High-Capacity Transmission with Dual Polarization M-QAM Levels Based on DWDM Technique for Wireless Networks

Fellag C. Abdennour[1], Borsali A. Riad[1] and Rouissat Mehdi[2]

Abstract – **Wireless networks have recently required the development of a backbone system with high bandwidth capacity and optical fiber transmission over long distances as well. Therefore, coherent optical technology provides broadband communications with advanced modulation techniques to meet the requirements of wireless networks, such as the fifth-generation 5G system. In this paper, the Dual Polarization-M-Quadrature Amplitude Modulation (DP-M-QAM) levels have been integrated with the Dense Wavelength Division Multiplexing (DWDM) technique. The system focuses on high data transmission over long-haul optical fiber with digital signal processing (DSP) treatment in the receiving section. The transmission of 100 Gbits/s, × 16 channels has been achieved using Single Mode Fiber (SMF) over lengths from 80 to 320 km, and channel spacing up to 100 GHz. The DP-M-QAM modulation levels based on coherent DWDM simulation were evaluated using the Optical Signal-to-Noise Ratio (OSNR) parameter. The performance of the proposed model is evaluated and analysed in terms of different results of Bit Error Rate (BER) and Error Vector Magnitude (EVM). Compared to already existing solutions, our system demonstrates the best compromise in terms of the number of channels, the long transmission distance of up to 300 km and also minimum BER, which makes it an efficient solution. The proposed transmission provides a DSP subsystem to support a broader range of DP-M-QAM modulation formats for high-speed wireless communication networks.**

Keywords – **Dual Polarization M-QAM, DWDM, Digital Signal Processing, Optical Signal-to-Noise Ratio, Bit Error Rate, Error Vector Magnitude.**

I. INTRODUCTION

In these years, the world has seen an increasing demand for advanced wireless communication networks in order to provide fifth-generation (5G) mobile services, so these services require a high capacity and long-haul of transmissions. Therefore, it is necessary to resort to technologies that meet the requirement of the 5G users with an advanced architecture transmission of data, efficient modulation schemas and effective cost. The main function of the 5G mobile broadband communication system with optical access network-based broadband transmission supports Mobile Front-Haul (MFH) architectures for communication between Central Office (CO) and Remote Radio Heads (RRHs) with optical fiber link [1], [2]. The optical network provides small cells that use a broadband signal to modulate optical carriers in the Base Band Unit (BBU) located in CO and injection into the optical link directed towards RRHs. Fig. 1 shows Dense Wavelength Division Multiplexing (DWDM) transmission from the central office to RRH units via front-haul technology [1]. The optical fiber front-haul gives an efficient solution for big data but the High-frequency transmissions in mobile networks are subject to linear and non-linear influences that lead to transmission losses over optical fibers. The optical fiber attenuation, Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) are the linear effects [3]. The nonlinear effects deteriorate the performance of the intra channel in the WDM optical system and these effects are categorized into two types. The first one is represented by Self-Phase Modulation (SPM), Cross-Phase Effect (XPM) and Four-Wave Mixing (FWM), and the second one includes Stimulated Brillouin Scattering (SBS) and Stimulated Raman Scattering (SRS) [4].

Due to the high communication capacity and splitting bandwidth in the optical access networks, DWDM is the suitable system for the transmission of mobile networks in optical fibers. This technique is widely used in the 5G system to increase the number of channels per fiber optic [1], [5].

