DOI: 10.21917/ijct.2022.0413

DEVELOPMENT AND ANALYSIS OF HIGH-SPEED SINGLE-CHANNEL ISOWC TRANSMISSION LINK USING A SPECTRALLY EFFICIENT HIGHER-ORDER MODULATION FORMAT

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Abstract

Studies have used IsOWC interconnections as a practical way to trans receive signals in between satellites using carrier as optical signal and propagation medium as a space. Information can be safely transported across the globe via IsOWC connections. The current work describes a polarisation division multiplexed quadrature phase shift keying (PDM-QPSK) based highest speed and longest reach IsOWC system using a single channel. To increase receiver sensitivity, at receiver terminal coherent detection is installed and DSP module has been implemented to reduce losses caused by abductant atmospheric effects and to forecast the phase (carrier). We have evaluated necessary OSNR (optical signal to noise ratio) to obtain the appropriate BER (bit error rate) to evaluate the output of suggested link (BER). According to the results, a reliable 112 Gbit/s transmission with a good BER is possible at 22,500 km. Additionally, we quantitatively examine how connections with rising pointing faults perform in terms of OSNR. Additionally, a comparison of the suggested link with the body of current literature points to a better system towards (maximum data with maximum range) and spectrum efficiency (maximum data with maximum range). Coherent detection, DSP, and PDM-QPSK provide a strong foundation for creating spectrally effective IsOWC connections.

Keywords:

Polarization division multiplexing (PDM), Quadrature phase shift keying (QPSK), Inter-satellite optical wireless communication (IsOWC), Coherent detection and Digital signal processing (DSP)

1. INTRODUCTION

Free space optics, another name for optical wireless communication, is the transmission of data between two endpoints that are geographically apart [1-3]. IsOWC proved and is considered the most popular technique because of its many benefits over conventional microwave links [4–7]. A 50 Mbit/s data transmission between two satellites, SPOT-4 and ARTEMIS, was successfully executed as the first experimental IsOWC link [8]. Some of the variables that affect the performance of the IsOWC connection are power, errors, coding techniques and modulation formats. For practical IsOWC system, line-of-sight (LOS) connection must be established between transmitter and receptor devices is necessary. Any deviation from the intended LOS configuration may lower the received signal's quality and eventually cause the connection to fail. Pointing error angle loss is the name given to this.

The three main root causes of pointing problems have been identified as electronics devices synchronizations and their accuracy, vibrating devices, and interconnectivity oscillations [6]. According to the study in [9], which examines IsOWC system for ten gigabytes over approx. transreception range of 1200 kms using the frequencies 193.1 THz and 352.69 THz, the highest selected frequency is a superior selection for best executed performance. According to [10], increasing transmission power enhances the IsOWC connection's performance, while losses and error during transreception degrade system performance. [11] evaluates the execution of a 120 Gbit/s IsOWC connection using wavelength division multiplexing-polarization interleaving (WDM-PI) at transmission range of thousand km and an NRZ protocol.

The effectiveness of phase modulation-interferometric detection and intensity modulation-direct detection methods for an IsOWC connection are compared by Zhu et al. [12]. According to the results, the gain using radio frequencies and range using dynamic compression were boosted using the phase modulation-interferometric detection method. Low air turbulence ground to satellite OWC using differential amplitude pulse position modulation (DAPPM) was developed and tested, according to Gopal et al. [13]. After a numerical analysis of the suggested interconnection, BER performance was discovered that adding more levels of amplitude to the scheme of DAPPM changes connection's BER in circumstances for mild turbulence but degraded it in those of heavy turbulence. Separate research [14] compares alternative modulation methods for optical wireless communication lines between satellites and between satellites and the earth. While requiring more bandwidth, they discover that pulse position modulation works better than alternative modulation systems.

