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Performance Optimization of Long-Haul Optical Transmission Link with Optical-OFDM

Jyoti Prashant Singh[1*], Deepak Kumar Singh[2], B B Tiwari[3]

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Abstract: This research focuses on improving communication system performance by implementing optical orthogonal frequency division multiplexing (OFDM). OFDM is utilized to extract data from high-capacity systems involved in extensive information transmission. Advanced computer programs and strategic methodologies are employed to develop a measurable and highly efficient communication system. The study delves into both theoretical and practical applications of these techniques. Using MATLAB simulations, the investigation into OFDM capabilities offers a robust platform for comprehensive analysis and evaluation. Researchers can easily adjust subcarrier separation, modulating schemes, and other key parameters to gauge their impact on system performance. This adaptability facilitates thorough exploration of various scenarios and optimization strategies. The findings of this study provide valuable insights into the effectiveness and feasibility of optical multiplexing with OFDM for high-capacity transmission in optical communication systems. Optical OFDM, through simulations, demonstrates outstanding spectrum utilization in the light domain compared to conventional radio-frequency (RF) OFDM, owing to its ability to tightly allocate subcarriers.

Keywords: Optical-OFDM, Subcarriers, Long-haul transmission, RF-OFDM, MIMO, MATLAB.

I. INTRODUCTION

The primary objective of this ongoing research is to develop, analyze, and implement a high-capacity method for transmitting messages in optical communication networks. This technique is referred to as "optical orthogonal wavelength division multiplexing (OFDM)". The aims include establishing and evaluating an optical OFDM communication network, considering factors such as subcarrier spacing, diverse modulation techniques, and methods for mitigating dispersion. Evaluation will involve assessing the system's reliability, error correction capabilities, and signal-to-noise ratio. Additionally, to evaluate performance in large-scale video networks, we will compare optical OFDM with traditional radio frequency multiplexing. The growing demand for high-capacity data transmission over optical fibers necessitates exploration of cutting-edge technologies. This demand arises from the limitations of conventional RF OFDM, which may struggle to keep pace with escalating data requirements. Optical OFDM presents a promising solution, offering enhanced resilience and performance capabilities.

II. LITERATUREREVIEW

A. *Research background*

The research framework revolves around advancing optical technology for communication and meeting the pressing need for efficient data transmission solutions, with a focus on optical orthogonal frequency division multiplexing (OFDM) in high-capacity transmission [1]. The surge in digital content, cloud computing, streaming video, and emerging technologies like the Internet of Things (IoT) and 5G networks has led to a rapid escalation in demand for fast data transfer and internet services over the past few decades. Optical connections, renowned for their unparalleled data-carrying capacity and reliability, have supplanted traditional telecommunications networks as the backbone infrastructure to accommodate this surge in data traffic [2]. However, conventional optical communication networks primarily based on intensity modulation and direct detection (IM/DD) techniques faced limitations in spectrum efficiency and signal robustness, struggling to keep pace with escalating data rates for both long-haul and short-reach optical connections.

In response to these challenges, optical OFDM has emerged as a groundbreaking solution. Optical OFDM applies the principles of orthogonal subcarrier multiplexing to the optical domain, drawing from its well-established RF (radio frequency) counterpart [3]. High-capacity optical networks encountered challenges such as chromatic dispersion and irregularities, which were effectively addressed through advanced signal processing techniques. The standardization and deployment of optical OFDM by telecommunications organizations and network service providers are crucial elements within the research context. Over time, optical OFDM has been recognized as an effective means to enhance the capacity and spectral efficiency of optical networks for data transmission [4].

[1,2,3] Department of Electronics Engineering
VBS Purvanchal University, Jaunpur, U.P. 222001

* *Corresponding Author: Jyoti Prashant Singh*
Email: jyoti.oct@gmail.com

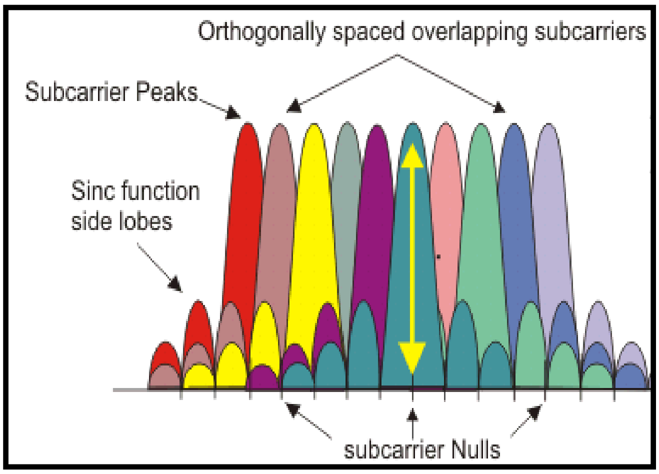

Fig.1: OFDM signal frequency spectrum [3]

The International Telecommunications Union (ITU) and the Institution of Electrical and Electronics Engineers (IEEE) played pivotal roles in international standardization efforts crucial to the development of requirements and standards for optical OFDM-based systems. Furthermore, ongoing research into advanced optical OFDM variations, such as coherent and polarization-multiplexed systems, remains underway. These variations are instrumental in shaping future optical communication networks by promising enhanced spectral efficiency and data throughput [5]. The research trajectory of optical DFT in high-capacity transmission underscores the continual advancement of optical communication technology, driven by the imperative to meet escalating data demands. It underscores the significance of state-of-the-art transmission methods like optical OFDM in addressing these challenges and guiding the future development of optical networks.

B. *Critical Assessment*

The assessment of this project, which utilizes MATLAB simulations to model optical orthogonal frequency division multiplexing (OFDM) technologies, highlights both strengths and areas for improvement. One of the project's notable advantages lies in its comprehensive exploration of Optical OFDM concepts and applications. Through MATLAB simulations, the project successfully examines multiple scenarios, offering a deep insight into the effectiveness of optical OFDM under various conditions [6]. This approach aids in identifying optimal system configurations for high-capacity optical communication. Moreover, the extensive computational and communication toolbox capabilities in MATLAB simplify the implementation of complex algorithms, expediting the resolution of Optical OFDM challenges such as synchronization and dispersion compensation. Consequently, this enhances the project's credibility in addressing real-world optical communication issues. However, there are evident areas for further development [7].