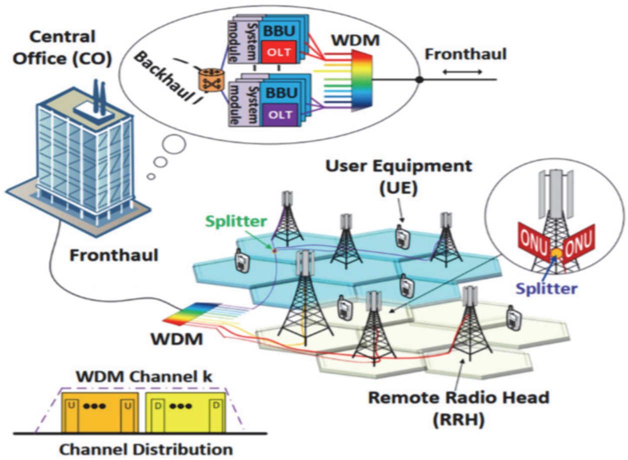

Fig. 1. High capacities DWDM for optical network based front-haul technology

In this paper, a proposed structure system introduces the performance of an optical network based on the DWDM multiplexing to transmit 1600 Gbits/s over 16 channels with different frequencies. Dual Polarization-M-Quadrature Amplitude Modulation (DP-M-QAM) modulation levels are evaluated, improved, and simulated using the Optisystem tool

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from Optiwave; the coherent receivers consist of a Digital Signal Processing (DSP) for detecting signals.
The rest of the paper is structured as follows, section 2 presents studies dealing with coherent optical networks using DP-M-QAM and DWDM techniques; section 3 describes the schematic design setup of the DP-M-QAM simulation transmission over the DWDM technique. Section 4 gives simulation results and describes the effectiveness of the proposed system and finally the conclusion discussed in Section 5.

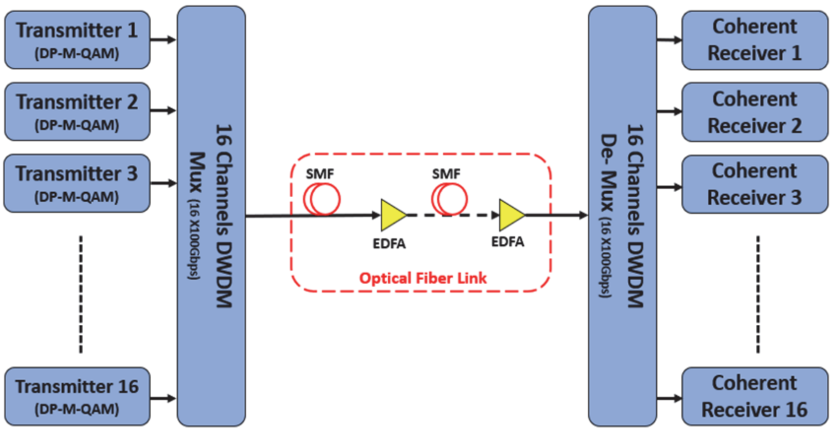
II. Related Works and Contributions

Recently, some research studies support the excessive use of data in wireless networks such as DP-M-QAM technology over optical fiber with coherent detection and DSP at the receiver for an extraordinary performance of transmission for the wireless networks. M-QAM shows an efficient modulation system and high data rate transmission over long distances of Single Mode Fiber (SMF) [6]. The coherent optical transmission is widely employed in long-haul optical fiber communications systems and is compatible with advanced modulation techniques as well as has better spectral efficiency; it is also suitable against linear and non-linear influences [7]. The DP-M-QAM modulation format achieves a large bandwidth and broadband communications, by transmitting more bits per symbol with high-capacity transmission. This is a very efficient method, using the orthogonal polarization feature doubles the spectral efficiency compared to modulating single polarization [8, 9]. But these systems only provide transmission over one channel at a low data rate.

Currently, multi-level modulation formats based on coherent technologies are integrated into WDM, this system with a DSP receiver is proposed in order to support high data rate and overall bandwidth demand, WDM-DSP provides mitigation of interference of inter-channel by detecting single wavelength [10, 11]. The high capacity of a data rate system operating with DP optical transmission is obstructed by CD and PMD. These scatterings are reduced using filters, while static filters applied to reduce CD and equalizers often lower PMD [12]. The auteurs in [13] Demonstrate WDM based Dual Polarization Quadrature Phase Shift Keying (DP-QPSK) transmission with a passive optical network up to 100 Gbits/s and 50 GHz channel spacing over 80 km for the 5G network. Furthermore, the data rate in the 5G MFH MBH can be up to 1.6 Tb/s for a BBU transmission for optical link terminal and Optical Network Units (ONUs). High transmission performance based on DP-M-QAM and DWDM modulation levels using long optical transmissions has not been suggested in previous and similar systems.

