Impact of Post-Transmission Dispersion Compensation on 16-QAM Optical Links with OFDM

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***Abstract*—This research examines the efficacy of post-transmission dispersion compensation techniques in optical communication systems under 16-QAM modulation with and without Orthogonal Frequency Division Multiplexing (OFDM). Fiber dispersion is a serious challenge to the integrity of the optical signals and may compromise quality and reach in the most efficient optical networks. These networks are becoming more significant as high-speed, low-latency optical links emerge for robust backhaul connectivity in the new 5G structures. This research studies the performance of two of the most used techniques: Fiber Bragg Grating (FBG) and Dispersion Compensating Fiber (DCF). Detailed simulations will be conducted at a transmission rate of 40 Gbps for various performance analyses, i.e., Error Vector Magnitude (EVM) versus fiber length and Symbol Error Rate (SER) versus laser power. Findings indicate a substantial improvement in the system performance by OFDM when it is implemented with both dispersion compensation techniques. The comparative insights gained through this research reveal critical advantages while the limitations of both methods inform strategies to advance the future efficiency of optical communication networks.**

***Index Terms*—16-QAM, OFDM, dispersion compensation, Fiber Bragg Grating (FBG), Dispersion Compensating Fiber (DCF), error vector magnitude (EVM), symbol error rate (SER), optical communication, 40 Gbps transmission.**

I. INTRODUCTION

Optical fiber communication has become the foundation of modern high-capacity networks, supporting the growing demands of internet traffic, cloud data centers, and 5G deployments. Its advantages—high bandwidth, low attenuation, and immunity to electromagnetic interference—make it ideal for long-distance transmission. However, as data rates scale toward 100 Gbps and beyond, physical-layer impairments such as chromatic dispersion and fiber nonlinearities emerge as major performance bottlenecks [1].

To address these challenges, higher-order modulation schemes like 16-Quadrature Amplitude Modulation (16-QAM) are widely adopted due to their spectral efficiency, transmitting 4 bits per symbol. Despite this advantage, 16-QAM signals are highly susceptible to dispersion and noise, requiring robust compensation techniques to maintain signal fidelity [2].

Chromatic dispersion (CD) causes temporal spreading of the optical pulse due to different wavelengths traveling at varying speeds, leading to inter-symbol interference—especially critical in dense modulation formats like 16-QAM. Dispersion compensation strategies such as Dispersion Compensating Fiber (DCF) and Fiber Bragg Grating (FBG) are commonly deployed to mitigate CD by introducing negative dispersion or realigning spectral components, respectively [3].

Orthogonal Frequency Division Multiplexing (OFDM) further enhances dispersion tolerance by dividing the signal into multiple orthogonal subcarriers with flat fading properties. When combined with Digital Signal Processing (DSP) at the receiver, OFDM offers powerful mitigation against both chromatic dispersion and polarization mode dispersion (PMD)[3].

The comparative study is done on the two kinds of system architectures, a 16-QAM OFDM system that involves DSPs and a 16-QAM OFDM system without DSPs, both of which consider a common Post-DCF and Post-FBG dispersion compensation. The performance measurement is on Error Vector Magnitude (EVM) and even on Symbol Error Rate (SER) changing fiber lengths, which gives important trade-offs between optical and digital compensation methods for high-speed transmission systems. Most importantly, these are significant for 5G backhaul and fronthaul networks, where the optical links should be reliable and throughput at low latencies to meet demanding service-level requirements.

- 16-QAM with OFDM
- 16-QAM without OFDM

This study explores four optical transmission configurations employing 16-QAM OFDM: with and without DSP, each integrated with either Post-DCF or Post-FBG dispersion compensation. Performance is evaluated based on EVM and SER over varying fiber lengths and optical power levels, offering guidance for designing robust optical infrastructures suitable for future 5G deployments. [1].

II. Literature Review

Several studies have explored the performance of optical OFDM systems, particularly under varying QAM modulation formats and dispersion conditions. These research efforts provide foundational insights into the design and optimization of high-capacity, long-haul optical networks.

