraviolet LED, they need to have another lamp such as fluorescent lamp as source of light. Ultraviolet LED is suitable for industrial departments such as mechanical workshops or operation theaters since it has higher illuminance than visible light LED. For instance, in operation theater, ultraviolet LED can be used since doctors and surgeons need bright light to focus on certain part in human body.

6.4 Future Work

Improvement needs to be applied in this project to ensure the project is going smoothly and generates better outcomes. One of the improvements is by generating and find Qfactor in those technologies. The signal quality also determines the speed with which data is received and sent; the higher the signal quality rating, the better the signal quality. The Q-Factor indicates the minimal SNR necessary to achieve a specified BER for a transmission. Based on the result above, Q-factor cannot be read since the noise of the eye diagram is minimal. Other improvement that can be made in this project is do experimental to validate the simulation results. Experimental project is important in order to detect the capability for both technologies to transmit signal and solve problems regarding data transmission especially for indoor environment since in this contemporary world, majority of people do their work everywhere including cafe and library.

6.5 Sustainability and Environmental Friendly

As the vision of IR4.0 is coming nearer and nearer, both systems can help overcome the spectrum crunch in radio frequency (RF) communications. This helps meet the growing demand for high-speed communication links between consumer electronics, sensors, and the infrastructure. This project has commercial value, especially in the communication and data transmission field, as it offers high-speed wireless communication as a complementary solution for overcrowded RF and WIFI systems. This project is considered a green technology because the component used (LED) in the project is an efficient lighting source and consumes less electricity than the typical fluorescent light. Other than that, OWC and UVC systems are compatible with the radio frequency wireless technology in many applications.



REFERENCES

- [1] Abdelbaset and Hamza, "Optical wireless communication for the internet of things: Advances, challenges, and opportunities," 2020.
- [2] J. E. Harald Haas and I. White, "Optical wireless communication," *Philosophical Transaction of the Royal Society*, 2020.
- [3] J. W. Liang Guo, Yanan Guo and T. Wei, "Ultraviolet communication technique and its application," *Semiconductor*, vol. 42, 2021.
- [4] V. K. Jitendra Singh and N. Kumar, "Performane evaluation of high speed optical wireless communication system," *Computer Application*, 2012.
- [5] H. Manor and S. Arnon, "Performance of an optical wireless communication system as a function of wavelength," *Applied Optics*, vol. 42, no. 21, 2003.
- [6] M. S. Amanda Onion and M. Mullen., "Morse code & the telegraph," *History*, 2019.
- [7] "Different types of wireless communication with applications," 2021.
- [8] K. Wang and T. Song, "Indoor optical wireless communication system with continuous and simultaneous positioning," *Optics Express*, vol. 29, no. 3, 2021.
- [9] A. I. Mostafa Zaman Chowdhury, Md. Tanvir Hossan and Y. M. Jang, "A comparative survey of optical wireless technologies: Architectures and applications," 2020.
- [10] L. E. M. Matheus, L. F. M. V. Alex Borges Vieira, M. A. M. Vieira, and O. Gnawali, "Visible light communication: Concepts, applications and challenges," *IEEE Communications Surveys & Tutorials*, vol. 21, 2019.
- [11] M. S. M. Gismalla and M. F. L. Abdullah, "Performance evaluation of optical attocells configuration in an indoor visible light communication," *Electrical Engineering and Computer Science*, vol. 14, no. 2, p. 668 676, 2019.
- [12] N. CHi, *LED-Based Visible Light Communications*. Tsinghua University Press, Beijing, China, 2018.