III. Design Schematic DWDM Transmission with DP-M-QAM Modulation Levels

The development provides the transmitter by converting the DP-M-QAM signal to the optical signal with an optical modulator for each channel; M is the number of QAM levels per symbol. With using a DWDM multiplexer, 16 optical signals are combined and injected into the SMF. In this step, the optical link uses Erbium-Doped Fiber Amplifiers (EDFA) to amplify the optical signal through the transmission path to compensate for the attenuation and the nonlinearities of the SMF [14]. At the end of the optical transmission, the DWDM de-multiplexer separates the signals for each receiver by a Gaussian optical filter. The DSP and decision subsystems detect the transmitted codes. Fig. 2 shows the proposed DWDM transceiver system consisting of the DP-M-QAM technique and DSP processing.



(a)

(b)

Fig. 2. Block diagram representing (a) the DWDM transceiver system with a DP-M-QAM, (b) a single channel of reception and detection

On the transmission side, the system generates DP-M-QAM signals at 100 Gbits/s that are produced by the Pseudo Random Bit Sequence Generator (PRBS). The serial data is transformed into two branches towards the M-QAM modulator. The injection of the In-phase and Quadrature components of the M-QAM signal into Mach Zehnder Modulators (MZM) converts the informational signal into a high-frequency optical signal. The Continues Wave (CW) laser is responsible for generating the optical source applied to the MZM, the connection between a Polarization Beam Splitter (PBS) and one CW laser can provide an optical source for MZM modulators. After that, the Polarization Beam Combiner (PBC) combines modulated polarizations to form a DP signal. Figure 3 shows the design of the DP-M-QAM optical signal generator. The different parametrs of the simulated system for the DP-M-QAM transmitter and optical link are listed in Table I.

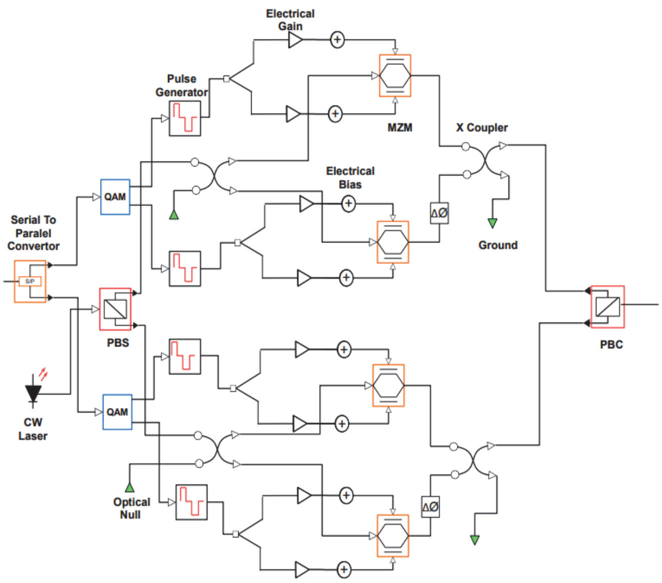


Fig. 3. DP-M-QAM optical generator

Fig. 4 shows the DP-M-QAM coherent receiver structure with a DSP module, the DP coherent photocurrents block detects the polarized electrical signal using PIN photodetectors. Then the DSP circuit restores the information signal through several important algorithms stages The first-stage Bessel filter is used to filter out-of-phase noise, and the Quadrature Imbalance (QI) compensation is performed to mitigate amplitude and phase imbalances of the signals. The CD compensation algorithm is implemented in the DSP to compensate the chromatic dispersion resulting from fiber optic transmission. In the next stage, the Adaptive Equalizer (AE) function is present in the system to reduce inter-symbol interference and the linear effects such as the CD and the PMD. The Frequency Offset Estimation (FOE) algorithm provides an efficient solution to the frequency and phase shift provided by the combination between the local oscillator and the carrier receiver. The last stage of the DSP allows the Carrier Phase Estimation (CPE) algorithm to estimate the phase of the optical carriers. Table II defines the parameters for the coherent receiver. After the signal processing is complete, the decision component normalizes the amplitude of the I and Q electrical signal to the respective symbol of the M-QAM level.