In [3], Taspınar and Alhalabi investigated the performance of a high-data-rate optical OFDM system employing Intensity Modulation/Direct Detection (IM/DD) with different QAM modulation schemes. Their study analyzed long-haul scenarios and demonstrated that higher-order QAM formats significantly enhance spectral efficiency but increase system susceptibility to fiber impairments. The authors emphasized the need for optimized modulation and filtering techniques to balance complexity and performance.

Alatawi et al. [4] conducted a simulation-based study of a 1 Tbps Wavelength Division Multiplexing (WDM) coherent optical OFDM system. Their findings highlighted the effectiveness of coherent detection in enhancing system robustness and supporting high data rates. The study also underscored the importance of channel spacing and modulation format selection to minimize inter-channel interference and nonlinear distortions.

Ahmed and Fyath [5] analyzed the impact of fiber nonlinearity on WDM dual-polarization coherent OFDM systems. Their results showed that nonlinear effects such as Self-Phase Modulation (SPM) and Cross-Phase Modulation (XPM) severely degrade performance at higher power levels. The paper suggested optimal power balancing and advanced dispersion compensation to mitigate these effects.

In a recent work, Kaushik and Saini [6] focused on the selection and optimization of optical filters in a 16-QAM coherent OFDM system. The study examined various filter configurations to improve signal integrity and minimize intersymbol interference. Their results confirmed that filter choice critically influences performance, especially in high-speed transmission scenarios.

Collectively, these studies reinforce the importance of advanced modulation schemes, dispersion compensation, and optimized filtering in achieving efficient and reliable optical OFDM systems.

Despite extensive research in this domain, few studies provide a direct comparative analysis between a 16-QAM system with OFDM and DSP versus a conventional 16-QAM system without OFDM and DSP, particularly in the context of post-DCF and post-FBG compensation. This paper addresses this research gap by evaluating system performance using EVM and SER across varying fiber lengths and launch powers. The goal is to assess the trade-offs between hardware simplicity and signal quality in modern high-speed optical transmission systems.

III. System Design and Methodology

This research employs an OptiSystem-based simulation approach to evaluate the performance of a 16-QAM Orthogonal Frequency Division Multiplexing (OFDM) optical transmission system under different configurations. Two system models were developed: (i) a 16-QAM OFDM system with DSP, and (ii) a 16-QAM OFDM system without DSP. Each configuration was further examined using two chromatic dispersion compensation techniques: Post-DCF and Post-FBG). The primary objective is to analyze the effect of dispersion compensation and DSP on system performance, as evaluated through EVM and SER [1].

A. System Configuration

The optical transmitter incorporates a pseudo-random bit sequence generator, a 16-QAM mapper, and an OFDM modulator. The OFDM modulation is implemented using Inverse Fast Fourier Transform (IFFT) and cyclic prefix insertion. The electrical signal modulates an optical carrier using a Mach-Zehnder Modulator (MZM) driven by a continuous-wave laser source operating at 193.1 THz with a linewidth of 10 MHz [4].

The modulated signal propagates through a SSMF characterized by a dispersion coefficient of 16 ps/nm/km, attenuation of 0.2 dB/km, and a nonlinear index of 2.6×10^{-20} m^2/W. Chromatic dispersion is mitigated using either a Post-DCF module or a Post-FBG module positioned immediately after the transmission fiber. The compensation modules are designed to counteract dispersion over each respective fiber length.

The receiver design differs based on the presence or absence of DSP. For DSP-enabled configurations, signal processing includes cyclic prefix removal, Fast Fourier Transform (FFT), frequency-domain equalization, carrier phase recovery, and 16-QAM symbol demodulation. In the non-DSP configuration, the optical signal is directly detected using a PIN photodiode, and no digital correction techniques are applied [5].