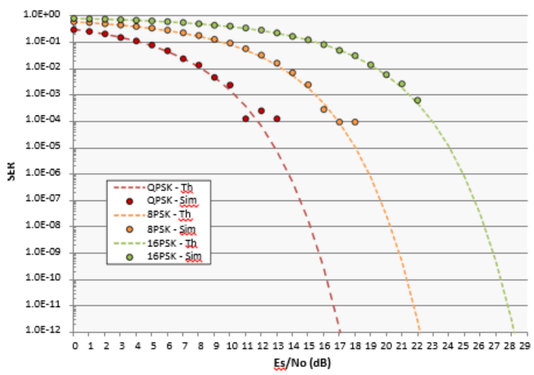


Fig.1. SER against $E_S=N_0$ charts in PSK M-ary system.

The results shown that the performance of the IsOWC connection increases with increase in execution cycle for RZDPSK format increased. Rashid et al. [17] in 2019 released an updated comparison of IsOWC connections with a data transmission rate of 0.5 Tbps and a maximum transmission reach of 20,000 km between differrnt orbit layers. Findings show that the used pulse generator and the modulation approach outperform all others. Viswanath et al. [18] show a Ground-to-Satellite interconnection in another paper [18], discussing the effects of various interferences on different modulation schemes. The findings show that performance decreases as system temperature rises, with on-off keying providing the best performance. A. Gupta et al. demonstrated how to build an IsOWC connection with the least amount of expense and complexity [19]. Authors in [20] suggested a dual channel WDM based IsOWC connection in 2019 using two different operating wavelengths of 1550 nm and 1551 nm. The system also includes an booster and amplifier as pre schematic to increase the link's maximum transmission range. By using RZ encoding and a 0 dBm laser input power across a 2200 km transmission distance, the authors claimed 20 Gbps data speed. Sharma et al. [22] investigated and validated a 100 Gbps IsOWC connection while accounting for route loss and pointing error loss. To improve connection performance, a 16-16 transmitter-receiver pair has been added to the suggested setup. The effectiveness of NRZ, AMI, and duobinary modulation approaches were also assessed by the authors.

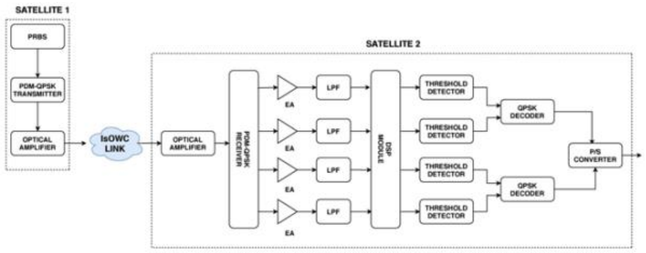


Fig.2. PDM-QPSK-IsOWC system block diagram

The authors in [23] examined the modelling and functionality of a IsOWC connection with 5.6 Gbit/s across a 6000 km transreception of signal with the use of binary phase shift keying (BPSK). [24] describes how to deliver 10 Gbit/s of data using DPSK technology across an IsOWC connection range of 6000 kilometres. In order to analyse a IsOWC connection across a 5000 km with 7.2 Gbit/s speed, [25] looks into the usage of optical subcarrier multiplexing (SCM). [26] describes research that optimises a ten Gbit/s IsOWC connection across a twenty thousand km link distance using DPSK and orthogonal frequency division multiplexing (OFDM). [27] shows the transmission of sixty-four, forty Gbit/s data across a 2500 km link range using an IsOWC connection based on WDM and the AMI technique. [28] describes the use of mode division multiplexing (MDM) and differential quadrature phase shift keying to send 64 40 Gbit/s of data across a 2500 km IsOWC connection range. [29] explains how to transmit 40 Gbit/s of data across an IsOWC connection range of 19,100 km using DPSK and Manchester coding. Coherent detection and hybrid polarisation division multiplexing (PDM) and OFDM technologies were used by the authors of [30] to create a 400 Gbit/s IsOWC link.

The results demonstrate that high-speed data were precisely sent at sixty thousand kilometres. Another research [31] demonstrated a PDM-based IsOWC connection using data capacity of 100 Gbit/s across a distance of 25,000 kilometres. The research in [32] discusses a system with reliable performance at 25,000 km that uses two-dimensional modulation techniques such hybrid differential quadrature phase shift keying-polarization phase shift keying.