TABLE 1

PARAMETERS USED IN THE TRANSMISSION

Parameters	Values
CW Laser power	10 dBm
The frequency of the first channel	193.1 THz
Linewidth	0.1 MHz
Phase shift	90°
Sequence length	65536
Single Mode Fiber length	80 km
Fiber attenuation	0.2 dB/km
Dispersion	16.75 ps/nm/km
Dispersion Slope	0.075 ps/nm^2/km
Effective area	80 um^2
EDFA gain	20 dB
Amplifier noise	4dB

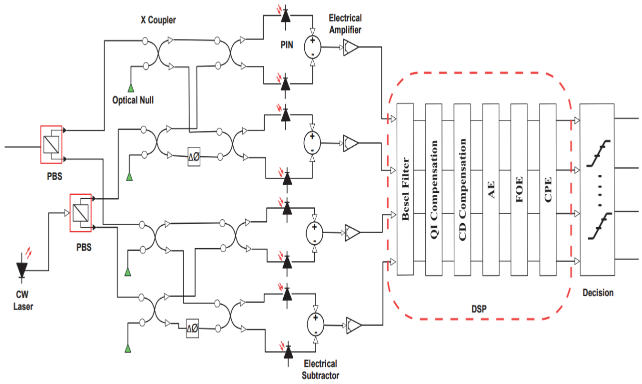


Fig. 4. DP-M-QAM coherent detection design with DSP processing

TABLE 2

PARAMETERS USED FOR RECEIVING

Parameters	Values
Gaussian optical filter Bandwidth	50 GHz
PIN responsivity	1 A/W
PIN dark current	10 nA
Insertion loss	0 dB
Filter order	3
Polarization type	Dual
Dispersion compensation reference wavelength	193.1 THz
Modulation format	16QAM, 32QAM, 64QAM and 128QAM

In this specific transmission, we have planned 16 subsystems composed of DP-M-QAM optical generator component and on the other side 16 subsystems composed of DP-M-QAM coherent detection design with DSP processing. Fig. 5 shows the Schematic simulation performed with the Optisystem of the system.

