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Performance and Distance Enhancement of 160 Gbps IsOWC System Using Polarization Division Multiplexed 256-QAM

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ABSTRACT

For communication in space, information transmission lines are critical for reaching the whole world. A long delay and a poor data transfer rate has been observed in radio frequency (RF) communication. Intersatellite communication has become more common in recent years and optical wireless communication (IsOWC) has advanced dramatically in recent years. Owing to its multiple advantages, including as large channel bandwidth, high-speed connectivity, and inexpensive cost, IsOWC technology is becoming popular among researchers. Uniphase modulations such as Non return to zero modulation does not have efficient spectrum for high speed inter-satellite communication. 256-Quadrature amplitude modulation (QAM) with polarization division multiplexing (PDM-256-QAM) at 160 Gbps over IsOWC channel is demonstrated in this work using matched filter and Digital signal processing (DSP). Proposed system is investigated for PDM-256-QAM at 1550 nm wavelength and results analyzed in terms of Q factor, log symbol error rate (SER) and Error vector magnitude (EVM). Results reveal that 160 Gbps data is successfully transported over a distance of 22,000 kilometres with a bit error rate (BER) that is acceptable.

Keywords - QAM, IsOWC, DSP, Matched filter, BER

1. INTRODUCTION

In 1962, laser technology was initially created for use in space communication. Scientists, commercial organisations, colleges, and government agencies have made significant technological advances in space communication during the previous five decades [1]. For delivering high-speed data between two satellites, optical communication with the incorporation of laser technology has considered as an appealing and realistic option [2]. The European Space Agency (ESA) established a 50 Mbps IsOWC transmission between two satellite such as ARTEMIS and SPOT-4 satellites [3]. When compared to traditional microwave links, IsOWC links have several advantages, including increased bandwidth due to (i) low mass and power requirements, (ii) high-frequency carrier signals, (iii) unregulated spectrum, (iv) high directivity, (v) electromagnetic interference absence, and (vi) transmission links with improved data security [4] [5]. However, extrinsic variables such as satellite vibrations, Doppler shift, noises in the background, and misalignment errors, affect IsOWC performance. The IsOWC link's most significant difficulty, however, is misalignment of angle between satellites and introduce errors due to space turbulence [6]. There are two major factors of pointing error loss: (i) Optoelectronic devices introduce noises and initiate tracking error, (ii) disturbances in the mechanical operations of satellites [7]. For getting better pointing error free link, several factors needs to be considered such as uplink beacon, sensors, and celestial reference can all help with pointing accuracy in IsOWC networks. Performance of IsOWC depends upon diverse parameters such as wavelength of operation, amplifier, diameter of satellite antennas, additional losses due to weather or turbulences, pointing errors, and modulation etc. Different modulations in IsOWC at 10, 20, 40 Gbps, such as compressed spectrum return to zero (CSRZ), duo-binary RZ (DRZ), and modified DRZ (MDRZ), were shown in [8] for 1250 km, and MDRZ was suggested for greater bit rates. Author in [9] investigated the impact of pointing errors across 1000 kilometres using a capacity of 6*20 Gbps and a wavelength division multiplexing (WDM) polarisation interleaved (PI) technology. Emergence of polarization interference is more in case of multiple channels and PI technique suppress the polarization interference among adjacent WDM channels.

When compared to the single WDM system in IsOWS, WDM-PI suppressed polarisation crosstalk better. An optical wireless system with MDRZ and polarization interleaving was investigated in [10] having 50 GHz channel spacing. Orthogonal frequency division multiplexing (OFDM) was investigated over IsOWS at

10 Gbps using differential phase shift keying (DPSK) instead of QAM and outcomes revealed that DPSK increased distance to 20,000 km [11]. Previous modulation formats have a maximum data transmission of 40 Gbps per channel. Higher order modulations are needed to meet the growing demand for spectrum efficiency. Author in [12] exhibited a comparison of single polarised PDM-QAM and 16-QAM at 120 Gbps, with the findings revealing that PDM outperforms single polarised 16-QAM due to higher spectrum efficiency. In [13], the author demonstrated a 20,000 long IsOWC link with the deployment of PDM-16-QAM at 160 Gbps data speed and exhibited the log BER of -2.42. The goals of this study are to: (1) investigate the effects of various parameters on the quality of information signals; (2) performance enhancement by DSP and (3) higher order modulation (more bits per symbol) techniques to enhance the system's bandwidth utilization and spectrum efficiency.

