Faculty of Engineering

DEVELOP HIGH GBPS NETWORK ACCESS USING WAVELENGTH DIVISION MULTIPLEXING-MULTIPLE INPUT MULTIPLE OUTPUT (WDM-MIMO) IN FIBER OPTIC COMMUNICATION SYSTEM (FOCS)

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Bachelor of Engineering

Electrical and Electronics Engineering with Honours

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UNIVERSITI MALAYSIA SARAWAK

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DEVELOP HIGH GBPS NETWORK ACCESS USING WAVELENGTH DIVISION MULTIPLEXING-MULTIPLE INPUT MULTIPLE OUTPUT (WDM-MIMO) IN FIBER OPTIC COMMUNICATION SYSTEM (FOCS)

MICHELLE KIMBERLY ANAK MICHEAL

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ABSTRACT

Free optical space is a wireless communication technology that has started transforming the world into a modern society by enabling data's secure and rapid transmission. Data is transferred through an air medium without significantly contaminating the environment through a high-powered laser beam transmitted through free space. WDM-MIMO (wavelength division multiplexing-multiple inputs and multiple outputs) system is a potential future technology for optical networks due to its great capacity and adaptability. Optisystem software was used to run simulations to study how various transmission range affected the performance of multiple size of FSO channel. In this project, the bit rate is set higher up to 2 Gbps for increased capacity, improved throughput, and efficient utilization of available bandwidth. MIMO and WDM-MIMO systems are being modelled and analyzed respectively using 2, 4, or 8 channels at various transmission ranges between 5 – 30 km. Metrics such as Eye Diagram, BER and Q Factor are evaluated. Simulation results show that implementing WDM-MIMO techniques for FSO systems enable numerous carrier signals multiplex onto single fiber using non-identical wavelengths and expand the data rate. The best outcome shows that by using 8 channels of WDM-MIMO, the optimum transmission range is able to reach up to 27 km with maximum Q Factor of 5.53 and minimum BER of 9.55e-09. The efficiency of each channel was also calculated, showing that 8 channels of WDM-MIMO system is proven to be the highest which is 108% more efficient compare to other size of channels. The result was affected due to a few factors such as faster data rate, flexibility and scalability, resilience against impairments, and improved spectral efficiency. Overall, this study demonstrates the capability of WDM-MIMO systems for high-capacity and reliable communication in future optical networks.

ABSTRAK

Optik ruang bebas adalah teknologi komunikasi tanpa wayar yang telah mula mengubah dunia pada era modenisasi masa kini dengan membolehkan data dihantar dengan selamat dan pantas. Data tersebut dipindahkan melalui medium udara tanpa mencemarkan alam sekitar melalui pancaran laser berkuasa tinggi yang dihantar melalui ruangan bebas. WDM-MIMO adalah teknologi masa depan yang berpotensi tinggi untuk rangkaian optik kerana kapasiti dan kemampuan penyesuaiannya yang hebat. Simulasi Optisystem digunakan dalam kajian ini untuk mengkaji bagaimana kepelbagaian jarak transmisi boleh mempengaruhi prestasi kepelbagaian saiz saluran FSO. Dalam projek ini, kadar bit ditetapkan kepada nilai yang tinggi sehingga 2 Gbps untuk meningkatkan kapasiti, pengeluaran, dan penggunaan jalur lebar yang sedia ada dengan cekap. Sistem MIMO dan WDM-MIMO dirangka dan dianalisis masing-masing menggunakan 2, 4, dan 8 saluran pada pelbagai jarak transmisi antara 5 – 30 km. Metrik seperti Eye Diagram, BER dan Q Factor akan dinilai. Hasil simulasi menunjukkan denggan menggunakan teknik WDM-MIMO untuk sistem FSO, banyak isyarat pembawa akan dimultiplex ke serat tunggal menggunakan panjang gelombang yang tidak serupa sekaligus memperluaskan kadar data. Hasil terbaik menunjukkan bahawa dengan menggunakan 8 saluran WDM-MIMO, jarak optimum transmisi mampu mencapai sehingga 27 km dengan Q Factor maksimum 5.53, dan minimum BER 9.55e-09. Kecekapan setiap saluran juga diambil kira, menunjukkan bahawa 8 saluran sistem WDM-MIMO terbukti paling tinggi iaitu 108% lebih efisien berbanding dengan saiz saluran lain. Hal ini dipengaruhi oleh beberapa faktor seperti kadar data yang lebih cepat, fleksibiliti dan kebolehskalaan, ketahanan terhadap kerosakan, dan peningkatan kecekapan spektrum. Secara keseluruhan, kajian ini menunjukkan keupayaan sistem WDM-MIMO untuk berkomunikasi dalam kapasiti yang tinggi dan boleh dipercayai dalam rangkaian optik masa hadapan.