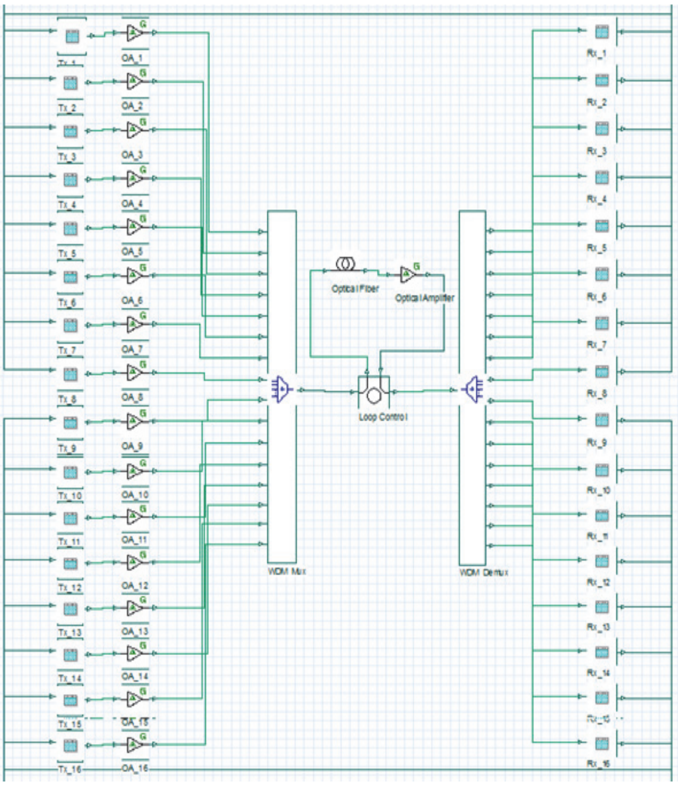


Fig. 5. Schematic simulation of the proposed system

IV. Simulation Results

The performance of coherent DWDM with DP-M-QAM modulation levels and DSP processing is presented and summarized in this section. The analysis of the simulation has been measured at the receivers; the proposed system aims to improve the Bit Error Rate (BER) and Error Vector Magnitude (EVM) results with several variations such as the channel spacing, the optical fiber length, the Optical Signal-to-Noise Ratio (OSNR) and the modulation level. The OSNR is the measure of the ratio of signal power to noise power in an optical channel, also the EVM Calculates the difference between the received signal and the reference signal. The OSNR (dB) equation of the optical system given by Eq. (1), the EVM (%) and BER are calculated at signal resolution with Eqs. (2) and (4).

$$OSNR = 10\log(Ps/Pn) \tag{1}$$

The *OSNR* (in dB) is defined as the ratio of the signal power to the noise power, where *Ps* is the signal power, and *Pn* is the noise power.

$$EVM\ (\%) = \frac{\sqrt{Sm^2}}{|Sd|^2} \times 100 \tag{2}$$

In an optical communication system, *EVM* is a measure of the quality of a digital communication signal and represents the difference between the ideal signal and the received signal. It can be affected by a variety of factors, including noise, distortion and non-linearities, where *Sm* is the mean value of the symbol sequence and *Sd* is the decision of the symbol.

$$Sm = \overline{|S - Sd|} \tag{3}$$

S is the sequence of the symbol, $\overline{(.....)}$ indicating the mean value.

$$BER = \frac{Errors}{Ls - 2 \times Gb} \tag{4}$$

Here *Ls* is the sequence length, and *Gb* is the guard bits.

The system investigates the BER in proportion to OSNR after 80 km is shown in Fig. 6. The results are obtained by changing 50 GHz, 75 GHz and 100 GHz of the spacing between the transmitted channels and the operating OSNR is 11 to 18 dB, the optical frequencies used in the system are tabulated in Table III. This performance also made it possible to calculate the EVM change with the OSNR variation that appears in Fig. 7. The obtained results determine the performance of DWDM transmission over optical fiber. The BER and EVM values decrease while raising OSNR in optical signals. This is due to the strength of the received optical signal and the weak effect of noises, which did not have a significant effect on the transmission. Besides, the higher spacing between channels increases system performance of the dense optical communication as shown in Fig. 6, this leads to an increase in the effect of signals overlapping in the transmission. The simulation performance with channel spacing as low as 50 GHz showed an acceptable rating for controlling scattering and inter-symbol interference effects.

TABLE 3

Optical frequency signals per channel with variable frequency spacing

Frequency Spacing	Ch 1 (Thz)	Ch 2 (Thz)	Ch 3 (Thz)	Ch 4 (Thz)	Ch 5 (Thz)	Ch 6 (Thz)	Ch7 (Thz)	Ch8 (Thz)	Ch9 (Thz)	Ch10 (Thz)	Ch11 (Thz)	Ch12 (Thz)	Ch13 (Thz)	Ch14 (Thz)	Ch15 (Thz)	Ch16 (Thz)
50 GHz	193,1	193,15	193,2	193,25	193,3	193,35	193,4	193,45	193,5	193,55	193,6	193,65	193,7	193,75	193,8	193,85
75 GHz	193,1	193,175	193,25	193,325	193,4	193,475	193,55	193,625	193,7	193,775	193,85	193,925	194	194,075	194,15	194,225
100 GHz	193,1	193,2	193,3	193,4	193,5	193,6	193,7	193,8	193,9	194	194,1	194,2	194,3	194,4	194,5	194,6