While MATLAB simulations are valuable, reliance on them necessitates cautious interpretation. Discrepancies between mathematical models and actual physical situations may impact the accuracy of simulation findings. To validate the project's feasibility and reliability in practical scenarios, it is imperative to conduct practical experiments and confirm simulation results in real optical communication setups. Considering the resource requirements and scalability of MATLAB simulations is crucial. As optical networks become larger and more complex, the computational demands escalate, limiting the scope and efficacy of simulations [8]. Enhancing the project's capability to handle broader and more intricate optical communication scenarios could be achieved through exploring the use of parallel or high-performance computing technologies. Despite these considerations, the project's utilization of MATLAB for simulating optical OFDM remains commendable for its insights into high-capacity optical communication.

C. *Linkage to Aim*

The primary objective of this project is to develop, investigate, and showcase the effectiveness of visual orthogonal frequency division multiplexing (OFDM) as a high-capacity transmission method in optical communication systems [9]. The outlined theoretical framework distinctly establishes this objective. The design and modeling of an optical OFDM system for transmission serve a specific goal closely aligned with the development aspect [10]. This goal is to pioneer an advanced optical communication protocol that efficiently meets the demands of high-capacity data transmission by optimizing crucial factors such as subcarrier spacing, modulation schemes, and dispersion correction algorithms [11].
The investigative aspect of the objective directly benefits from the performance analysis objective, which focuses on metrics such as spectral performance, bit error rate (BER), and signal-to-noise ratio (SNR) [12]. Its aim is to empirically evaluate how well optical OFDM satisfies the performance criteria for high-capacity data transfer in optical networks. The demonstration component of the goal is facilitated by the comparative evaluation objective, which contrasts the advantages and performance of optical OFDM with traditional RF OFDM. This comparative analysis will provide tangible evidence of the capabilities of optical OFDM, thereby establishing its viability as a practical option for high-capacity optical communication networks [13]. These objectives coalesce to form a cohesive philosophical framework that not only supports the project's overarching purpose but also provides a systematic approach to achieving it.

D. *Theoretical Framework*

The development, investigation, and implementation of optical transverse frequency division multiplexing, an innovative high-capacity transmission technique tailored for optical communication systems, forms the theoretical basis of this research. System Design and Simulation.

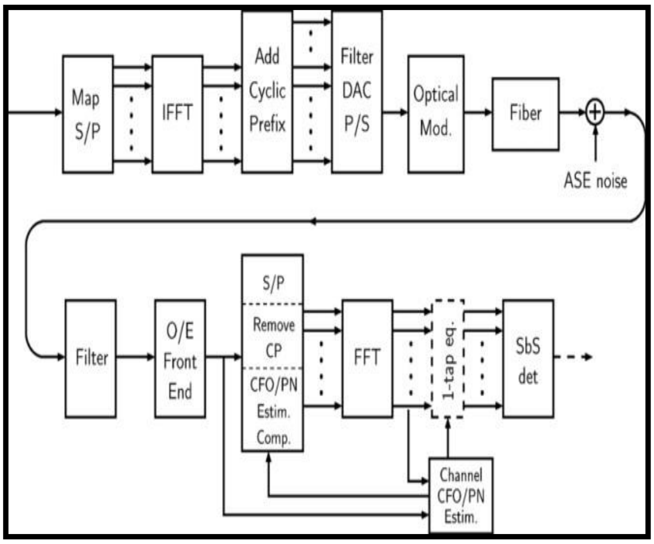

Fig.2: Optical Communication Link with OFDM [5]

To attain the initial objective, meticulous design and comprehensive simulation of an optical OFDM transmission system are imperative [14]. Factors such as subcarrier spacing, modulation techniques, and dispersion correctional algorithms are carefully considered in this design process. By optimizing these elements, the research aims to develop a robust and efficient optical OFDM system that maximizes data throughput while minimizing signal degradation [15].

Our second objective necessitates a thorough evaluation of the optical OFDM system [16]. This assessment encompasses critical aspects such as spectral efficiency, bit error rate (BER), and signal-to-noise ratio (SNR) [17]. These metrics will provide insights into the system's performance, enabling us to determine its suitability for transmitting large volumes of data through light in fiber optic cables. Below is a summary of some measurements and their significance for a quick overview.

Table.1: Performance Analysis of Parameters

Performance Parameters	Descriptions
Bit-error-rate (BER)	Measure the number of bits incorrectly received
Signal-to-noise ratio (SNR)	Determines the ratio of signal power to noise power
Throughput	Represents the rate of data achieved after error corrections
Error vector magnitude	It is a symbol of the accuracy of the transmitted parameters.

The ultimate aim is to evaluate and contrast the advantages and performance characteristics of optical OFDM with traditional RF OFDM, particularly within the realm of high-capacity distribution in optical communication networks [18]. This comparative analysis will facilitate a better understanding of how optical OFDM could potentially surpass or complement existing methods in optical communication across network environments. These objectives are geared towards enriching the theoretical foundations of visual OFDM as a high-capacity broadcasting technique for optical communication networks [19]. The insights gleaned from this study will contribute to the development of more reliable and efficient optical communication technologies, potentially reshaping the capabilities of current optical networks [20].

E. *Literature Gap*

While there has been extensive research in the literature on optical orthogonal frequency division multiplexing (OFDM), the objectives of this specific project diverge significantly from the existing body of work [21]. Although optical OFDM has been a focal point in numerous studies within optical communications, there remains a notable gap in the literature that requires addressing.

Despite the abundance of research on the efficacy of optical OFDM, there remains a need for a more thorough examination of key factors. What sets this study apart is its comprehensive analysis of various aspects influencing performance, including spectral efficiency, bit error rate (BER), and signal-to-noise ratio (SNR) [22]. Understanding the real-world applications of optical OFDM in optical network environments is further complicated by discrepancies between literature sources, a critical consideration.

Another notable deficiency lies in the limited comparative evaluation of optical OFDM versus traditional RF OFDM within the context of high-capacity optical communication networks. Existing research often scrutinizes these technologies individually, failing to provide a holistic understanding of how the benefits and performance characteristics of optical OFDM compare to well-established RF OFDM systems. Given the significance of informed decision-making regarding the adoption of new technologies in optical network architecture, such a comparative analysis is essential.

This project aims to bridge the knowledge gap in the current literature and advance the field of optical networks by addressing these deficiencies. By offering insightful information on the performance and practicality of OFDM as a high-capacity broadcast technique, it aims to contribute significantly to the advancement of optical communication technologies.