B. Simulation Parameters and Scenarios

The simulation study comprises four distinct configurations:

1) 16-QAM OFDM and Post-DCF
2) 16-QAM OFDM and Post-FBG
3) 16-QAM without OFDM and Post-DCF
4) 16-QAM without OFDM and Post-FBG

Each scenario is evaluated by varying the following parameters:

- **Fiber Length:** from 1 km to 50 km, in 10 km
- **Launch Power:** from -3 dBm to 3 dBm, in 2 dBm steps

C. Performance Evaluation Metrics

Two primary performance metrics are used to evaluate the system:

- **EVM:** EVM quantifies the root-mean-square deviation between the ideal and received symbol constellation points. It provides insight into signal distortion and degradation.
- **SER:** SER represents the ratio of incorrectly detected symbols to the total number of transmitted symbols, serving as a direct indicator of system reliability [6].

D. Output Analysis

For each configuration, the following performance graphs are plotted and analyzed:

- EVM versus fiber length
- SER versus fiber length
- EVM versus input power
- SER versus input power

These plots enable a comparative study of the impact of DSP and the chosen dispersion compensation techniques across varying transmission distances and optical power levels.

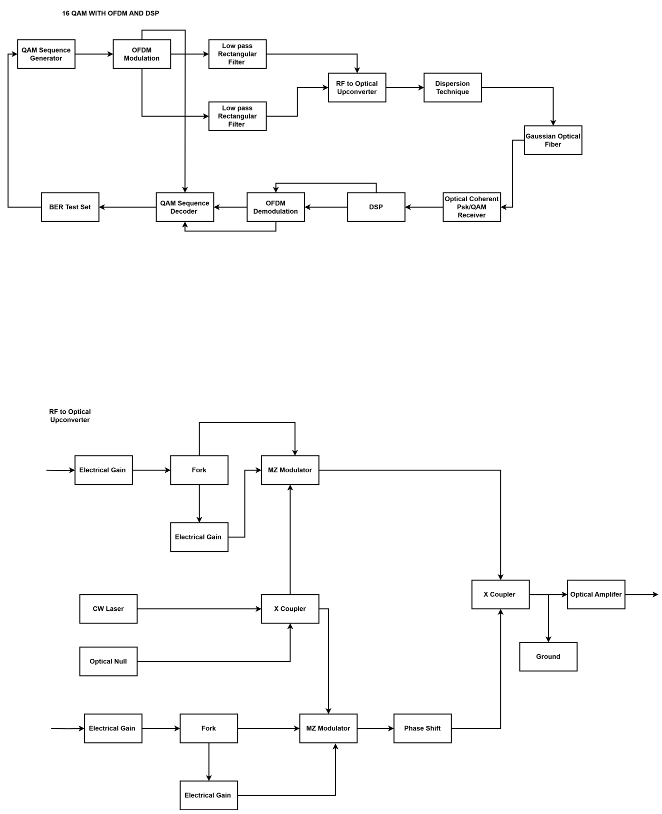

Fig. 1. Block diagram for System A: 16-QAM with OFDM and DSP

1) Figure 1: 16-QAM with OFDM and DSP: This configuration includes a complete DSP chain at the receiver side. The 16-QAM modulated signal is passed through an OFDM transmitter, transmitted over an optical channel, and received by an OFDM receiver. At the receiver, DSP techniques such as dispersion compensation, adaptive equalization, and low-pass filtering are applied to reduce distortion and inter-symbol interference.

2) Figure 2: 16-QAM with OFDM without DSP: In this setup, the same 16-QAM and OFDM modulation scheme is used, but all DSP processing blocks at the receiver are removed. The signal is directly demodulated after transmission through the noisy optical channel. This configuration demonstrates the degradation in performance when signal correction and enhancement techniques are not applied.