Coherent optical networks may make use of data modulation methods that are becoming more and more common for use because they are bandwidth efficient. Improved methods like forward error correction (FEC) may also increase the resilience and reach of optical networks [33]. A 100 Gbit/s QPSK and PDM transmission with a twenty five GBd symbol rate is shown in [34].

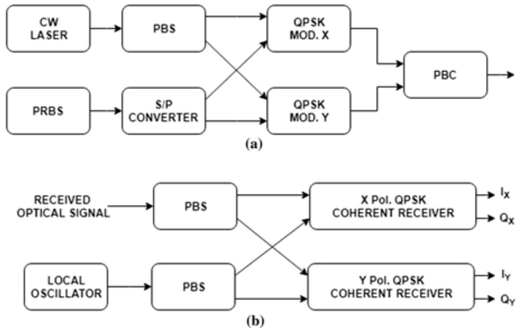


Fig.3. Block diagram of PDM-QPSK transreceiver

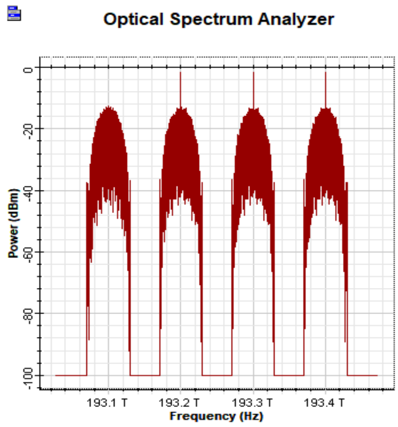


Fig.4. Transmitted Signal (112Gbit/s) Optical spectrum

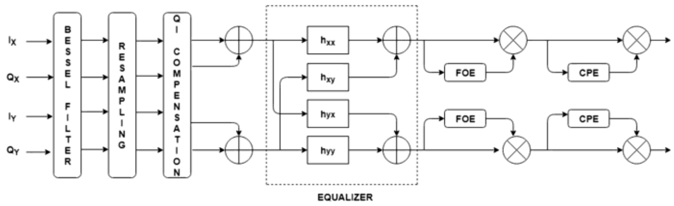


Fig.5. DSP module Schematic diagram

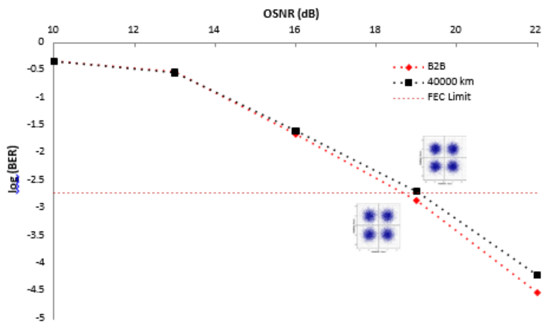
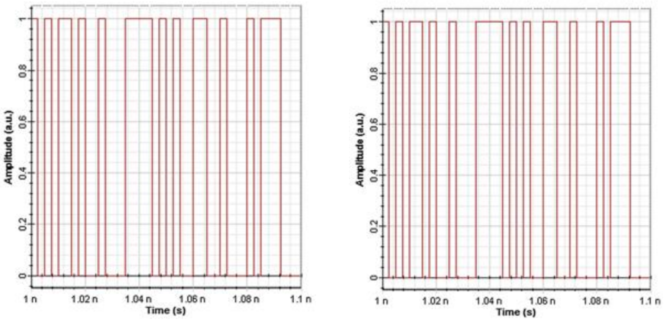


Fig.6. OSNR vs BER for 22,500 km range

In Section 3, the design of the system and parameters used in the simulation are detailed. Sections 4 and 5 then provide the results and draw a conclusion.



(a) (b)

Fig.7. Information signal (binary sequence at 22,500 km link distance) for (a) T_x section (b) R_x section

The current analysis proposes unique coherence observation and DSP at the receiver terminal based 112 Gbit/s PDM-QPSK based IsOWC connection for connection reach improvement. In order to improve performance, the goal of this work is to develop a single high speed IsOWC channel transreception connection using a methodically efficient highest-order modulation technique and DSP techniques on end terminal. Additionally, suggested connection's output results is statistically evaluated in terms of expanding transreception range and pointing errors. Next Section discusses the symbol error rate (SER) performance of M-ary PSK.