III. METHODOLOGY

A. *Research philosophy*

This research work demonstrates the facets of optical communication systems aimed at achieving high-capacity transmission. It underscores the importance of frequency division within communication systems, offering a perspective on its significance. Employing a multifaceted approach, this research integrates various features of communication systems, leading to efficient problemsolving through novel exploration and innovative methodologies [23]. The study adopts a positive approach, employing critical data analysis and meticulous frequency considerations to enhance communication effectiveness. Thus, the research philosophy here is positivism, aiming to facilitate the effective design of the OFDM system.

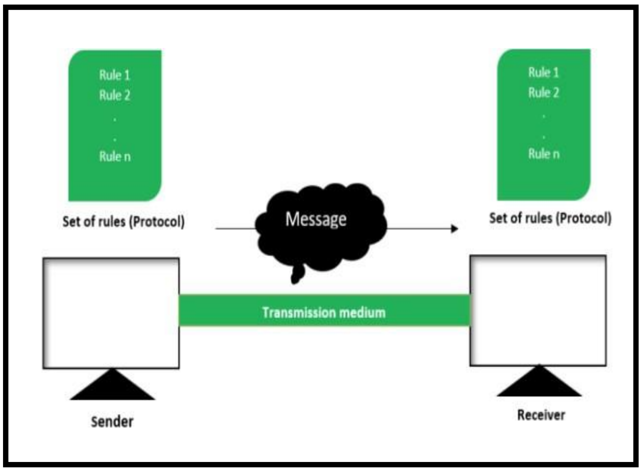

Fig.3: Data Transmission system [6]

This philosophy underscores the true significance of OFDM for highly efficient optical communication. The modulation technique within this multiplexing system is optimized to enhance data speed and spectral efficiency in the communication network.

This project provides an honest assessment of the limitations inherent in the OFDM system. Challenges are effectively addressed through the implementation of efficient linearization techniques. By embracing this positive outlook towards the OFDM system, innovative ideas are generated to mitigate oscillations in optical communication systems, thereby enhancing effectiveness. This research facilitates seamless exchange of vast datasets, contributing to the effectiveness of high-capacity systems in developing communication networks worldwide.

B. *Research approach*

This study adopts a positivist perspective and underscores the importance of optical connections, as well as the role of frequency division in achieving high-capacity distribution [32]. It employs a comprehensive approach that integrates elements of communication systems, cutting-edge technological advancements, and thorough data analysis. To enhance modulation techniques for faster data transmission and improved spectral efficiency, the research emphasizes the relevance of "orthogonal frequency division multiplexing (OFDM)." Effective linearization techniques are applied and the limitations of OFDM are evaluated. With the aim of facilitating seamless high-capacity data exchange and the advancement of international communication systems, the positive orientation aims to address disruptions in visual communication networks.

C. *Research Design*

A systematic approach is employed to establish the OFDM system within a well-structured optical communication framework. The designs are tailored based on the specific objectives of frequency division multiplexing in efficient communication systems. Effective systems are developed through a combination of theoretical analysis and software experiments, with meticulous validation of datasets. Challenges are assessed within the framework of the OFDM system in high-capacity transmission systems. Additionally, evolutionary parameters of communication systems are considered in the design process [24]. Consequently, both descriptive and software-based practical designs are executed in this research. The applicable software tools include Simulink and MATLAB, which facilitate spectrum analyses for the frequency division of the system. Theoretical analysis serves as the foundation to blueprint the effective OFDM system, followed by mathematical modeling to demonstrate the advantages of OFDM in spectral efficiency and data rate.

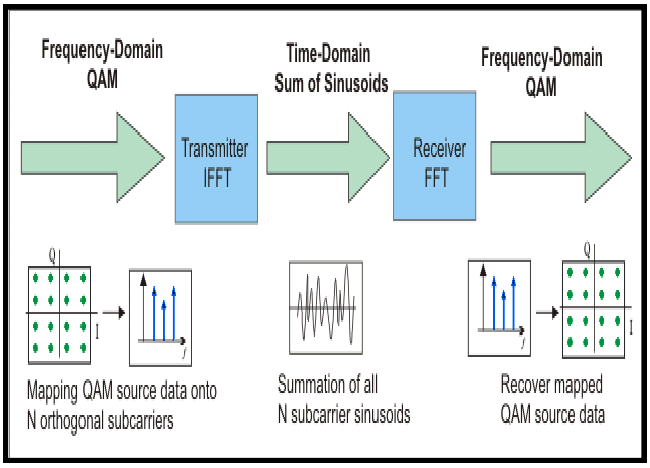

Fig.4: OFDM System framework [12]

Thorough analysis is conducted to ensure the efficacy of the designs by addressing errors and glitches in the communication system. Dispersions and nonlinearities are mitigated through the adoption of appropriate frequency-based techniques in this research. Quality assurance is heavily reliant on the efficient spectral design of the OFDM system, facilitated by mathematical modeling and rigorous optical simulation.

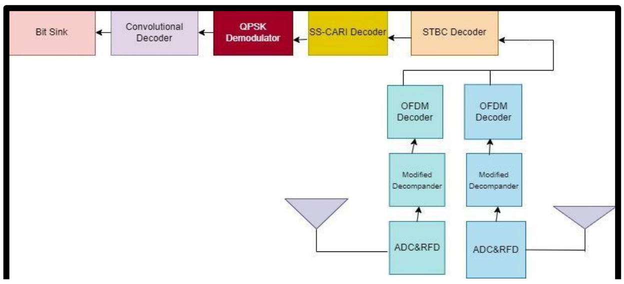

Fig.5: MIMO OFDM System [14]

D. Experimental validations are conducted using various telecom techniques, with optical parameters being justified. Synchronization is meticulously tested to ensure the accuracy of outcomes in effective high-capacity transmission systems. Extensive measures are taken to mitigate obstacles in digital signal processing for frequency-based communication and data transmission systems. These techniques are employed to precisely modulate and encode schemes for error correction while orthogonal frequency division multiplexing (OFDM) frequency divisions are multiplexed. Performance is enhanced through the optimization of subcarrier allocation in data transfer, aimed at minimizing error rates. Thus, thorough research is conducted on the systematic design of communication structures using the OFDM system in the field of optical communication.