3) Figure 3: Post DCF , Post FBG:

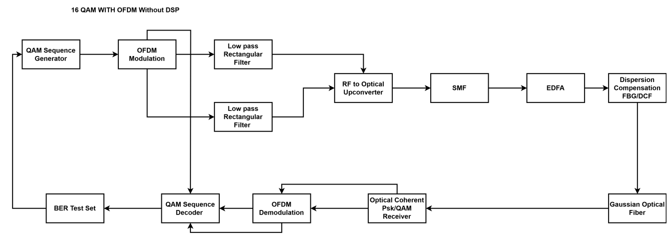

Fig. 2. Block diagram for System B: 16-QAM without OFDM without DSP

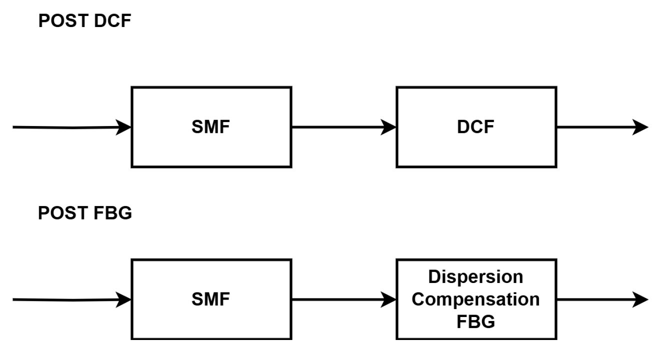

Fig. 3. Block diagram for Post DCF , Post FBG

E. Figure 3: Dispersion in Optical Fiber Communication

Dispersion is one of the critical impairments in optical fiber communication that leads to pulse broadening as the optical signal propagates through the fiber. It causes overlapping of pulses, leading to inter-symbol interference (ISI), which severely degrades system performance, especially at higher bit rates.

There are mainly two types of dispersion in single-mode fibers:

- **Chromatic Dispersion**: This occurs due to the dependence of the refractive index on the wavelength of the transmitted light. Different spectral components of the signal travel at different speeds, causing temporal spreading of pulses.
- **PMD**: This results from asymmetries in the fiber core, which cause different polarizations of light to propagate at different velocities.

To combat the effects of dispersion and ensure signal integrity over long distances, dispersion compensation techniques are employed [7]. In this work, we implement two commonly used methods:DCF and FBG.

1) DCF: DCF is a specially designed fiber with negative dispersion characteristics that counteract the positive dispersion of standard single-mode fibers. It is inserted in the transmission line either before, after, or on both sides (symmetrical compensation) of the main fiber span [8].

In our system, we use **post-compensation** DCF to balance dispersion accumulated in the main transmission fiber. The length of the DCF is chosen based on the total accumulated dispersion and the dispersion coefficient of the DCF [9].

2) FBG: FBG is a periodic variation of the refractive index in a fiber core, acting as a wavelength-specific reflector. FBGs can be used to compensate dispersion by reflecting different spectral components of the pulse at different points along the grating, thus re-aligning them temporally [8] [9] [10].

In this project, we utilize **post-compensation using FBG**, where the FBG module is placed after the transmission fiber to reverse the pulse spreading and improve the signal quality at the receiver [11] .

IV. Experimental Results and Simulation

This part contains a complete study of the simulation outputs obtained using *OptiSystem* for the performance evaluation of coherent optical systems employing 16-QAM modulation. The focus of this analysis is to investigate how the dispersion compensation techniques—Post-DCF and Post-FBG—influence signal integrity and overall system performance.

Performance comparisons are made between systems integrating OFDM and DSP versus those that do not use OFDM. The two primary performance parameters considered are **EVM** and **SER**. These parameters are analyzed with respect to variations in the following key system parameters:

A. Overview of Evaluation Parameters

The simulations were conducted under the following standard conditions:

- **Bit Rate:** 40 Gbps
- **Modulation Format:** 16-QAM
- **Transmission Distance:** 100 km to 150 km
- **Input Optical Power:** Ranging from -3 dBm to +3 dBm
- **Dispersion Compensation Techniques:** Post-DCF and Post-FBG
- **OFDM Integration:** Enabled in relevant cases
- **DSP Utilization:** Applied only to systems incorporating OFDM

B. Test Configurations

The tests were conducted in the following four configurations:

1) Post-DCF 16-QAM (Non-OFDM)
2) Post-FBG 16-QAM (Non-OFDM)
3) Post-DCF 16-QAM with OFDM and DSP
4) Post-FBG 16-QAM with OFDM and DSP