2. CONDUCT OF M-ARY'S PSK (SYMBOL ERROR RATE)

An important statistic that may be used to analyse the act of highest order modulation formats used as SER as a purpose of surrounded disturbances, which is represented by the notation E_S=N_0. Equation below may be used to calculate the error rate in symbol for M-ary PSK. [35]:

$$SER = \operatorname{erfc}\left(\sqrt{\frac{E_S}{2N_0}}\right)$$

In this study, we used the OptiSystem programme to evaluate SER against E_S=N_0 plots, as shown in Fig.1. It should be noted that the QPSK strategy performs effectively in this situation. Therefore, we implemented the QPSK strategy in our proposed system.

3. PDM-QPSK OUTLINE WITH SPECIFICATIONS

The outline of the PDM-QPSK IsOWC connection is sketched in Fig 2, and it has been modelled and tested in the OptiSystem test environment.

A PDM-QPSK transmitter transmits the 112 Gbit/s data that is produced by a pseudorandom bit sequence (PRBS) generator. The Fig.3(a) depicts the layout of the PDM-QPSK transmitter component. A continuous wave (CW) laser is utilised to generate a laser beam of thirty dBm. Polarisation rays divider, splits an ray into orthogonal (X) and (Y) polarizations (PBS). 112 Gbit/s data is divided into two clear cut streams by serial to parallel convertor, which are then modulated across a discrete orthogonal polarisation state by a QPSK modulator.

The orthogonally modulated signals are combined with the aid of a polarisation beam combiner (PBC). At the moment, 112 Gbit/s PDM-QPSK signals are generated, boosted, and sent into orbit. Fig 4 displays the optical spreading of signals that were sent.

The following is the IsOWC connection equation: [36]:

$$P_R = P_T \eta_T \eta_R \left(\frac{\lambda}{4\pi Z}\right)^2 G_T G_R L_T L_R$$

where P_R is the received optical power, G_R is the receiver antenna efficiency, and G_T is the transmitter antenna efficiency (0.8). P_T is the signal's optical power (30 dBm) at the transmitter terminal (0.8). While k is the operating wavelength, Z is the IsOWC transmission range (850 nm). The gain of the receiver optics is denoted by G_R, whereas the gain of the transmitter optics called as by G_T. The losses at the transmitter and reception terminals, denoted by L_T and L_R, respectively, are stated by Eq.(3) and Eq.(4).

$$L_T = \exp\left(-G_T \theta_{T^2}\right)$$

$$L_R = \exp\left(-G_R \theta_{R^2}\right)$$

where T and R stand for, respectively, transmitter/'s pointing errors and collector units (1.1 rad).

Received optical signal is amplified by an optical amplifier with a 12 dB gain before being processed using PDM-QPSK receiver. The PDM-QPSK receiver architecture is shown in Fig.3(b). The PBS divides the input signal (at the receiver side) into two orthogonally polarised beams. The IQ components of each polarisation beam are separated using a coherent receiver and an eleven DBm power local oscillator.

The individual IQ components of the orthogonally polarised beam are then directed into an electrical amplifier (EA) with a gain of twenty dB and a noise power with -100 dBm. A filter (Low Pass) is implemented before the proposed DSP block to take nonlinear losses into account with further determination of the carrier signal's phase. As a consequence of synchronisation problems and background noise radiations, an additional 5 dB of loss is projected. The Fig.5 depicts the DSP module's layout as well as all of the numerous activities.

The authors in [37] [38] examine the use of a DSP module at different stages in receiver blocks to reirrigate the I and Q components for observed data and to overcome different disturbances in order to construct quick and dependable optical connections. The stages listed below make up the recommended DSP module: The orthogonal signal's in-phase and quadrature components are passed to a Bessel filter, which integrates the cubic interpolation to resample the collected beams.