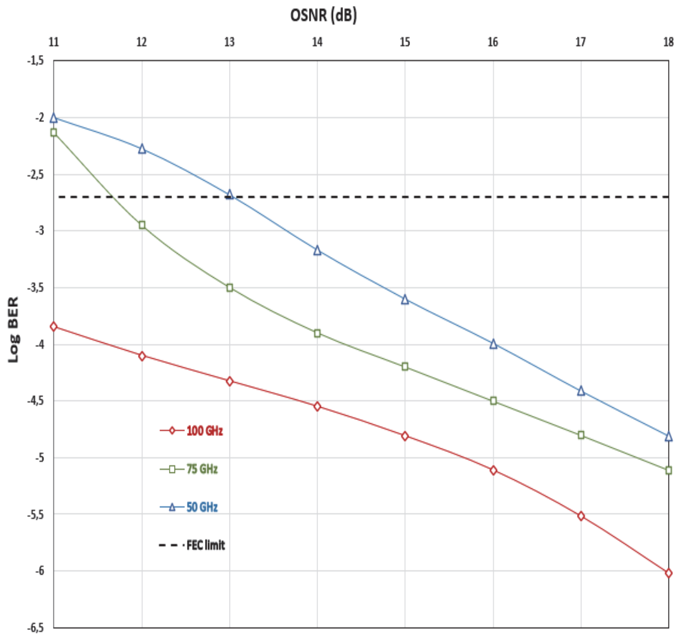


Fig. 6. Log (BER) vs OSNR

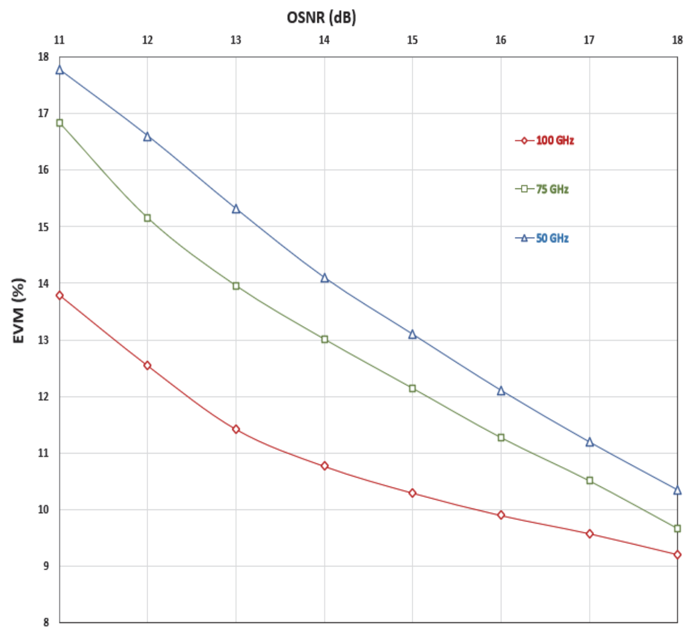


Fig. 7. EVM (%) vs OSNR

Fig. 8 shows the Log (BER) results with elevating the optical fiber length up to 320 km, and Fig. 9 reveals the performance of the EVM (%) as the transmission distance increases. This investigation compares the performance of modulation levels for DP-16QAM, DP-32QAM, DP-64QAM and DP-128QAM, the system produces 16, 32, 64 and 128 constellations respectively. The transmission system operates at 18 dB OSNR and 100 GHz channel spacing.

As observed in Figs. 8 and 9, both BER and EVM deteriorate with increasing transmission distance for each modulation level; this means that the system supports lower modulation levels such as the DP-16QAM. Increases in link length are also reflected in communication performance due to CD, PMD, SPM, and OSNR degradation. Furthermore, the noise reduces the optical transmission efficiency in the higher modulation order of the QAM signal because of the increased number of constellation points. In our system, the DSP block consists of recovery stages with different treatments such as CD compensation, adaptive equalizer, FOE and CPE used to compensate for signal attenuation during propagation. Moreover, in both linear and nonlinear effects, it is observed that for a higher value of OSNR, the transmission has good performance for EVM and BER. The performance comparison of the results confirms that high-efficiency outputs are obtained with the DP-16QAM modulation level and DSP. The acceptable transmission distance has reached 300 km with this technique when compared to the FEC limit (2×10^{-3}).