In this work, an IsOWC system with the integration of PDM-256-QAM is demonstrated and to remove the various performance degrading effects, DSP and matched filter are also employed. A single channel at 160 Gbps over link length of 22,000 km is investigated.

Next sections of the paper includes: Section 2 covers the principle of QAM modulation, Section 3 consists of system setup information and is followed by results and discussions in Section 4. Conclusion and future scope is covered in Section 5.

2. PRINCIPLE OF QAM MODULATION

A spectrum efficient multilevel modulation for IsOWC are playing important role because of high performance and enables long distance transmission. Out of multifarious multilevel modulations, QAM modulation is competent to provide better performance in IsOWC systems. QAM is a capacity doubling technique with two amplitude modulated (AM) data streams. Spectral efficiency of QAM is improved by taking amplitude as well as phase of the signal into consideration. Quadrature in QAM basically means the difference of phase in two identical frequencies by 900. Real and imaginary are the two types of signals and denoted by I and Q respectively. Sine and cosine waves are technical representation of I and Q components. Prior to the transmission in the communication medium, both I and Q are combined in QAM modulation. At the receiver, both I and Q components are separated to obtain data from each of them. The information is subsequently included into the modulating data itself. The fundamental benefit of QAM variants is that they make the most efficient use of available bandwidth. Because QAM contains more bits per carrier, this is the case. For example, 256-QAM maps eight bits per carrier, whereas 16-QAM maps four bits per carrier. QAM is available in different variants such as 4-QAM, 8-QAM, 16-QAM, 32-QAM, 64-QAM, 128-QAM, and 256-QAM. It is evident that with the increase in the bits per symbol, spectrum becomes more and more spectral efficient. Therefore, higher QAMs such as 256-QAM is always better than the lower variants of QAM. Bits per symbol are eight in the 256-QAM and 256 unique are formed in this case. Performance, capacity and high data rates are advantages in higher level QAMs.

3. SYSTEM SETUP

Optisystem is considered for the implementation of the proposed work, and a system diagram is shown in Fig.1 (a). Proposed system employs a single channel PDM-256-QAM modulation with the integration of DSP and matched filter. Fig.1. (b) shows the internal architecture of PDM-256-QAM which includes a binary data generator that generates a 160 Gbps serial bit stream, as well as a serial to parallel converter and QAM modulators X and Y. The laser signal is split into two halves and sent to the QAM X and Y modulators. Both polarization X and Y are combined by using polarization combiner.

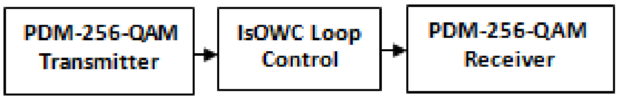


Figure 1. (a) Proposed PDM-256-QAM system diagram

As illustrated in Fig. 1(c), combined signals are conveyed from the satellite to the IsOWC channel, which consists of amplifiers, the IsOWC channel, and signals received by satellite.