E. *Data Analysis and Collection Method*

This research project necessitates extensive data collection and meticulous analysis through efficient software techniques. This methodology involves quantitative secondary data analysis utilizing the specific tools available in MATLAB and Simulink. The datasets used are secondary in nature as they are sourced from existing data repositories. This data analysis is primarily aimed at facilitating trustworthy optimization methods in developing necessary techniques. Pertinent online repositories are utilized to access the numerical datasets required for this research. The project aims to enhance understanding of key trends in the latest advancements in OFDM technologies, utilizing software implementation to visually represent the numeric data through spectral representation. Errors are scrutinized using advanced analytics methods in MATLAB to address nonlinearity and oscillations in the communication system. Secondary data is also gathered to identify various advanced algorithms aimed at improving the system's performance level.

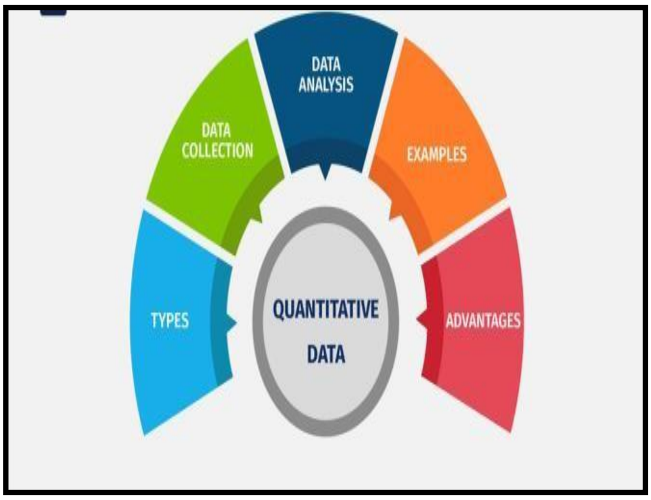

Fig.6: Quantitative Data [13]

Experiments and surveys are conducted with critical attention to detail to ensure precise outcomes aimed at enhancing the OFDM system for the development of a highly effective transmission system. Performance improvements are achieved through multiple testing phases of the collected secondary data, ensuring the system's synchronization. This method of data analysis and collection provides a fresh perspective for this research to explore solutions for optical communication techniques. As a result, the efficient development of the OFDM system is facilitated by several research recommendations and pieces of evidence.

F. *Ethical Considerations*

Maintaining ethical standards is paramount in this study. All research data is handled discreetly and in compliance with applicable data protection laws, ensuring confidentiality and the safety of information. Furthermore, proper citations are utilized, and intellectual property rights are respected when disseminating findings [26]. Upholding a sense of ethics across the research process ensures the respectful and responsible advancement of knowledge and creativity in the field of optical exchanges.

IV. RESULTS AND DISCUSSION

A. *Critical Analysis*

The examination of optical orthogonal frequency division multiplexing (OFDM) capabilities in this study is conducted through simulation using MATLAB software, providing a valuable platform for comprehensive analysis and evaluation. MATLAB's versatility in system design and parameter manipulation stands out as a significant advantage. Researchers can easily adjust subcarrier separation, modulating schemes, and other critical factors to assess their impact on system performance. This adaptability facilitates a thorough exploration of various scenarios and optimization techniques.

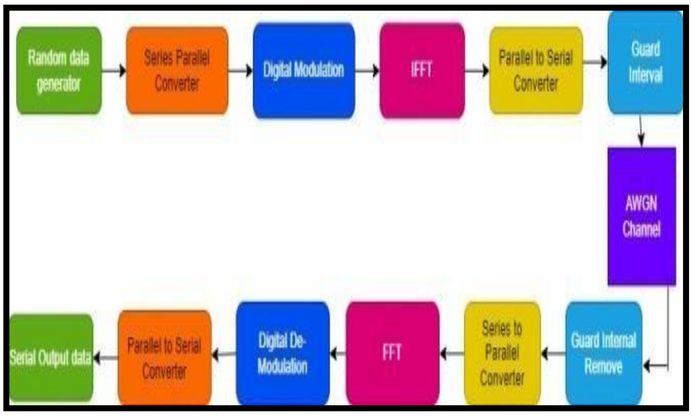

Fig.7: Block diagram of Optical-OFDM [12]

The execution of essential computations, including channel equalization, dispersion correction, and synchronization, crucial for mitigating the inherent challenges of Optical OFDM, is streamlined by the extensive library of processing and communications toolbox functions available in MATLAB [27]. Researchers can gain insights into the performance of optical systems employing OFDM in diverse scenarios through the robust simulation and analysis tools provided by MATLAB.

B. *Evidence of practical work*

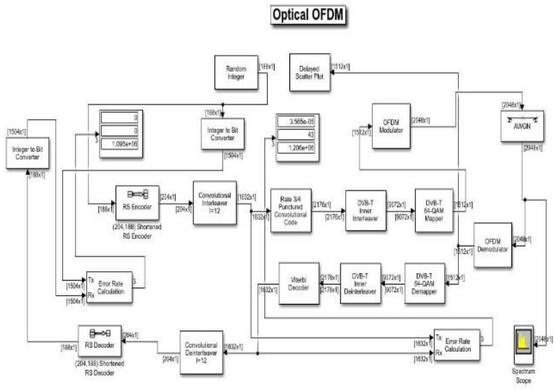

Fig.8: OFDM simulation model

The OFDM model depicted in the image is utilized for simulation purposes, generated through MATLAB. It serves as a representation of digital communication, incorporating various subsystems within the model to simulate the behavior of the OFDM system. The first equation provided here pertains to subcarrier frequencies, which are evenly spaced.

Algorithm: Obtain Decimal Number $\boldsymbol{Z}$ from Indices Sequence $\boldsymbol{J}$

1**: Input**: The binary sequence of p_1 bits, the number of subcarriers n, the number of active subcarriers k

2**: Initialization**: Convert p_1 bits into a decimal number

$Z, jj \leftarrow n$

3**: for** $\boldsymbol{i} = \boldsymbol{k}: -1 : 1$ **do**

4**: repeat**

5: $jj \leftarrow jj - 1$

6: ComCoef $\leftarrow C\ (jj, i)$

7: **until** ComCoef $\leq Z$

8: $j_i \leftarrow jj$

9: $Z \leftarrow Z -$ ComCoef

10: **end for**

11: **return** array j_i

Thus, the frequency of the n$^{\text{th}}$ subcarrier is given by

$$f_n = \left({}^{n}\!/_{T} \right) \qquad (1)$$

where n is subcarrier index and T represents symbol-duration.