C. EVM vs. Optical Power

The comprehensive examination of EVM instead foreshadows a downtrend with respect to increasing optical input power with respect to all the system set-ups. Improving launch powers increased the clarity of signals and subsequently gave rise to better fidelity although such non-OFDM systems did not show much improvement beyond +1 dBm due to development of non-linear distortion and fiber non-linearity, asserting a limit to efficiency. However, an improvement would be seen even without the increment in input input. They become more tolerated with regard to such demerit with input increase. Most importantly, the configuration with Post-DCF and OFDM with DSP yielded the lowest EVM values across all power levels, indicating its efficiency in chromatic dispersion alleviation and quality preservation of the signal.

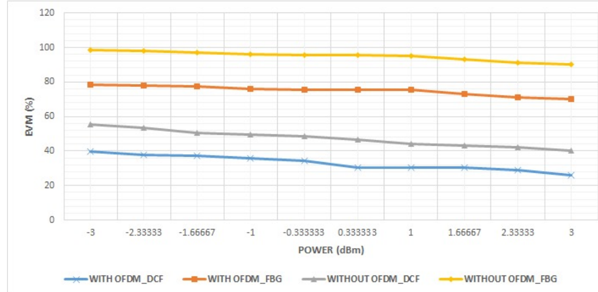

Fig. 4. Graph of EVM vs Power

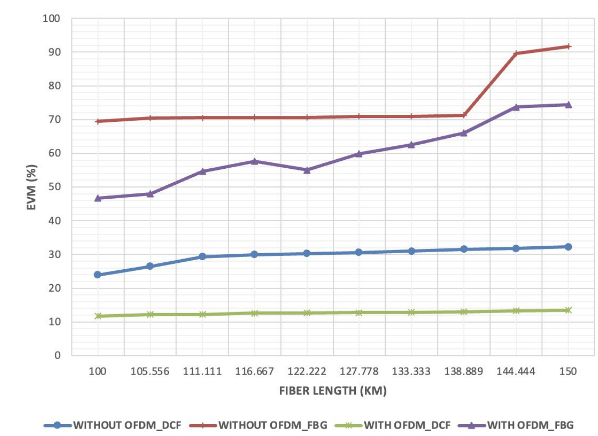

Fig. 5. Graph of EVM vs Fiber Length

D. EVM vs. Fiber Length

The study of EVM gave declining trend results according to increased light input power at all system setups. With the increasing launch power, a more clear signal improved the fidelity much with an exception of non-OFDM systems, which were barely increased beyond +1 dBm as a result of the nonlinear distortion onset and nonlinearity in fiber causing the effectiveness limits. On the contrary, OFDMA systems were able to gain higher input powers for which they still showed improvement. It is therefore derived from this that Post-DCF with OFDM and DSP was the prototype with the lowest EVM values across all levels of power hence portraying higher efficiency towards chromatic dispersion alleviation and preserving the quality of the signal.In contrast, Post-FBG systems—especially those lacking OFDM—suffered a sharp increase in EVM values beyond 125 km. This suggests that while FBG-based dispersion compensation offers initial benefits, it lacks the long-distance resilience provided by digital compensation methods.

E. SER Analysis

1) SER vs. Optical Power: SER trends resembled those shown by EVM. An increase in optical power showed better SER performance across all setups, implying improved signal-to-noise ratio; however, in systems that had no OFDM, there was some plateauing or slight worsening of SER with an increase in power due to the nonlinear effects becoming progressively more dominant at higher power. On the contrary, the systems with OFDM and DSP kept the clear downward trend of SER with increasing power, indicating the strength of those systems in high-power conditions. Among the different configurations evaluated, the Post-DCF with OFDM and DSP succeeded with a consistent top-notch performance in a SER, thus showing its adherence to combating effects due to both dispersion and distortion.