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LIST OF ABBREVIATIONS

FSO	-	Free Space Optical
FSOC	-	Free Space Optical Communication
FOCS	-	Fiber Optic Communication System
RF	-	Radio Frequency
LED	-	Light Emitting Diodes
LASER	-	Light Amplification by the Stimulated Emission of Radiation
WDM	-	Wavelength Division Multiplexing
MIMO	-	Multiple Input Multiple Output
MISO	-	Multiple Input Single Output
SISO	-	Single Input Single Output
SIMO	-	Single Input Multiple Output
BER	-	Bit Error Rate
Q-factor	-	Quality Factor
SNR	-	Signal-to-Noise Ratio
Wi-Fi	-	Wireless Fidelity
Li-Fi	-	Light Fidelity
VLS	-	Visible Light Spectrum
ILS	-	Infrared Light Spectrum
UNIMAS	-	Universiti Malaysia Sarawak
Gbps	-	Giga Bit per Second
Mbps	-	Mega Bit per Second
FDM	-	Frequency Division Multiplexing
OFDM	-	Orthogonal Frequency Division Multiplexing
OTDM	-	Orthogonal Time Division Multiplexing
QAM	-	Quadrature Amplitude Modulation
NOMA	-	Non-Orthogonal Multiple Access
SM	-	Spatial Multiplexing
AMC	-	Adaptive Modulation and Coding
WLAN	-	Wireless Local Area Network
WMAN	-	Wireless Metropolitan Area Network
Tx	-	Transmitter
Rx	-	Receiver
km	-	kilometer
FEC	-	Forward Error Correction

Chapter 1

INTRODUCTION

1.1 Project Background

FSO communication has developed as a technological revolution in the wireless communication field, which has been around since the eighth century and is now more advanced [1]. Due to its various benefits over conventional RF based communication systems, have enabled numerous channel usability and cost-effectiveness enhancements and optimizations. [2-4]. FSO conveys data by propagation of light in a medium like space, air, or a vacuum [5]. LED and LASER are common semiconductor-based light sources in optical fibre communication systems, due to their numerous benefits over other optical sources. These benefits include small size, remarkable efficiency, the appropriate wavelength of emission, and, most importantly, the ability to modulate at high speeds directly. [6]

Fundamental qualities of a system in fiber optic include the capacity to function at more powerful levels for more excellent communication range, the absence of a licence need, and a high level of security. [7]. These qualities have generated tremendous interest in the field, especially as the need for high-bandwidth applications increases. The FSO communication technology's adaptability and high data rate enable it to provide several feasible solutions for the last-mile problem. The FSO communication system can provide options for applications requiring high data rates and bandwidth, such as resolving issues of delay in web browsing, electronic commerce, information access libraries, communication service, on-demand video, monitoring health, network sharing, and faster internet connections. [8]. Due to their inherent benefits, most applications favour FSO systems.

WDM is a method that multiplexes and transmits multiple signal and convert it into a single signal. Thus, numerous signals modify multiple carriers, which are subsequently multiplexed and transmitted by a single laser beam [9,10]. These systems make optimal usage of channel’s capacity, enhancing the data transmission capability of the FSO link. An optical multiplexer is utilised to alter and merge the streams of data to make the data flow from numerous optical sources with different wavelengths transmit over a single optical channel in WDM. Optical demultiplexers demodulate this stream at the remote end of a WDM system [11]. Since it allows for the removal or addition of channels at any time, this system is considered versatile.

MIMO is a system consisting of multiple transmitter and receiver antennas. This wireless technology has dramatically enhanced the bandwidth and range of channels in wireless communication. A MIMO system enables spatial multiplexing by employing several channels of transmission to the receiver, which causes data discharges, and hence, improves transmission reliability. This approach increases the amount of data transferred, providing high-speed, dependable data transmissions of the same power and bandwidth [12]. MIMO is, therefore, an advantageous method for the FSO system.

This project will be focusing on implements a hybrid combination of WDM-MIMO in FSO system, which gains several independent copies of the signal at the receiver and analyses them for different streams of channels in MIMO, i.e. 2 channels, 4 channels, and 8 channels. OptiSystem is used to examine metrics like BER, Q-factor, SNR, and eye diagram for WDM-based FSO communications using MIMO.