The base band signal is represented by $x(t)$ which is a function of time and the sum of all subcarriers. It is expressed as

$$x(t) = \sum_{n=0}^{N-1} D_n e^{j2\pi f_n t} \qquad (2)$$

where N represents the total number of subcarriers, $x(t)$ denotes the time-domain signal on Y-axis and t is the time on X-axis.

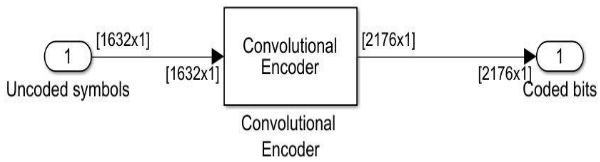

Fig.9 Channel subsystem

The channel subsystem depicted in the image above serves the purpose of simulating how signals propagate. Within this subsystem, there are components such as the convolutional encoder, coded bits, and uncoded bits. It plays a crucial role in defining the transmission of signals through a communication channel, accounting for various effects and distortions.

Firstly, the channel impulse response is defined herewith a function called $h(t)$ concerning received signal $r(t)$ and transmitted signal $x(t)$.

Thus, the equation of channel impulse response is defined by

$$r(t) = x(t) \times h(t) + n(t) \qquad (3)$$

where $n(t)$ is the additive white Gaussian noise and '$*$' represents convolution operator.

The equation of channel transfer function is given by:

$$H(f) = F\{h(t)\}. \qquad (4)$$

In above Equation (3), F represents the Fourier transform.

The channel equalization compensates the effects of the channel and it is represented by

$$y(t) = r(t) \times\ w(t) \qquad (5)$$

where $r(t)$ represents equalised signal and $w(t)$ is impulse response of equalizer.

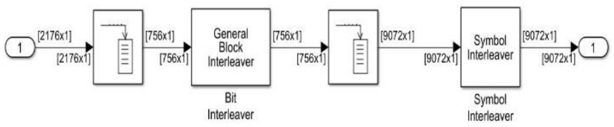

Fig.10 Receiver subsystem

The receiving end of the optical link is depicted in the image, which is utilized to simulate the optical OFDM system. Within the Simulink model, the Receiver Subsystem represents the receiving endpoint of the optical link. This subsystem encompasses essential components that convert optical impulses into electrical signals, including optically-to-electrical converter modules and intricate signal processing strategies. Collectively, these components facilitate accurate data recovery from transmitted signals. A matched filter is employed to enhance the signal-to-noise ratio (SNR) and detect the presence of the transmitted signal. The impulse response of the matched filter is a time-reversed conjugate of the transmitted signal $x(t)$.

The equation is given by

$$h_m(t) = x \times (-t) \qquad (6)$$

where $x^{\times}(-t)$ represents complex conjugate of $x(t)$.

Thus, the output of the matched filter is given by

$$y_m(t) = r(t) \times h_m(t). \qquad (7)$$

Equalized signal for the receiver subsystem is given by

$$y(t) = y_m(t) \times w(t) \qquad (8)$$

The Equalization Subsystem helps in mitigating distortion that occurs during transmission. It is employed to rectify signal distortions resulting from the transmission process. The algorithms within this subsystem are capable of adapting to changing channel conditions and reducing distortion caused by factors such as frequency-selective fade and multipath interference.

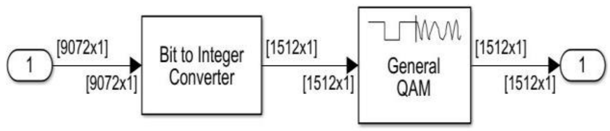

Fig.11: Equalization subsystem

Table.2: Simulation parameters descriptions

Parameter	Description
N	Number of scbcarrier in the OFDM system
T	Symbol period (time duration of one symbol)
Δ	Subcarrier spacing in the frequency domain
$x(t)$	Time domain representation of the OFDM signal
$X(f)$	Frequency domain representation of the OFDM signal

This subsystem aims to achieve the most accurate outcome by mitigating the effects of channel distortion.

Zero-forcing equalization is employed to counteract the impact of the channel by inversely adjusting the channel response. Therefore, the transfer function of the equalizer corresponds to the inverse of the channel transfer function, as represented by the following equation:

$$W(f) = {}^{1}/_{H(f)} \qquad (9)$$

Another type of equalization is required to minimize the mean square error between the transmitted symbols and equalized output, i.e., MSME. The transfer function $W(f)$ is calculated as:

$$W(f) = H^{\times}(f)/[|H(f)|^2 + (1/\mathrm{SNR})]. \qquad (10)$$

where $H^{\times}(f)$ is complex conjugate of channel transfer function and SNR is the signal-to-noise ratio

The Synchronization Subsystem is tasked with addressing timing and phase synchronization issues that may arise during transmission.

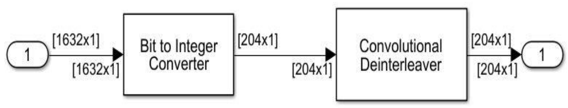

Fig. 12: Synchronization subsystem

In high-capacity optical communication systems, precise time synchronization is crucial for accurately extracting data from complex modulation signals, making this component essential for enhancing signal reception. The synchronization subsystem employs a cross-correlation method between the received signal $r(t)$ and the generated symbolic waveform $s(t)$. The peak of the cross-correlation function is referred to as the timing offset, and is determined by the Equation:

$$T = \arg max_x = |\int r(t)s^{\times}(t-x)dt| \qquad (11)$$

In above Equation, $s^{\times}(t)$ represents the complex conjugate of the symbol waveform.
A table is given for describing the synchronization subsystem with multiple considerations below.

Table.2: Synchronization components and their functions

Synchronization Component	Function
Frame Synchronization	Indicates the start and end of OFDM frames and symbols.
Frequency Offset	Estimates and corrects the carrier frequency offset.
Timing Offset	Estimates and corrects the symbol timing offset.
Channel Estimation	Shows the properties of channels for equalization.
Pilot Signals	Utilizes the pilot symbols for synchronization.

C. *Interpretation of results (Governing Equations)*

This study provides valuable insights into the efficiency and feasibility of optical multiplexing using orthogonal frequency division (OFDM) for high-capacity transmission in optical communication systems. Optical OFDM exhibits exceptional spectrum utilization in the light domain compared to conventional RF OFDM, as demonstrated by the simulations. This capacity stems from its ability to tightly allocate subcarriers, enhancing its effectiveness in utilizing the spectrum.