QI compensation and nonlinearity compensation are used to minimise the amplitude disturbances of signal and phase changes and symbol quadrate balancing after adaptive equalization. Then AE is used to demultiplex independent polarisation states. Frequency offset estimation (FOE) performs the adjustment of frequency discrepancies by uniting local oscillator with the transmitting laser. Using blind phase search (BPS) technique, the difference in phases between the transmitting laser and the local oscillator is finally erased.

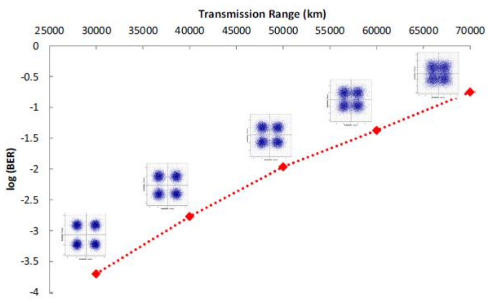


Fig.8. BER vs 22,550 km range

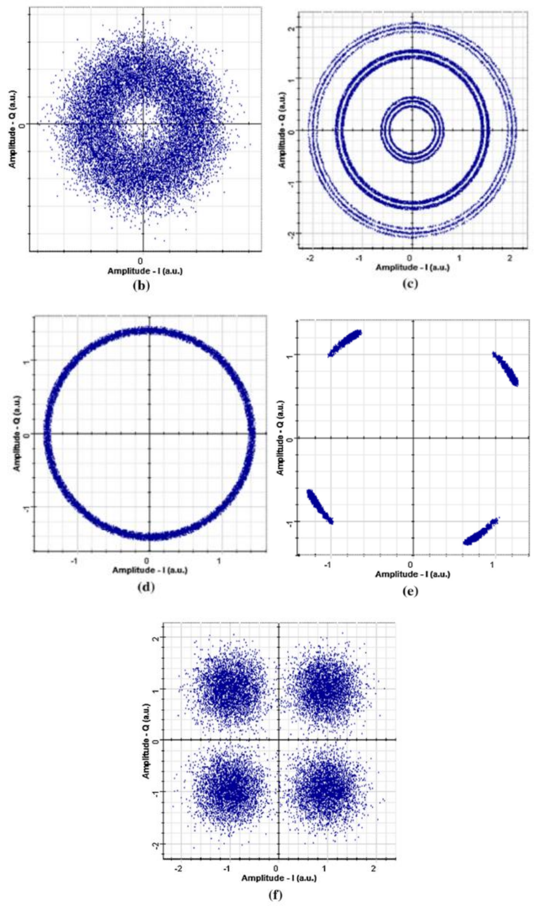


Fig.9. Constellation charts for 22,500 kilometres at 112 Gbit/s IsOWC connection is at the transmission unit, at the receiving unit before DSP, at the equalisation, at the quadrature imbalance and nonlinearity correction, at the FOE, and at the BPS

4. RESULTS AND DISCUSSION

In order to attain a target BER of 2x10-3, Fig 6 depicts the OSNR requirement curve for back-to-back (B2B) transmission over a distance of 22,500 km (FEC limit [39]). The results exhibits that increasing OSNR enhances the BER performance for system. An OSNR of 18.6 dB is needed for a B2B link to reach the desired BER, and this number rises to 19 dB for transmission distances of 22,500 km. There might be a minor OSNR forfeit towards 22,500 kilometres of transmission compared with B2B transmission. Additionally, constellation plots of the processed received signal at a distance of 22,500 km, demonstrating the dependable transmission of 112 Gbit/s data. Figs 7(a) and (b), respectively, depict the binary order of the data at the both the ends which are transmitter end and received end at the 22,500 km connection. The results reveal, suggested technique would permit reliable transmission since the received bits resemble the broadcast bits more than any other bits.