1.2 Problem Statement

Wireless networks have limited bandwidth and capacity because a finite number of radio spectrums are employed to transmit data. [13]. RF waves and the number of accessible channels govern the bandwidth for a wireless network. In contrast, capacity refers to the number of devices that may connect to a network and the amount of information that can be sent simultaneously. The capacity of a wireless network can impact multiple variables, including the distance between devices, the number of walls or other impediments between devices, and the type of devices being connected [14].

Several factors can contribute to a low internet connection, including the network's capacity, the number of users on the web, and the weather [15].

- *The capacity of the network*: The ability of the network refers to the amount of data that can be transferred via the network at any time. If the network's capacity is low, the internet connection may be sluggish.
- *The number of users on the network*: The more users connected to a web, the greater the bandwidth demand. This issue may cause a slow internet connection for all users.
- *The condition of weather*: Poor weather, such as heavy rain or strong winds, might hinder the efficiency of a wireless Internet connection. This is because the radio waves used to send the data are susceptible to interference from atmospheric conditions [13].

Wi-Fi is a wireless technology that transmits data between devices such as computers, smartphones, and tablets using radio waves. A modem, which connects to the internet and emits a Wi-Fi signal to which other devices may connect, is required to use Wi-Fi. Li-Fi, on the other hand, is a wireless data transmission system that employs light. Li-Fi transfers data using visible light spectrum (VLS) or infrared light spectrum (ILS) rather than radio waves like Wi-Fi [16]. Li-Fi can thus be utilised in radio signals that are susceptible to interference and require a transceiver to transmit and receive data using light. In addition, Li-Fi can save electricity costs and function as light to enlighten the room or hall in university campus while simultaneously turning on the network connectivity.

1.3 Objectives

The main goals of this project are as follows:

- To design WDM-MIMO system in university campus.
- To develop high Gbps network access for students and educators in UNIMAS for learning and teaching purposes.
- To compare and validate the performance of multiple channels of WDM-MIMO in FSOC system using various range.

1.4 Project Scope

The aim of this project is to develop system of WDM-MIMO in university campus (UNIMAS). This project involves research on the general concept of WDM-MIMO and fundamental of FSO communication system. The development of the simulation model for this project is based on the parameters obtained from study of previous research. This project focuses on improving the network access in UNIMAS from Mbps to Gbps. Throughout this project, Optisystem by Optiwave software will be used to design realistic model of fiber optic communication system which able to analyze BER, Q-factor, SNR and eye diagram. The result obtained the simulation will be used to validate the performance of WDM-MIMO with predictive control under different number of FSO channels.

1.5 Thesis Outline

This project report is divided into five chapters, with an appendix including references and various attachments. The project is organized in the following order: introduction, literature review, methodology, results and discussion, and conclusion. The summary of each chapter is described as follows.

Chapter 1 (introduction) entails the background study of the proposed project, which is related to fiber optic communication system. This chapter also includes the problem statement, objectives, and scope of the project.

Chapter 2 (literature review) explains the reviews and studies that have been done for better comprehension of proposed project. This chapter elucidates the main component and features of WDM-MIMO technology then followed by the recent developments and advancement of WDM-MIMO made in previous researches. Apart from that, the study of strengths, limitations and applications of WDM-MIMO were also covered in this chapter.

Chapter 3 (methodology) outlines the proposed methodology and succinct process that involved in the project accomplishment. Further details on the method and technique used for the proposed project are discussed in this chapter. This chapter also consists of project flowchart and simulation software that will be used throughout the project completion.

Chapter 4 (results and discussion) emphasizes on the further and detailed discussion regarding the simulation results and outcomes of the proposed project from Optisystem. This chapter also presents line graph constructed from Microsoft Excel.

Chapter 5 (conclusion) summarizes the entire project and conclude the obtained results. This chapter also provides few recommendations for future improvements to overcome the limitations encountered throughout the whole project.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter elucidates on the literature review writing of the proposed project. Various studies and literature were done in order to verify the feasibility of this research project and to clarify the research gap. This chapter starts with the Main Component and Features of WDM-MIMO Technology then followed by the Recent Developments and Advancement of WDM-MIMO made in previous researches. In addition, the study of strengths, limitations and applications of WDM-MIMO were also discussed in this chapter.