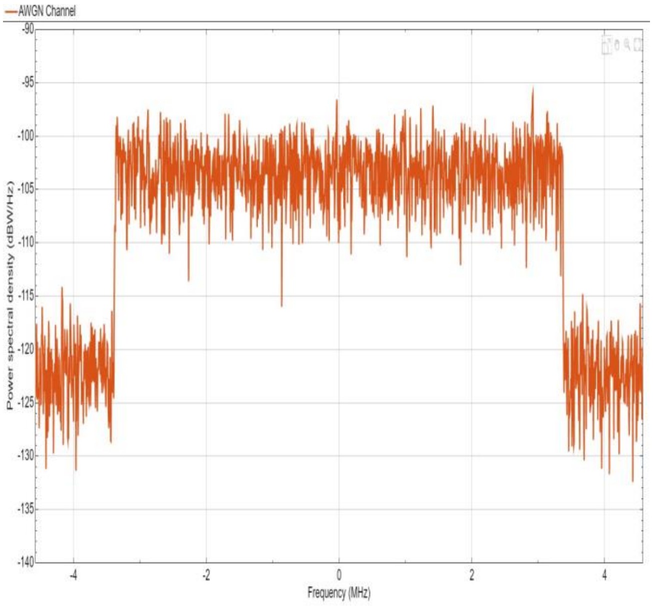

Fig.13: Spectrum scope output

The image displays the output of the spectrum scope, revealing frequency details along with power spectral density. It has been observed that, especially in long-distance optical transmission scenarios, the higher spectrum efficiency of OFDM comes at the cost of increased susceptibility to phase noise and nonlinearities. Additionally, it was found that signal integrity across various distances heavily relies on adaptive algorithms designed to counteract phase noise [28]. These findings underscore the importance of synchronization techniques and highlight the necessity of accurate synchronization for the efficient deployment of optical OFDM. The spectrum scope output delineates the spectral waveform characteristics of received signals from OFDM, as represented by the equation:

$$S_k = |X(f_k)|^2 \qquad (12)$$

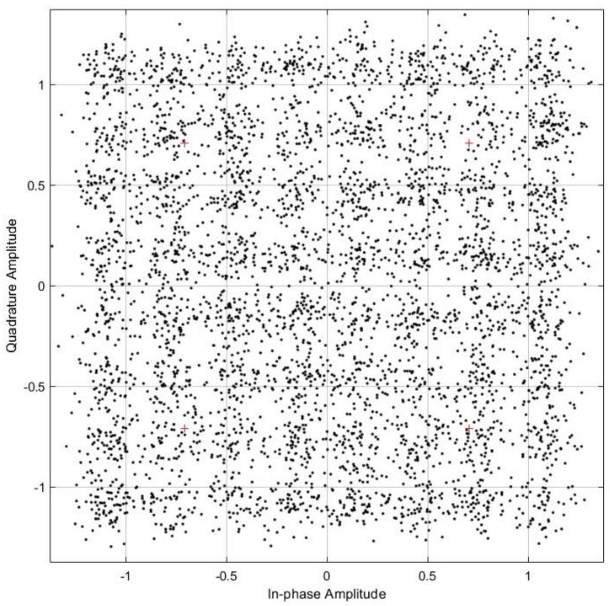

Fig.14: Scattered Plot of OFDM

The depiction of the OFDM system illustrates the in-phase amplitude on one axis (x-axis) and the quadrature part on another axis (y-axis). Simulations also provided insights into the effectiveness of Optical OFDM across various communication scenarios. The technology's adaptability for large city transport networks and data center links demonstrates its capability to efficiently handle the increasing demand for data transmission in modern communications.

$$X(k) = N_1 \sum_{n=0}^{N-1} x(n) e^{-j2\pi kn/N} \quad (13)$$

where $X(k)$ represents the complemented module symbols, N shows the overall collected number of sub-carriers and $x(n)$ is the symbols of data in time domain.

$$H(f) = e^{-j\beta^2 2\pi f} \quad (14)$$

where $H(f)$ represents the frequency results after divergent payment, β^2 is the velocity of collected groups in divergent parameters.

$$SNR = P_{signal}/P_{noise} \quad (15)$$

where P_{signal} is the signal power and P_{noise} represents noise power.

$$\text{BER} = 1/(2 \times \text{SNR}) = erfc\ (2 \times \text{SNR}) \quad (16)$$

where $erfc$ represents error function.

$$r(t) = A\cos(2\pi(f_c + del(f))t + \varphi) + n(t) \quad (17)$$

where $del(f)$ represents frequency offset due to the channel effects or Doppler shifts, $n(t)$ is the noise distortion and $del(f)$ is corrected with estimated functions of frequency recovery algorithms such as PLL.

The demapped signal equation for binary phase-shifting is given by:

$$b = sign\ (\cos(2\pi f_c t)\varphi) \times r(t) \quad (18)$$

where b is estimate bit value, $r(t)$ denotes received signal, A is signal amplitude, f_c is Carrier frequency and φ represents Phase shift.

Demapper equation for Quadrature Amplitude is given by:

$$I = \arg min_i |r(t) - s_i(t)|^2 . \quad (19)$$

where I is the estimated in-phase component and i denotes symbol index for minimizing the euclidian distance.

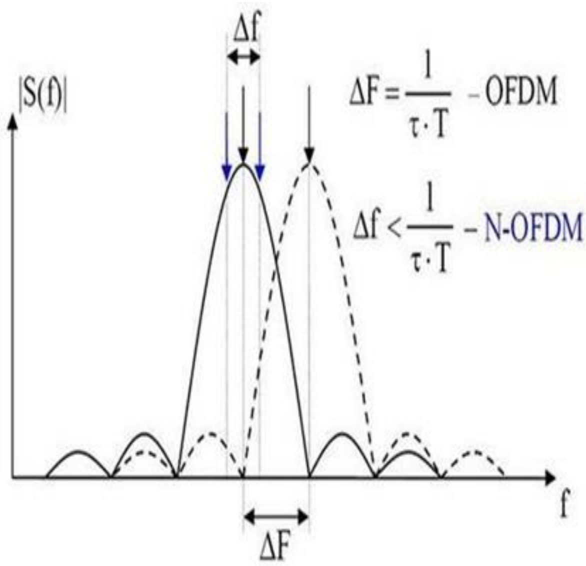

Fig.15: Frequency division representation

V. CONCLUSION

This study underscores the significance of optical "orthogonal frequency division multiplexing (OFDM)" as a transformative method for high-capacity transfer in optical networked communications [29]. Through extensive simulations and thorough research, this technology undergoes a rigorous evaluation revealing both its strengths and weaknesses. A robust platform for analyzing the performance of optical OFDM has been established by leveraging MATLAB as a fundamental simulation tool. With MATLAB's flexibility, various scenarios including modulation schemes and subcarrier spacing can be examined to assess their impact on system efficiency.