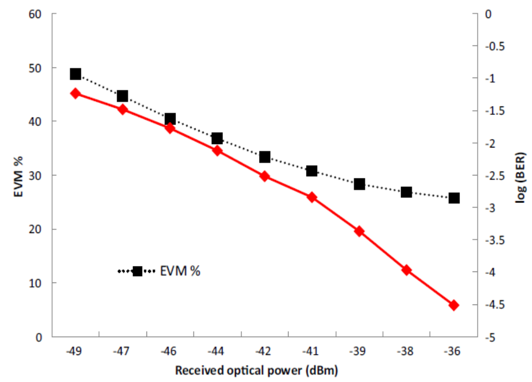


Fig.10. Optical power received vs EVM % and BER

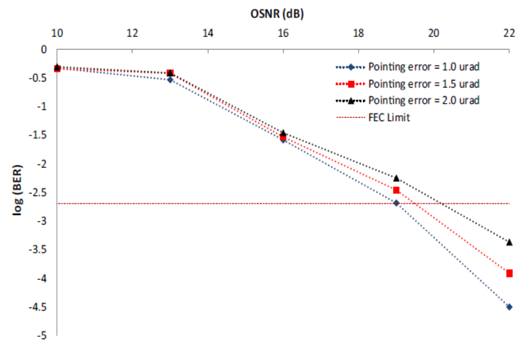


Fig.11. Pointing errors impact for BER vs OSNR at 22,500 km

Furthermore, Fig.8 shows how transreception of signal affects the BER performance of the proposed system for a given nineteen dB OSNR value. Findings reveal when the IsOWC range increases, the constellation plots get skewed and log(- BER) decreases. This is brought on by an increase in route loss. Fig 9 illustrates, an increase in received data signal worth when implementing the initiated DSP block using signal orderliness plots. The results express, use of DSP module significantly raises the calibre of the received data.

The Fig.10 shows Optical power received vs EVM % and BER for the 112 Gbit/s IsOWC system at the 22500 Gbit/s km signal last end reach point. The conclusion predicts output in context to EVM% & BER rises as received optical power does. This is due to the possibility that the demodulator device will only choose the information signal that has a higher received intensity. It is claimed that a fruitful BER production is achieved at optically received powers of at least - 40 dBm.

The Fig 11 illustrates how pointing out errors on the recommended connection affects output of system. The analytical output show that if pointing errors increased, then they have a negative impact on connection performance. 19 dB of OSNR is necessary to produce fruitful BER at one lrad aiming angle of error at the 22,500 km IsOWC connection range. If we change e1rad to 1.5rad and 2 rad the pointing errors changes to 19.5dB and 20.2 dB.

In addition, as indicated in Table.1, we evaluate the proposed IsOWC system against previously released works. This comparison analysis demonstrates that, in terms of last end received signal and connection capacity, the proposed IsOWC system outperforms previously published results. To accomplish the increased data transmission rate per channel, highest order modulation format employing hybrid PDM-QPSK technique was utilised, as opposed to prior attempts that used traditional used formats, which can only send 1 bit/s/Hz. For improved connection performance, the last end-reach range is carried out when coherence detection and a DSP module are integrated.

Table.1. Range and link capacity comparison of current work with previous works.

Ref	**Method (based IsOWC link)**	**Link capacity**	**Max Range (km)**
[8]	WDM-PI	6λ x 20 Gbit/s	1,000
[6]	BPSK	5.6 Gbits/s	6,000
[9]	DPSK	10 Gbits/s	6,000
[10]	Optical SCM	4x1.8 Gbits/s	5,000
[11]	OFDM using DPSK	10 Gbits/s	20,000
[12]	WDM using AMI scheme	64λ x 40 Gbit/s	2,500
[13]	MDM using DQPSK scheme	64 spatial modes x 40 Gbit/s	2,500
[14]	DPSK with Manchester coding	40 Gbit/s	19,100
Proposed work	PDM-QPSK based 112gbit/s (IsOWC) system	112 Gbits/s	22,500

5. CONCLUSION

Current research focuses on development and analysis of high-speed single-channel isowc transmission link using a spectrally efficient higher-order modulation format. Using numerical models, 112 Gbit/s data is successfully sent across a 22500 km IsOWC transmission range with a reasonable BER. The performance of the proposed approach is also analyzed in connection to effect of received pointing errors, and it is shown with system's OSNR must achieve reasonable BER climbs as the pointing error angle increases. The proposed approach may lead to a bandwidth-efficient high-speed, long-distance IsOWC transmission system. The effectiveness of the proposed system might be further investigated in further studies using WDM channels and regional diversity strategies.

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