2.2 Main Components and Features of WDM-MIMO Technology

2.2.1 Wavelength Division Multiplexing (WDM)

WDM is a part of the technique used to expand the communication system's channel capacity. It is employed frequently in fiber optic communication networks. WDM is the technique that corresponds to FDM. The direct contrast between the two techniques is the frequency or wavelength spectrum across which they operate. Over a single optical channel, WDM modulates and transmits several data streams carried by different light carriers with varying wavelengths. WDM may optimise fibre utilisation by exchanging a substantial quantity of data. Multiplexers aggregate and share data streams from numerous optical sources over a single optical channel in a WDM system. As seen in Figure 2.1, demultiplexers at the far end of a WDM system undergo information retrieval using basic demultiplexing methods [17].

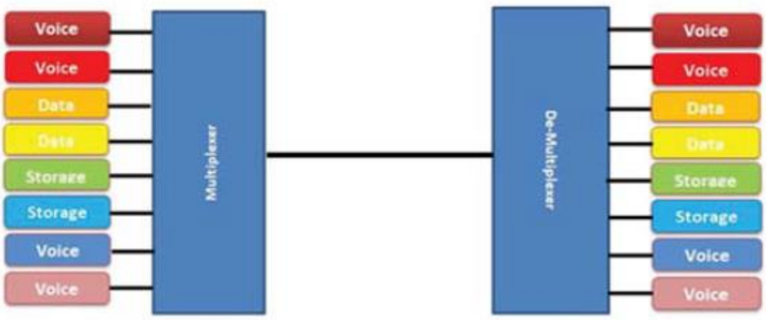

Figure 2.1: General concept of WDM system [17]

2.2.2 Multiple-Input-Multiple-Output (MIMO) Configuration

The development of wireless communication resulted in several technological developments in data exchange and transmission. Single-input-single-output (SISO) technology was employed in the first wireless communication models, which only required only one antenna for both the transmitter and the receiver. However, recent wireless communication models, also known as MIMO techniques, employ multiple antennas in place of a single conventional antenna at transmitters and receivers. This method takes advantage of multipath signal transmission through an independent external setup, commonly referred to as the medium or the channel. Wireless optical communication systems, which employ a particular configuration of LED or LASER beams as transmitters, can also use the MIMO approach. Figure 2.2 displays a block diagram of 4x4 FSO-MIMO [17].

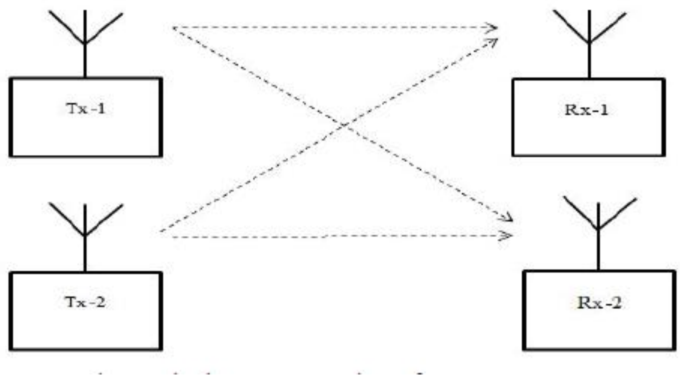

Figure 2.2: Block representation of a MIMO system [17]

2.2.3 Spatial Multiplexing (SM)

In WDM-MIMO, spatial multiplexing refers to the process of using several antennas at the transmitter and receiver to transmit at the same time receive multiple independent data streams over the same frequency band simultaneously [18]. The purpose of spatial multiplexing is to improve the capacity of a communication system by using the spatial diversity of the wireless channel. This is done by dividing the data to be transmitted into several parallel data, in which each of it is transmitted from a different antenna element at the transmitter. At the receiver, the data streams are separated and recovered using MIMO techniques such as spatial filtering or maximum likelihood decoding. Spatial multiplexing can significantly improve the bandwidth of a system in wireless communication, but it requires a sufficient unit of antennas at both end of transmitter and the receiver, as well as a sufficient SNR to enable the recovery of the multiple data streams.