It is recommended to conduct large-scale real-world trials to further validate the findings of the study. These trials should involve the practical implementation of optical OFDM in optical networked communications to evaluate its performance under diverse conditions and confirm the consistency of predictions. The study acknowledges that MATLAB models can capture certain nonlinear effects. Therefore, a comprehensive examination of the effects of fluctuations in photonic systems with OFDM is essential. Understanding and mitigating nonlinear effects will be crucial for ensuring reliable high-capacity data dissemination. Collaboration with telecommunications institutions and internet service providers is advised to accelerate standardized and widespread implementation of optical OFDM. Cross-industry collaborations could expedite the adoption of this technology in industrial optical networks.

Further the investigations in the study of Optical "Orthogonal Frequency Division Multiplexing (OFDM)" for high-capacity transmission could explore several potential directions. Real-world confirmation through practical trials remains crucial to bridge the gap between theoretical calculations and practical implementation. These trials should evaluate the technology's performance under various conditions to ensure its effectiveness. Moreover, a deeper exploration of the impacts of nonlinear phenomena in optical OFDM systems is warranted. Understanding and mitigating these instabilities and uncertainties will be vital to ensuring dependable high-capacity data communication. Additionally, further research could explore the use of advanced signal processing methods to address issues such as hue dispersion and abnormalities. Enhancing distribution control and signal normalization techniques could greatly improve the performance of optical OFDM.

REFERENCE

[1] S. Kaur and R. Goyal, "Impact of Scintillation Effect on Clear Weather and Fog Conditions using MDM-WDM Modulation Technique," Journal of Physics: Conference Series, vol. 2426, (1), pp. 012062, 2023. Available: https://www.proquest.com/scholarly-journals/impact-scintillation- effect-on-clear-weather-fog/docview/2777448509/se-2. DOI: https://doi.org/10.1088/1742- 6596/2426/1/012062.

[2] F. M. Rodrigo et al, "A Review of Cognitive Hybrid Radio Frequency/Visible Light Communication Systems for Wireless Sensor Networks," Sensors, vol. 23, (18), pp. 7815, 2023. Available:https://www.proquest.com/scholarly-journals/review-cognitive-hybrid-radio- frequency-visible/docview/2869629798/se-2. DOI: https://doi.org/10.3390/s23187815.

[3] Q. Wu et al, "Machine Learning for Self-Coherent Detection Short-Reach Optical Communications,"https://www.proquest.com/scholarly-journals/machine-learning-self-coherent-detection-short/docview/2869480169/se-2. DOI: https://doi.org/10.3390/photonics10091001.

[4] P. A. Loureiro, F. P. Guiomar and P. P. Monteiro, "Visible Light Communications: A Survey on Recent High-Capacity Demonstrations and Digital Modulation Techniques," Photonics, vol. 10, (9), pp. 993, 2023. Available: https://www.proquest.com/scholarly-journals/visible-light- communications-survey-on-recent/docview/2869479843/se-2.

[5] F. Tian et al, "Kramers–Kronig Transmission with a Crosstalk-Dependent Step Multiple-Input Multiple-Output Volterra Equalizer in a Seven-Core Fiber," Photonics, vol. 10, (9), pp. 1017, 2023. Available: https://www.proquest.com/scholarly-journals/kramers-kronig-transmission-

[6] J. de Curtò, I. de Zarzà and C. T. Calafate, "UWB and MB-OFDM for Lunar Rover Navigation andCommunication,"Mathematics,vol. 11,(18),pp3835 2023.Available: https://www.proquest.com/scholarly-journals/uwb-mb-ofdm-lunar-rover-navigation-communication/docview/2869429844/se-2.DOI: https://doi.org/10.3390/math11183835

[7] G. K. Varotsos et al, "Energy-Efficient Emerging Optical Wireless Links," Energies, vol. 16, (18), pp. 6485,2023.Available:https://www.proquest.com/scholarly-journals/energy-efficient- emerging-optical-wireless-links/docview/2869335191/se-2.DOI: https://doi.org/10.3390/en16186485.

[8] X. Liu et al, "Joint Resource Allocation and Drones Relay Selection for Large-Scale D2D Communication Underlaying Hybrid VLC/RF IoT Systems," Drones, vol. 7, (9), pp. 589, 2023.

[9] J. Chung and L. Seong-Real, "Compensation of the Distorted WDM Signals by SymmetricDispersion Map with Nonuniform Zero-Crossing Place of Accumulated Dispersion in Midway-OPCSystem.

[10] B. A. Lisandra et al, "A Review of Hybrid VLC/RF Networks: Features, Applications, and FutureDirections,"Sensors,vol. 23,(17),pp. 7545, 2023. Available:

[11] L. Yuan-Zeng et al, "Flexible Data Rate Allocation Using Non-Orthogonal Multiple Access (NOMA) in a Mode Division Multiplexing (MDM) Optical Power Splitter for System-on-Chip Networks,"Sensors,vol.23,16),pp.7259, 2023. Available: https://www.proquest.com/scholarly-journals/flexible-data-rate-allocation-using-non/docview/2857446652/se-2.DOI: https://doi.org/10.3390/s23167259.

[12] J. Zhang et al, "Experimental Comparison of Carrier Phase Recovery Algorithms for Uniform and Probabilistically Shaped QAM in a 324.1 Gb/S Fiber-mm-Wave Integration System at W- Band," Photonics, vol. 10, (8), pp. 927, 2023. Available: https://www.proquest.com/scholarly-journals/experimental-comparison-carrier-phase-recovery/docview/2857438980/se-2.DOI: https://doi.org/10.3390/photonics10080927.