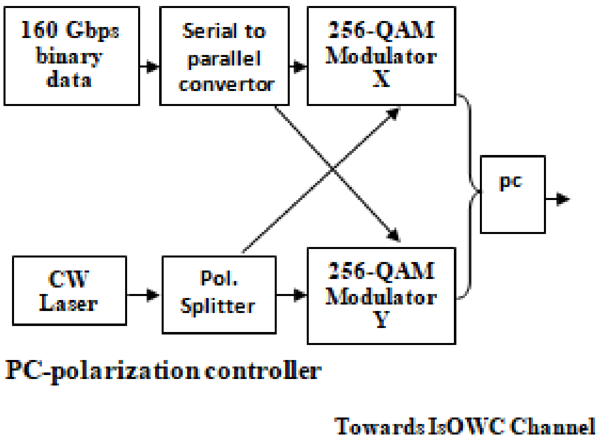


Figure 1. (b) Representation of internal structure of PDM-256-QAM

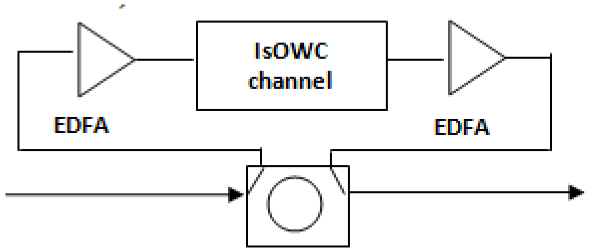


Figure.1. (c) Loop Control of IsOWC channel

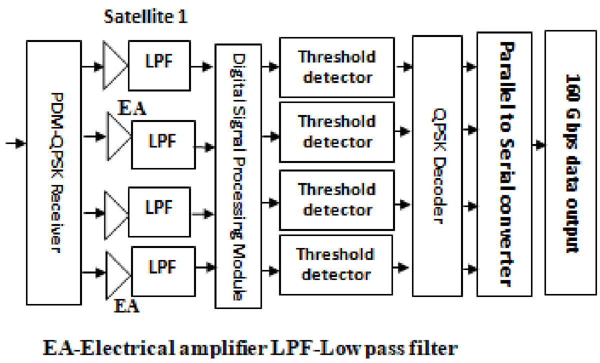


Figure 1.(d) Internal structure of PDM-256-QAM Receiver

Table.1. System simulation parameters

Parameter	Values
Data rate	160 Gbps
Operating wavelength	1550 nm
Modulation	PDM-256-QAM
IsOWC distance	1000 km – 22,000 km
CW Laser Power	30 dBm
Photodetector	PIN
PIN thermal noise spectral density	1 e-022 W/Hz
Photodiode responsivity	1 A/W
Additional loss (synchronization losses, background noise, pointing loss, etc.)	5 dB
Optical amplifier gain and noise figure	20 dB and 4 dB
Pointing error angle	1.1 rad
Local oscillator power	11 dBm
Transmitter and Receiver aperture diameter	150 mm

After loop control, signals are communicated towards matched filter for removing the unauthorized spectrums. Coherent receiver for the decoding of QAM signals are placed in the receiver and this is accomplished with local oscillator. Local oscillator and received signals are passed through polarization splitter. Photodetectors PIN for photons to electrons conversion, balanced detection, and local oscillator synchronisation are utilised in the receiver's internal architecture. In converted electrical signals, noise such as shot and quantum develops, and noise rectification is accomplished by running the signal through Low pass filters (Bessel Filter). As illustrated in Fig.1. (d), digital signal processing (DSP) performs further carrier phase estimation, frequency offset estimation, dispersion correction, nonlinear compensation, equalisation, and normalising, followed by threshold detection, QPSK decoders, and BER test set. Table 1 shows the simulation parameters for the proposed task.

4. RESULTS AND DISCUSSIONS

The suggested IsOWC system with PDM-256-QAM is explored and analysed in this part with the help of widely used optical design suite Optiwave's Optisystem. Parameters and components considered in demonstrated work are near to actual systems in the real-world. From Fig. 2, it is clearly observed that PDM-256-QAM has narrow optical carrier spectrum.

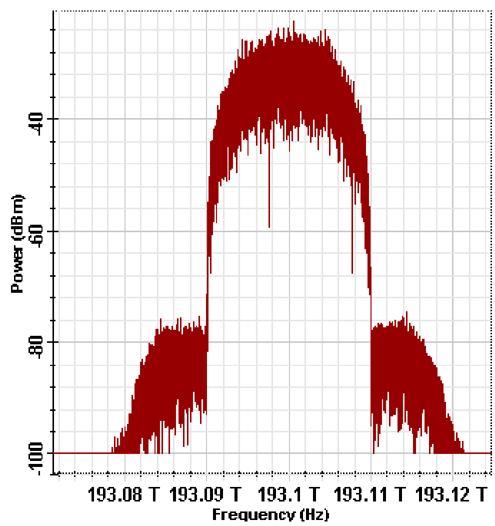


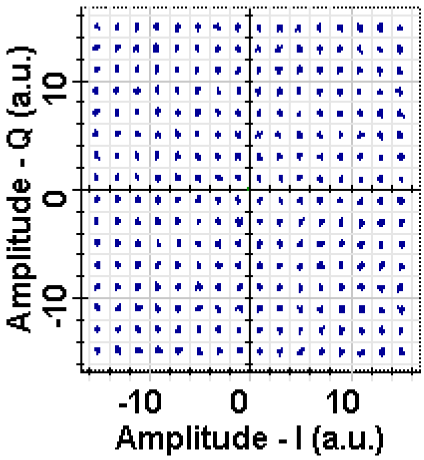
Figure 2. Optical carrier spectrum of PDM-256-QAM