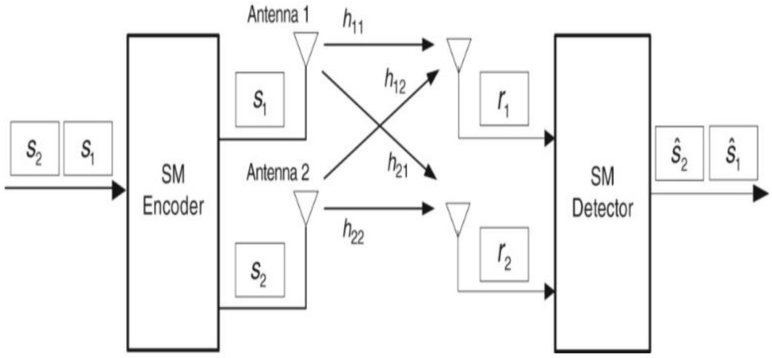

Figure 2.3: Block representation of a SM [19]

2.2.4 Adaptive Modulation and Coding (AMC)

AMC is a method used in wireless communication systems to adapt modulating and coding methods utilized for data transfer to the current channel circumstances. In WDM-MIMO systems, AMC can be used to improve the performance of system by adjusting the modulating and coding methods to the channel conditions experienced by each antenna element. AMC continuously monitors condition of the channel and determines the optimal modulating and coding method for the current situation. [20]. For example, if the channel is in perfect condition (e.g., high SNR), to attain a greater data rate, a relatively high modulation scheme and a lower-rate coding system can be employed. On the other hand, if the channel conditions are poor, a lower-order modulation scheme and a higher-rate coding scheme can be used to reduce the error rate.

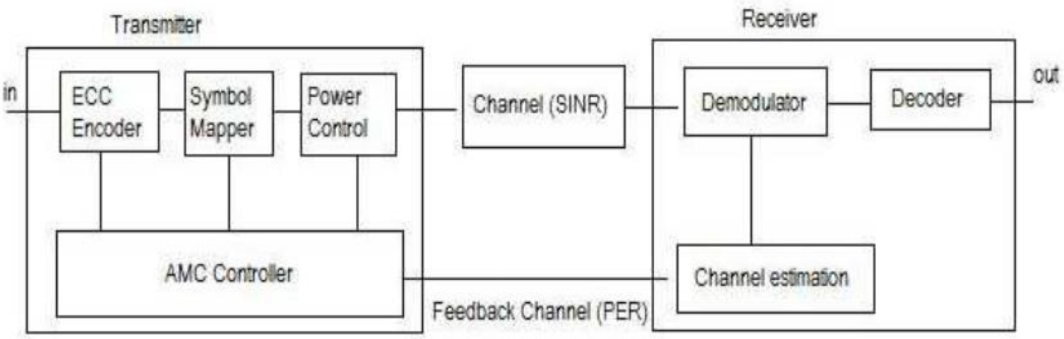

Figure 2.4: Block representation of an AMC [21]

2.2.5 Interference management

Interference management is an essential aspect of wireless communication systems, especially in WDM-MIMO systems where multiple antennas are used at both end of transmitter and receiver. Interference can occur in WDM-MIMO systems due to the presence of multiple users sharing the same frequency band and multiple data streams being transmitted and received simultaneously over the same frequency band [22]. Various techniques can be used for interference management in WDM-MIMO systems, including:

1. *Spatial multiplexing*: This involves using multiple antenna elements at the transmitter and receiver to transmit and receive multiple independent data streams simultaneously, which can help to reduce interference between the data streams [23].
2. *Beamforming*: This involves adjusting the phase and amplitude of the signals transmitted by each antenna element to form a directional beam, which can help to reduce interference from other users or sources [23].
3. *Interference cancellation*: This involves using signal processing techniques to estimate and subtract the interfering signals from the received signal, which can help reduce interference's impact on the system performance [24].

2.3 Recent Developments and Advancement of WDM-MIMO Technology

2.3.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a technique for encoding data digitally on multiple carrier frequencies. In recent years, OFDM has been an important technology that enables the development of WDM-MIMO systems due to its ability to mitigate inter-channel interference and provide high spectral efficiency [25]. Moreover, this system allows multiple data channels to be transmitted over different wavelengths and received over multiple antennas, thus, resulting in a significant increase in system capacity and reliability. This technology has been implemented in several industries, including high-speed internet, 5G networks, and internet in flight.