[13] X. Jiang, Y. Wang, and W. Lu, "Performance of HQAM/XQAM Laser Communication System in Anisotropic Non-Kolmogorov Ground–HAP–Satellite Uplink," Photonics, vol. 10, (8), pp. 895, 2023. Available: https://www.proquest.com/scholarly-journals/performance-hqam- xqam-laser-communication-system/docview/2857438968/se-2.

DOI:https://doi.org/10.3390/photonics10080895.

[14] T. Wang et al, "Error Characterization of Differential Detection and Non-Differential Detection for MIMO UWOC Systems in Seawater Turbulent Channels," Photonics, vol. 10, (8), pp. 859, 2023. Available: https://www.proquest.com/scholarly-journals/error-characterization- differential-detection-non/docview/2857438420/se-2.DOI: https://doi.org/10.3390/photonics10080859.

[15] J. Pérez Santacruz et al, "Outdoor mm-wave 5G/6G transmission with adaptive analog beamforming and IFoF fronthaul," Scientific Reports (Nature Publisher Group), vol. 13, (1), pp. 13945, 2023. Available: https://www.proquest.com/scholarly-journals/outdoor-mm-wave-5g-6g- transmission-with-adaptive/docview/2857165623/se-2. DOI: https://doi.org/10.1038/s41598-023-40112-w.

[16] F. Kanwal et al, "A Secure Optical Body Area Network Based on Free Space Optics and Time-Delayed 2D-Spectral/Spatial Optical CDMA," Applied Sciences, vol. 13, (16), pp. 9347, 2023. Available: https://www.proquest.com/scholarly-journals/secure-optical-body-area- network-based-on-free/docview/2856797617/se-2. DOI: https://doi.org/10.3390/app13169347.

[17] X. Yan et al, "Two-Stage Link Loss Optimization of Divergent Gaussian Beams for NarrowField-of-View Receivers in Line-of-Sight Indoor Downlink Optical Wireless Communication (Invited)," Photonics, vol. 10, (7), pp. 815, 2023. Available: https://www.proquest.com/scholarly- journals/two-stage-link-loss-optimization-divergent/docview/2843103411/se-2. DOI: https://doi.org/10.3390/photonics10070815.

[18] Y. Tien-Wei et al, "Design of Silicon Photonics Integrated Bulk Zigzag and Sinusoidal Structured Mode Conversion Devices Using Genetic Algorithm (GA) Optimization," Photonics, vol. 10, (7), pp. 759, 2023. Available: https://www.proquest.com/scholarly-journals/design- silicon-photonics-integrated-bulk-zigzag/docview/2843103345/se-2.DOI: https://doi.org/10.3390/photonics10070759.

[19] X. Liu et al, "Low-Complexity Pruned Convolutional Neural Network Based Nonlinear Equalizer in Coherent Optical Communication Systems," Electronics, vol. 12, (14), pp. 3120, 2023. Available: https://www.proquest.com/scholarly-journals/low-complexity-pruned- convolutional-neural/docview/2843054407/se-2.

[20] B. Dong et al, "Broadband quantum-dot frequency-modulated comb laser," Light: Science and Applications, vol. 12, (1), pp. 182, 2023. Available: https://www.proquest.com/scholarly-journals/broadband-quantum-dot-frequency-modulated-comb/docview/2841684310/se-2.DOI: https://doi.org/10.1038/s41377-023-01225-z.

[21] Y. Huo et al, "Technology Trends for Massive MIMO towards 6G," Sensors, vol. 23, (13), pp. 6062, 2023. Available: https://www.proquest.com/scholarly-journals/technology-trends- massive-mimo-towards-6g/docview/2836475565/se-2. DOI: https://doi.org/10.3390/s23136062.

[22] C. He and C. Chen, "A Review of Advanced Transceiver Technologies in Visible Light Communications," Photonics, vol. https://www.proquest.com/scholarly-journals/review-advanced-transceiver-technologies-visible/docview/2829846716/se-2. DOI: https://doi.org/10.3390/photonics10060648

[23] S. Edirisinghe et al, "Recent Development of Emerging Indoor Wireless Networks towards 6G," Network, vol. 3, (2), pp. 269, 2023. Available: https://www.proquest.com/scholarly- journals/recent-development-emerging-indoor-wireless/docview/2829844072/se-2.DOI: https://doi.org/10.3390/network3020014.

[24] D. M. Manias et al, "The Role of Optical Transport Networks in 6G and Beyond: A Visionand Call to Action," Journal of Sensor and Actuator Networks, vol. 12, (3), pp. 43, 2023. Available: https://www.proquest.com/scholarly-journals/role-optical-transport-networks-6g-beyond-vision/docview/2829817276/se-2.DOI: https://doi.org/10.3390/jsan12030043.

[25] N. G. Pantea et al, "Optical Systems Identification through Rayleigh Backscattering," Sensors,vol. 23, (11), pp.5269,2023.Available:https://www.proquest.com/scholarly-journals/optical- systems-identification-through-rayleigh/docview/2824047732/se-2.DOI: https://doi.org/10.3390/s23115269.

[26] E. Biernacka and J. Domżał, "Performance Analysis of Automatic Hidden Ligthpaths inMulti-LayerNetworks," Photonic.

[27] A. Cherifi et al, "Capacity Improvement of 3D-OCDMA-PON Hybrid System Next Generation Using Weight Zero Cross Correlation Code," Applied Sciences, vol. 13, (10), pp. 5869, 2023. Available: https://www.proquest.com/scholarly-journals/capacity-improvement-3d-ocdma-pon-hybrsystem/docview/2819278757/se-2.DOI: https://doi.org/10.3390/app13105869.

[28] D. Neves et al, "Beyond 5G Fronthaul Based on FSO Using Spread Spectrum Codes and GrapheneModulators,"v.

[29] X. Tang et al, "A Low-Complexity Joint Compensation Scheme of Carrier Recovery for Coherent Free-Space Optical Communication," Photonics, vol. 10, (4), pp. 389, 2023. Available: https://www.proquest.com/scholarly-journals/low-complexity-joint-compensation-scheme-carrier/docview/2806574880/se-2.DOI: https://doi.org/10.3390/photonics10040389

[30] X. Tang et al, "A Low-Complexity Joint Compensation Scheme of Carrier Recovery for Coherent Free-Space Optical Communication," Photonics, vol. 10, (4), pp. 389, 2023. Available: https://www.proquest.com/scholarly-journals/low-

complexity-joint-compensation-scheme-
carrier/docview/2806574880/se-2.DOI:
https://doi.org/10.3390/photonics10040389