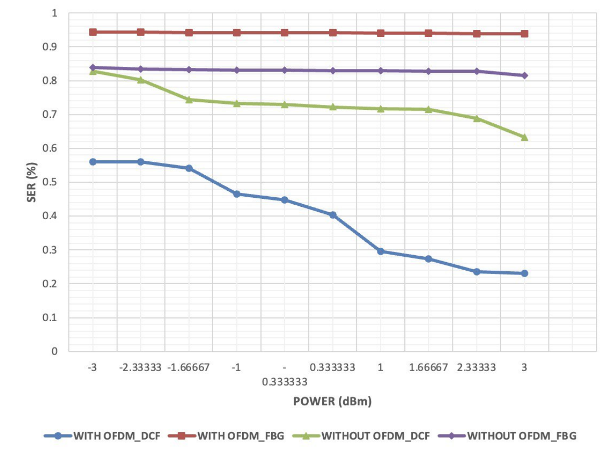

Fig. 6. Graph of SER vs Optical Power

V. Square QAM Maps

When transmitting information, we can vary the amplitude of a signal according to the source symbols.

For each output port, the amplitude takes one of the values from the set of amplitudes [11] [12].

$$a_i = (2i - 1 - M), \quad i = 1, 2, \ldots, M \tag{1}$$

where M is the number of possible sequences of binary digits, calculated according to:

$$M = 2^{h/2} \tag{2}$$

where h is the number of bits per symbol. The equivalent QAM set is given by the square of M.

This means:

- $h = 2,\ M = 2 \Rightarrow$ 4-QAM
- $h = 4,\ M = 4 \Rightarrow$ 16-QAM
- $h = 6,\ M = 8 \Rightarrow$ 64-QAM
- $h = 8,\ M = 16 \Rightarrow$ 256-QAM

A. OFDM Demodulation Dual Polarization

In the *OFDM Demodulation Dual Polarization* component, the training symbols must follow the format [13]:

$$t_k(i) = \begin{bmatrix} t_{X,k}(i) \\ t_{Y,k}(i) \end{bmatrix}, \quad t_k\left(i + \frac{N_T}{2}\right) = \begin{bmatrix} t_{X,k}(i) \\ -t_{Y,k}(i) \end{bmatrix}, \quad i = 1 \ldots \frac{N_T}{2} \tag{3}$$

where k is the sub-carrier index, i is the training symbol index, and N_T is the number of training symbols. Choosing Dual polarization "X" or "Y" ensures that the X and Y polarization symbols are respectively set correctly [14].

Users can get the PAPR parameter of the OFDM Modulator component through the "Component Results..." that can be accessed by right-clicking on the component. The PAPR parameter is given by [15]:

$$\text{PAPR} = \frac{P_{\max}}{\frac{1}{T}\int_T |E|^2 dt} \tag{4}$$

B. Laser Phase Noise and Polarization

In the CW case, the average output **Power** is a parameter that you specify. The laser phase noise is modeled using the probability density function [15] [16]:

$$f(\Delta\phi) = \frac{1}{2\pi\sqrt{\Delta f dt}} \cdot e^{-\frac{(\Delta\phi)^2}{4\pi\Delta f dt}} \tag{5}$$

where $\Delta\phi$ is the phase difference between two successive time instants and dt is the time discretization[14]. A Gaussian random variable for the phase difference between two successive time instants with zero mean and a variance equal to $2\pi(\Delta f dt)$ has been assumed, with Δf as the laser linewidth (which is equivalent to the full width at half maximum (FWHM) of the laser power spectrum [17] [18].

The output is multiplied with a complex vector considering the state of polarization:

$$\begin{pmatrix} E_X(t) \\ E_Y(t) \end{pmatrix} = \begin{pmatrix} \sqrt{1-k} \\ \sqrt{k}e^{-j\theta} \end{pmatrix} \cdot \sqrt{P(t)} \tag{6}$$

where the power splitting k and the phase difference θ are related to the parameters Azimuth α and Ellipticity ε as follows:

$$\tan(2\alpha) = \frac{2\sqrt{k(1-k)}\cos(\theta)}{1-2k} \tag{7}$$

$$\sin(2\varepsilon) = 2\sqrt{k(1-k)}\sin(\theta) \tag{8}$$

2. SER vs. Fiber Length: Longer fiber transmissions showed dramatic increases in SER. The Post-DCF and OFDM systems exhibited the smoothest SER curve, with minimal errors even for distances up to 150 km [16]. In contrast, Non-OFDM systems with Post-FBG showed a sharp increase in SER beyond the 120 km mark. This observation further confirms the limited dispersion compensation capabilities of Fiber Bragg Grating (FBG) devices [19].