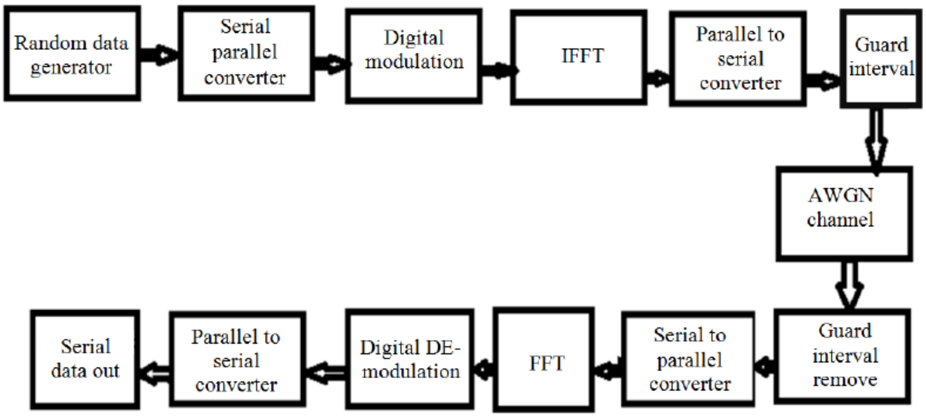

Figure 2.5: Block diagram of OFDM [26]

2.3.2 Orthogonal Time Division Multiplexing (OTDM)

OTDM is a technology that multiplexes multiple optical signals using the time domain. OTDM-WDM-MIMO systems can solve the drawbacks of conventional WDM systems, such as the necessity for complicated optical filtering and the lack of channel assignment flexibility [27]. Prior research on this system centred on various topics, including the design of optical pulse shaping, modulation formats, sophisticated receiver architectures, and wavelength routing. The paper [28] provided an overview of the recent advancements in OTDM-WDM-MIMO technology and discussed the performance enhancement to support high-capacity and high-reliability optical communication systems as portrayed in Figure 2.6.

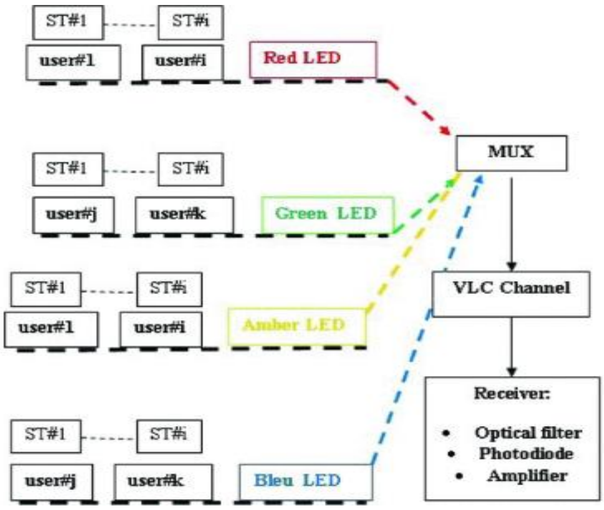

Figure 2.6: Block diagram of hybrid OTDM-WDM [28]

2.3.3 Quadrature Amplitude Modulation (QAM)

QAM is a common modulation method in WDM systems, which has been integrated with MIMO technology to improve the performance of these systems. Recent advancements in QAM-WDM-MIMO technology have focused on several areas, such as:

1. Development of advanced formats in modulation, such as relatively high order of QAM, to increase the system's data capacity [29].
2. Development of advanced receiver structures, such as digital signal processing (DSP) based receivers, to improve the receiver sensitivity and reduce the impact of noise and distortion. [30]
3. Adaptive modulation, allows the system to adjust the modulation format based on the channel conditions [31].
4. Wavelength routing, allows for the efficient use of the available optical spectrum [32].

2.3.4 Non-Orthogonal Multiple Access (NOMA)

NOMA is a method of multiple access that enables numerous users to share the same frequency resources. Integrating NOMA with WDM-MIMO technology allows optimal use of the optical spectrum and increases the system's capacity. NOMA-WDM-MIMO systems can overcome the restrictions of standard WDM-MIMO methods by enabling the transmission of numerous users simultaneously using the same frequency resources. Innumerable aspects of NOMA-WDM-MIMO systems have been the subject of research, including power allocation [33], user clustering, and interference control. This field of inquiry is relatively new. However, NOMA has been extensively explored in other communication systems, such as 5G, and it may be a viable option for future optical communication systems.

2.4 Strength of WDM-MIMO System

Table 2.1 presents the strength or benefits together with the impact given to WDM-MIMO system.

Table 2.1: Strength and impact to WDM-MIMO system

No.	Reference	Strength	Explanation	Impact
1.	[34]	Increased capacity	WDM-MIMO can significantly increase	Allows more users to connect to the network and