Performance of PDM-16-QAM and PDM-256-QAM are analyzed in terms of log BER at varied distances from 1000 km to 25000 km as depicted in Table 2. Results indicate that proposed PDM-256-QAM provide minimum bit errors as compared to PDM-16-QAM modulations in IsOWC systems. Reason behind the best performance of PDM-256-QAM system is ultra-narrow spectrum due to higher no. of bits per symbol. It is also observed that due to increase in attenuation, dispersion and nonlinear effects with distance increase, log BER also increases.

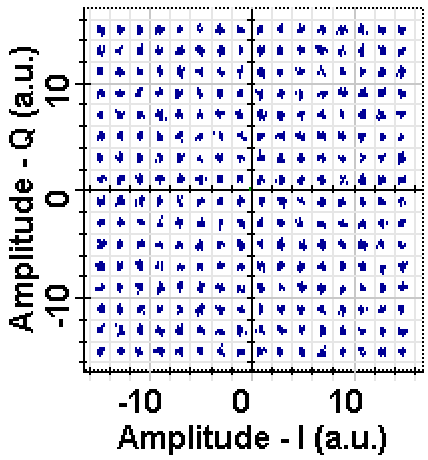
Table.2. Comparison of PDM-16-QAM and PDM-256-QAM at 1550 nm

IsOWC Distance (km)	PDM-16-QAM	PDM-256-QAM
2000	0	0
6000	0	0
10000	-4.51	0
14000	-3.28	-4.21
18000	-3.05	-4.01
22000	-0.47	-3.43

Fig.3. (a) represents the constellation diagram of proposed PDM-256-QAM at 2,000 km link distance between two satellites for polarization X. Constellation diagrams depicts the symbols i.e. 256 in this case and also represents the amplitude as well as phase of the symbols.



(a)



(b)

Figure 3. Constellation diagram of PDM-256-QAM for Polarization X (a) at 2000 km (b) 22,000 km

Deviation of symbols from their ideal positions causes EVM increase in the received signals. As shown in Fig.3. (b), it is evident that all the symbols in the polarization X are in their respective quadrants but more scattered symbols are observed at 22,000 km distance as compared to 2000 km. Further Fig.3. (c) (d) shows log symbol error rate, Q factor, EVM on polarization X receiver for 2000 km and 22,000 km respectively and it is clear that Q factor at 2,000 km is 8.32 and 22,000 km is 5.23 and within acceptable limits (3) recognized by international telecommunication union. Also EVM% is 5.5% at this instant for polarization X.

Name	Value
log of Estimated Symbol Error at	-16.10334318455479
Estimated Symbol Error at User	78.82369974021312e-018
Q Factor from Estimated Symbol	8.32956596490501
Error Vector Magnitude at User	0.03017424626516806

(a)

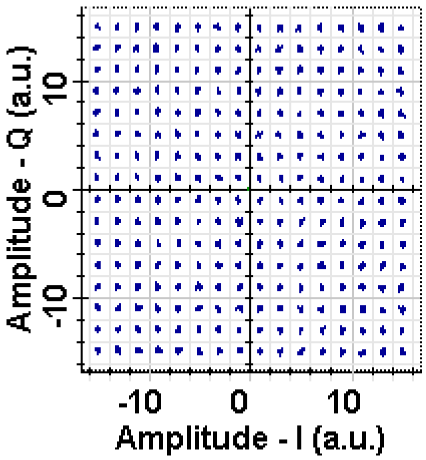
Name	Value
log of Estimated Symbol Error at	-6.793372233125109
Estimated Symbol Error at User	0.1609265744744368e-006
Q Factor from Estimated Symbol	5.239426467043876
Error Vector Magnitude at User	0.05588487713324452