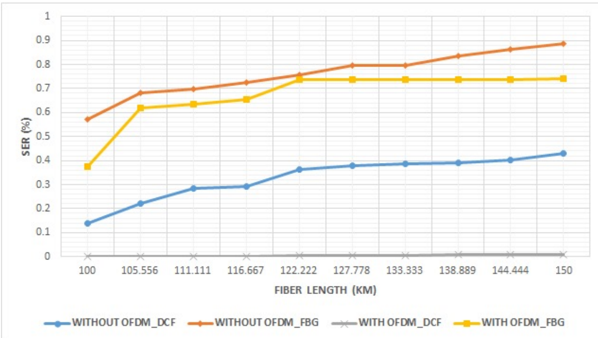

Fig. 7. Graph of SER vs Fiber Length

$$EVM = \frac{\sqrt{|S - \lfloor S \rceil_D|^2}}{||\lfloor S \rceil_D|^2} \times 100\% \tag{9}$$

$$SER = \frac{Errors}{SymbolSequenceLength - PilotSymbols - TrainingSymbols} \tag{10}$$

Comparative System Performance

a) Impact of OFDM and DSP:: The incorporation of OFDM improves spectral efficiency by distributing data across multiple subcarriers, thus mitigating dispersion. This benefit is further enhanced by DSP techniques such as phase recovery, frequency equalization, and symbol synchronization, which significantly improve signal quality [20]

Non-OFDM systems, lacking such signal processing support.Experienced pronounced dispersion-related distortions, highlighting the necessity of advanced modulation and processing schemes for high-data-rate optical systems [21].

b) Efficacy of Post-DCF vs Post-FBG:: Across all evaluations, Post-DCF consistently outperformed Post-FBG. DCF fibers, with tailored dispersion properties, provide effective chromatic dispersion mitigation. In contrast, FBGs, though compact and economical, offer limited bandwidth compensation and are thus less effective in long-haul coherent systems [22].

Insights from Data Trends

OFDM-based systems showed lower EVM and SER in all scenarios. Their resistance to multipath fading and dispersion, coupled with DSP's real-time correction capabilities, resulted in superior performance [23]. This effect was further strengthened when paired with Post-DCF, offering comprehensive dispersion cancellation[.

The interaction between optical power and fiber length revealed optimal operating conditions [24]. While OFDM systems thrived at launch powers exceeding 1 dBm, non-OFDM systems experienced nonlinear distortions. Post-FBG's performance degraded significantly with distance, revealing its limitations in wideband compensation [25].

Extended Observations and Discussions

Qualitative indicators such as eye diagrams, signal constellations, phase noise, jitter, and optical SNR confirmed the benefits of OFDM and DSP. These technologies allowed coherent receivers to decode complex symbols accurately even under degraded channel conditions.

Furthermore, nonlinear effects like four-wave mixing and cross-phase modulation were better mitigated in OFDM configurations. Post-DCF maintained stable performance across all tests, while Post-FBG showed fluctuations based on spectral alignment and fiber type.

Constellation and eye diagram analysis further verified that OFDM architectures yield cleaner signals, with wider eye openings and well-centered constellation points—indicators of lower phase and amplitude noise.