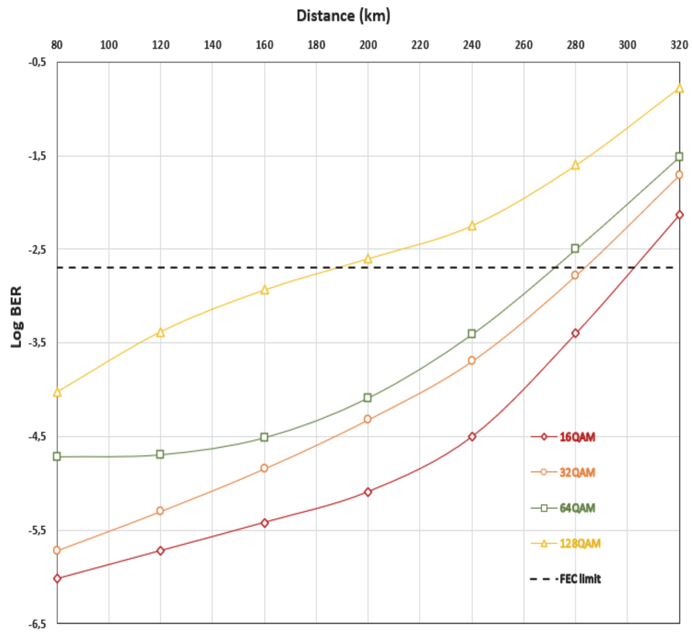


Fig. 8. LOG (BER) vs optical fiber length

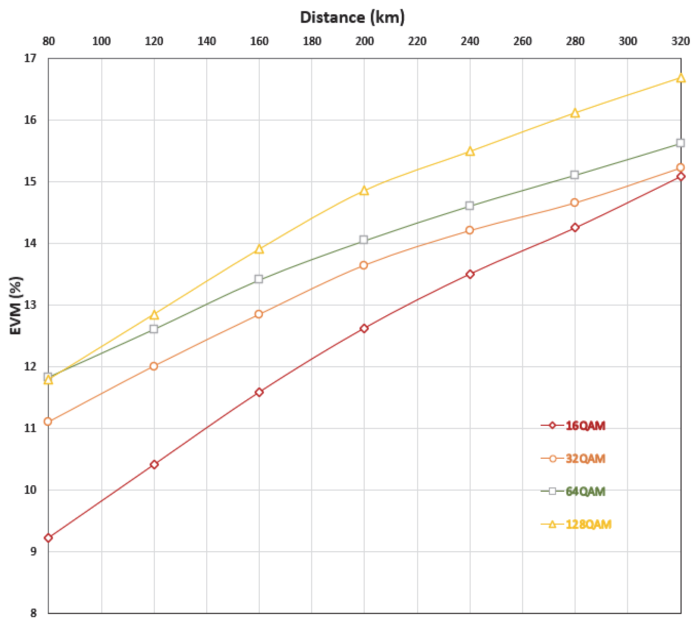


Fig. 9. EVM (%) vs optical fiber length

The efficiency of the system is also confirmed by the constellation diagram; Figure 10 shows the constellation diagram obtained at different DP-M-QAM levels after the DSP section. Table IV presents the importance of the coherent system using DP and DWDM techniques with high capacity transmission compared to previous works. It should be noted that the DP-M-QAM modulation signal level is implemented in the system with 16, 32, 64 and 128 constellations based on DWDM multiplexing compared to other systems [6], [10], [11], [13] and [15], and another significance appears in the transmission capacity compared to which are up to 16 channels with a data rate of 100 Gbits/s for a distance of up to 300 km, where other multi-channel systems achieved the highest distance of 240 km by 8 transmitters. This work achieved great effectiveness better than similar systems in terms of minimum BER of -6.0205 especially using DP-16QAM.