(b)

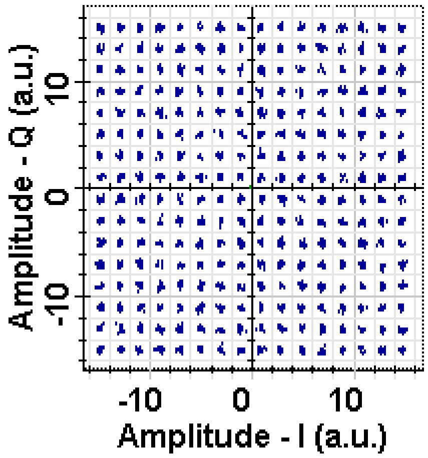
Figure 3. Different results observed at constellation analyser for Polarization X in PDM-256-QAM (c) at 2000 km (d) 22,000 km

Figure 4 (a) depicts the potential PDM-256-QAM constellation with a 2,000 km communication distance between two satellites for polarisation Y. Deviation of symbols from their ideal positions causes EVM increase in the received signals. As shown in Fig.4. (b), it is evident that all the symbols in the polarization Y are in their respective quadrants but more scattered symbols are observed at 22,000 km distance as compared to 2000 km. Further Fig.4. (c) (d) shows log symbol error rate, Q factor, EVM on polarization X receiver for 2000 km and 22,000 km respectively and it is clear that Q factor at 2,000 km is 8.05 and 22,000 km is 4.05 and within acceptable limits (3) recognized by international telecommunication union. Also EVM% is 4.9% at this instant for polarization Y.

Fig.5. represents the BER test set results at 22,000 km and it is clear that log BER is -3.56 and is under acceptable level i.e. -2.42.



(a)



(b)

Figure 4. Constellation diagram of PDM-256-QAM for Polarization Y (a) 2000 km (b) 22,000 km

Name	Value
log of Estimated Symbol Error at	-15.12134444104967
Estimated Symbol Error at User	0.7562328851659691e-015
Q Factor from Estimated Symbol	8.053352378504014
Error Vector Magnitude at User	0.0274138356193099

(a)

Name	Value
log of Estimated Symbol Error at	-4.304922188701459
Estimated Symbol Error at User	49.55389671492146e-006
Q Factor from Estimated Symbol	4.056887050264616
Error Vector Magnitude at User	0.04956129603603809

(b)

Figure 4. Different results observed at constellation analyser for Polarization Y in PDM-256-QAM at (c) at 2000 km (d) 22,000 km

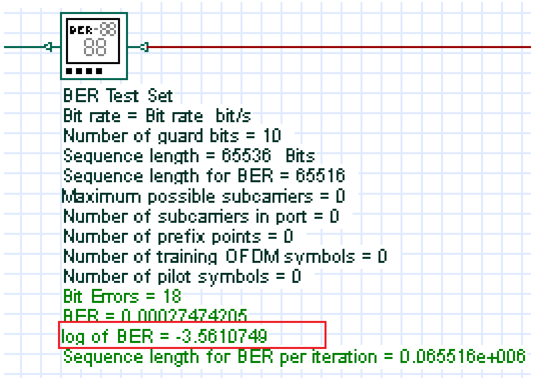


Figure 5. Log BER at 22,000 km distance on BER test set

5. CONCLUSION

We described the modelling and simulation of PDM-256-QAM based single channel high speed IsOWC transmission system with the incorporation of matched filter and DSP. The results reveal that 160 Gbps data transfer over a 22,000 km connection distance is possible with a reliable BER. In addition, the performance of PDM-16-QAM and PDM-256-QAM is evaluated in terms of log BER for distances ranging from 1000 to 25000 kilometres. In IsOWC systems, the suggested PDM-256-QAM modulation provides the lowest bit errors when compared to PDM-16-QAM modulations. The PDM-256-QAM system's highest performance is due to its extremely narrow spectrum and larger number of bits per symbol. In near future, mode division multiplexing can be combined with the PDM-256-QAM to get ultra high speed and in WDM-IsOWC systems.

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