VI. Experimental Results and Discussion

This section evaluates the system performance in terms of *EVM* and *SER* under varying conditions of optical power and fiber length. Four configurations were analyzed:

- With OFDM + DCF
- With OFDM + FBG
- Without OFDM + DCF
- Without OFDM + FBG

A. EVM vs Power

According to the graph of EVM versus power, it can be revealed that by using OFDM along with DCF configuration, EVM is the lowest when compared to any power levels and remains below 40% always; thereby implying that the signal is of very good integrity. On the contrary, for non-OFDM, and using FBG, there is the highest EVM that is more than or nearly 100%, and that shows a tremendous distortion of a signal. Overall, the performance can be said to be moderate when including FBG configurations; but, by a small margin, the OFDM-enabled setup has been slightly more effective than the non-OFDM. In addition, all configurations register slight increases in EVM at higher levels of optical power due primarily to the effect of nonlinear impairments at such higher power levels.

B. SER vs Fiber Length

The SER versus Fiber Length graph shows that the combination of OFDM with DCF keeps a Symbol Error Rate (SER) almost zero up to 150 km, being quite error-resilient over longer distances. On the other hand, the OFDM with FBG scheme displays performance which is fairly stable until 140 km, beyond which it sharply rises due to a threshold on its effectiveness. Apart from this, it can also be very clearly seen that for all distances, systems without OFDM–whether with DCF or with FBG–tend to have SER values that are significantly higher, thereby indicating poor error performance and resilience.

C. EVM vs Fiber Length

Here, one of the graphs illustrates EVM versus Fiber Length. The graph shows that the combination of OFDM with DCF will always provide a lower Error Vector Magnitude (EVM), which is in the range of 10% to 15% for all transmission lengths, indicating strong signal integrity. On the contrary, the EVM measurement in a system not using OFDM but employing an FBG increases rapidly over distance and eventually exceeds 70%, which denotes severe degradation. On the other hand, the OFDM with the FBG configuration can be classified as performing moderately well at distances of up to 140 km with acceptable EVM levels. Beyond that distance, however, its performance is highly degraded.

D. SER vs Power

Graphical observations derived from SER comparison with power reveal that the OFDM with DCF configuration displays improved performance overall, exhibiting a sharp decline in SER with increasing power while eventually stabilizing at a low error level beyond about 1 dBm, which indicates great power level-sensitive behavior in this case. On the contrary, the OFDM with FBG maintains a high steady measure of SER at about 0.95% across several power levels, showing its least responsiveness to the power variations. The performance of the system with no OFDM but with DCF has an uphill trend with power increase but still performs worse than their OFDM counterparts. On the other hand, the SER improvement in the case of the configuration that has no OFDM and has FBG remains marginal, which reflects its deficient error performance under varying power conditions.

E. Summary

It is revealed from the analysis that OFDM with DCF can bring the overall best performances of the system from both EVM and SER points of view. It can be noticed that OFDM was moderately effective with FBGs but could not be used creatively for large distances of transmission, as the performance deteriorated. All the evaluated parameters reveal a reduced performance with systems that do not incorporate OFDM or any dispersion compensation techniques. Therefore, a robust conclusion can be drawn in favor of DCF-based dispersion compensation in optical communication, with OFDM proving particularly well adapted for long-haul transmission scenarios.

VII. Conclusion and Future Work

The research studied the performance of 16-QAM coherent optical systems in OptiSystem by comparing the performance of OFDM + DSP with those not based on OFDM in Post-DCF and Post-FBG dispersion compensations, and the results indicate that OFDM, in particular with DSP and Post-DCF, greatly improved EVM and SER for varying fiber lengths and power levels. While Post-DCF performed better with long-distance dispersion compensation, Post-FBG had minimal adaptability in terms of bandwidth.

These findings are of direct importance to the 5G fronthaul and backhaul networks that require high-bandwidth low-latency reliable optical links to support large data traffic and heterogeneous service requirements. The good performance of OFDM with DSP and Post-DCF thus makes this architecture an attractive candidate for maintaining the stringent quality-of-service requirements of future-generation 5G infrastructures.

For further advancement, it is recommended to consider higher-order modulation formats such as 64-QAM, adaptive and tunable dispersion compensation, and machine learning-based DSP along with WDM integration. Also, integration on hardware testbeds and energy efficiency optimization will be crucial. Thus, this will lead to the advancement of intelligent high-speed optical networks for the future requirements of data and scalability required by 5G and beyond.

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