- [13] Z. Z. a. W. Zhi Li, "Multi-user accessible indoor infrared optical wireless communication systems employing vipa-based 2d optical beam-steering technique," *Optics Express*, vol. 29, no. 13, 2021.
- [14] Y. Kaleem and A. A. Malik, "Emerging optical wireless communication technology and future research direction," 2021.
- [15] A. B. Ameur Chaabna and X. Zhang, "An indoor positioning system based on visiblelight communication using a solarcell as receiver," *Energy Optimization and Engineering*, vol. 8, 2019.
- [16] I. B. Djordjevic, Advanced Optical and Wireless Communications Systems. Springer Nature, 2018.
- [17] C. G. Lee, "Visible light communication," Wireless Communication, 2011.
- [18] Y. Deng, Y. Wang, Y. Zhang, A. Du, and J. Liu., "The realization of wide-angle voice transmission non-line-sight ultraviolet communication system." *Semiconductor*, vol. 42, 2021.
- [19] Patmal and M. Hamed, "A study on ultraviolet optical wireless communication employing wdm," 2019.
- [20] X. S. et al, Z. Zhang, A. Chaaban, T. K. Ng, C. Shen, R. Che, and J. Yan, "71mbit/s ultraviolet-b led communication link based on 8-qam-ofdm modulation." *Optics Express*, 2017.
- [21] L. Guo, K. Liu, D. Meng, X. Mu, and D. Han, "Simulation and experimental research on the Alamouti code for ultraviolet communication," *Optical Engineering*, vol. 55, no. 1, pp. 1 – 7, 2016.
- [22] D. I. S. Gleb S. Vasilyev and O. R. Kuzichkin, "Method of semi-natural scale modeling of a wireless ultraviolet communication system," *Advances in Dynamical Systems and Applications*, vol. 15, no. 2, 2020.
- [23] S. Arya and Y. H. Chung, "Novel indoor ultraviolet wireless communication:design implementation, channel modeling, and challenges," *IEEE Systems*, vol. 15, no. 2, 2021.
- [24] T. E. o. E. Britannica, "Ultraviolet radiation," *Encyclopedia Britannica*, 2022.
- [25] V. R. M. Deva K. Borah and D. G. Voelz, "Single and double scattering event analysis for ultraviolet communication channels," *Optics Express*, vol. 4, no. 29, 2021.

- [26] T. Tokle, M. Serbay, J. B. Jensen, W. Rosenkranz, and P. Jeppesen, "Advanced modulation formats for transmission systems," *Conference on Optical Fiber Communication*, pp. 1–3, 2008.
- [27] C.Jenila and R. K. Jeyachitra, "Green indoor optical wireless communication systems: Pathway towards pervasive deployment," *Digital communication and Network*, pp. 410–444, 2020.
- [28] S. S. Manisha Ajmani and T. Boutaleb, "Opticalwireless communication based indoor positioning algorithms: Performance optimisation and mathematical modelling," *Computation*, 2018.
- [29] N. Nitish, "Implementation of visible light communications for indoor applications," 2018.
- [30] L. Z. Yu Yang, Xiongbin Chen and B. Liu, "Design of indoor wireless communication system using leds," *optical engineering*, vol. 7632, 2009.
- [31] A. A. E. A. Monette H. Khadr and H. A. Fayed, "Bandwidth and ber improvement employing a pre-equalization circuit with white led arrays in a miso vlc system," 2019.
- [32] "Signal-to-noise ratio (snr) and wireless signal strength," 2020.
- [33] C. C. K. Chan, *Optical Performance Monitoring*. Academic Press, 2010.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



APPENDIX A1



```
MF_out = conv(Rx_signal,rt)*Tsamp;
                                            %match filter
   MF_out_downsamp = MF_out(nsamp:nsamp:end);
   MF_out_downsamp = MF_out_downsamp(1:sig_length);
   OOK = randi(Max, 1, sig_length);
                                          %random signal
   Tx_signal = rectpulse(OOK,nsamp);
                                           %pulse shaping
   Rx_signal = R*Tx_signal+sgma*randn(l,length(Tx_signal));
   rt=pt;
   Max = 10;
   pt=ones(1,nsamp).*i peak(i);
   Rx_th=zeros(1,sig_length);
   Rx_th((MF_out_downsamp>Ep(i)/2))=1;
                                             %thresholding
   [nerr, ber]=biterr(OOK,Rx_th);
 end
 figure;
 semilogy(EbN0,ber,'o');
 hold on;
 semilogy(EbN0,qfunc(sqrt(10.^(EbN0/10))),'r-X','linewidth',2);
 grid on;
 xlabel('Eb/No, dB');
 ylabel('Bit Error Rate');
 title('Bit error rate for OOK modulation');
%% Power distribution
 theta=30;
                            % semi-angle at half power
 m#-log10(2)/log10(cosd(theta)); %Lambertian order of emission
                                                              1.0
                                      -20
                                                 mer.
      2 Juni all
                                                          ودرةم
 %Center luminous intensity
                                            1.0
 I0=0.73;
 UD_1011=50:60 10; TEKNIKAL MALAYSIA MELAKA
 % room dimension in metre
 lx=4; ly=4; lz=2;
 %the distance between source and receiver plane
 h=1;
 % position of LED1
 XTrans1=2.5; YTrans1=2.5;
 % number of grid in the receiver plane
 Nx=lx*20; Ny=ly*20;
 x=0:lx/Nx:lx;
 y=0:ly/Ny:ly;
 [XRec,YRec]=meshgrid(x,y);
```