The simulation results also show the effect of increasing modulation levels on BER and EVM measured in the system used with variable frequency spacing and fiber length so that attenuation, the linear and nonlinear impairments of the optical fiber have disabling effects, especially with the convergence the constellations points. This paper identifies a DP-M-QAM based on DWDM system as a potential candidate for optical transmission with attenuation problems and optical fiber effects such as XPM, SPM, FWM and CD in the optical network. Several studies have proven the reliability of this system by transmitting large amounts of data over long distances of optical fiber experimentally [16-18]. It is important to mention that there may be limitations for the realization of the system in practice, due to the influence of environmental factors such as fiber splicing, fiber curvature, and temperature. However, the system has the potential to be a viable solution for high-speed data transmission over optical networks.

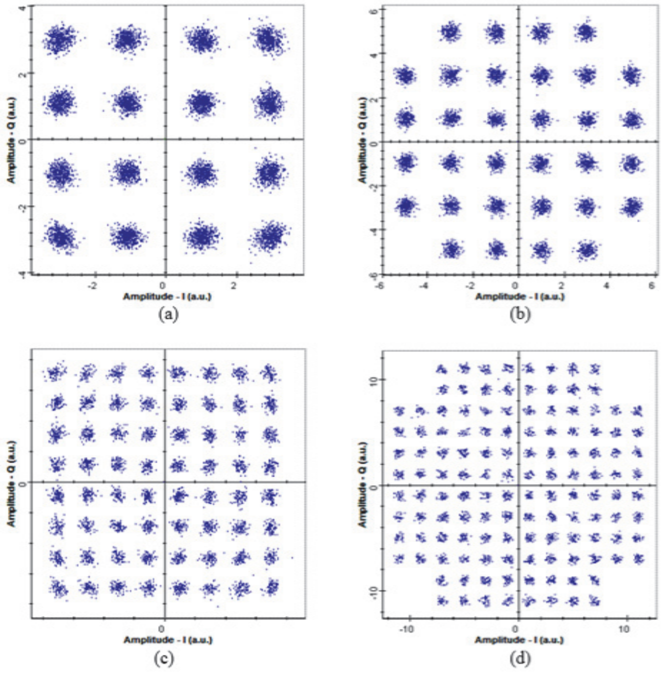


Fig. 10. Constellations diagrams of DP-QAM Levels:
(a) DP-16QAM, (b) DP-32QAM, (c) DP-64QAM, (d) DP-128QAM

TABLE 4
COMPARISON TABLE OF OUR WORK WITH PREVIOUS WORKS

Factors	Ref. No. [15]	Ref. No. [6]	Ref. No. [11]	Ref. No. [13]	Ref. No. [10]	Our work
Technology	Coherent Optical System	Coherent Optical System	Coherent Optical System	Coherent Optical System	Coherent Optical System	Coherent Optical System
Bit rate (Gb/s)	120	100	100	100	112	100
Polarization Type	Dual Polarization	Dual Polarization	Dual Polarization	Dual Polarization	Dual Polarization	Dual Polarization
Modulation signal level	16-QAM	32-QAM, 64-QAM, 128-QAM	QPSK	QPSK	16-QAM	16-QAM, 32-QAM, 64-QAM, 128-QAM
Number of channels	1	1	8	16	8	16
Link Distance (Km)	Up to 350	80	80	100	240	Up to 300
Launch power (dBm)	14	-20 to 5	2	-	-	10
Optical gain (dB)	6	16	16	-	-	20
OSNR (dB)	28	28	18	20	22	18
Log (BER)	-12.5	-4	-4.35	-4.2	-4.7	-6.0205

V. Conclusion

In this paper, a coherent DWDM transmission based on DP-M-QAM modulation levels has been designed and analysed. The proposed system transmits a data rate 1.6 Tb/s with 16 channels over long-haul optical fiber, at the receivers the model uses the DSP block in order to compensate for the optical interference and recover the data signals.

The system performance improves the BER and EVM results considered with distinct values of the frequency spacing between channels, the optical fiber length, the OSNR and the modulation level. The system discussion demonstrated optimal results for EVM (%) and minimal BER compared to the FEC limit. The system investigation asserts that our method can guarantee long-distance transmission up to 300 km using optical fiber. The proposed system gives a promising solution for application in future optical wireless networks.

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