© November 2022| IJIRT | Volume 9 Issue 6 | ISSN: 2349-6002

Performance investigations of WDM radio over Fiber technology for long-haul Optical link

[1] Saurabh Singh, [2]Deepak Kumar Singh, [3]B B Tiwari
[1]*M Tech student, Department of Electronics & Communication Engineering ,*
[2] *Assistant Professor,* [3]*Professor, Department of Electronics & Communication Engineering*
[1,2,3]*Uma Nath Singh Institute of Engineering & Technology, VBS Purvanchal University, Jaunpur, Uttar Pradesh, India 222001*

Abstract: **The study of the coherent optical fibre transmission network for next generation optical networks is presented using a C-band spectral analysis to determine the power of the adjacent channels. Using the intra-link optical network, the scheme of polarisation multiplexed-quadrature phase shift keying (PM-QPSK) is employed to compare probabilistic and conventional deterministic systems. The proposed design is validated using wavelength division multiplexing (WDM) radio over fibre (RoF) system. Further, to obtain more insight about the system characteristic, PM-16QAM (Polarisation multiplexed-quadrature amplitude modulation) and PM-QPSK system margins are analysed. It is observed that the optical launch power range of 4 dB has a maximum inaccuracy of 0.4 decibels. In addition, the coherent WDM optical system up to 6 dB dispersed link are analysed across 1000 discrete instantiations of PM-QPSK and PM-16QAM schemes using polarisation dependent loss (PDL) measurement. Over a 6 dB range of launch optical powers, the system gives less than 1 dB of signal-to-noise ratio (SNR) loss.**

Key index: **Coherent optical fibre networks, PM-QPSK, Erbium-doped fiber amplifier, Wavelength division multiplexing, Long-haul optical network.**

1.INTRODUCTION

As increasing the bandwidth demands, the existing installed optical networks would not be enough to meet expected future demand and handle a rising volume of data [1]. Core, metro, and access networks are the three main categories of optical transport networks. For the most part, the core network is made up of optical transport that is used for long-distance transmissions of more than 2,000 kilometers. The metro network includes all lines between 2,000 and 100 kilometers in length. There are often little more than a few hundred kilometers of 'last mile' links in the access network. With the exception of access networks, core and metro networks utilize fiber optic transmission technology. Even with the introduction of FTTC, copper, coaxial, and wireless connections are still widely used for "last mile" connectivity to customers. The implementation of optical networks to the end user, however, is now the subject of extensive study [2]. Figure 1 shows the basic structure of optical network layout.

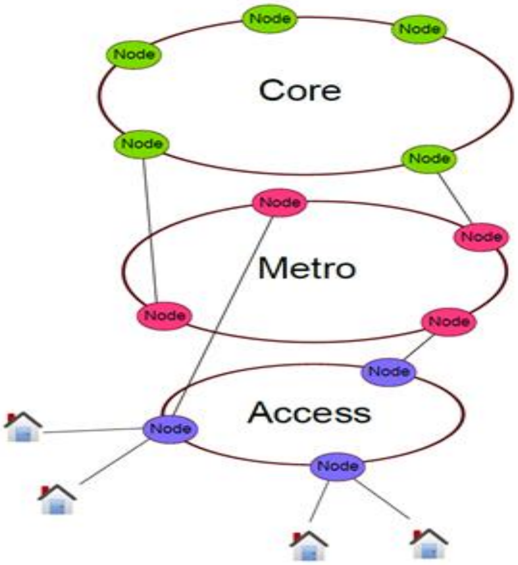

Figure1: Optical network layout

In optical fiber communications, the realization of suitable high-speed digital-to-analog converters, analog-to-digital converters, and digital signal processors has allowed advanced signal processing to offer substantial improvements in system performance and functionality [3]. The signal processing is performed in the transmitter or the receiver. In the transmitter, appropriate drive signals for an optical modulator are synthesized using digital signal processing and digital to-analog conversion. This permits the generation of modulated optical signals with unprecedented control of the time varying amplitude and phase. For example, the transmitted signal can be pre-compensated to account for the dispersion of an optical fiber, fiber nonlinear effects, and the filtering of reconfigurable optical add-drop multiplexers. In the receiver, the combination of coherent detection, analog-to-digital conversion, and digital signal processing has proven to be a particularly powerful approach. Coherent detection preserves both the amplitude and phase of the received optical signal in the photo detected signal. This allows for post-compensation using digital signal processing that effectively mitigates linear transmission impairments and implements key receiver functions. In coherent optical transmission systems, polarization multiplexed, quadrature phase shift keying1 (PM QPSK) and polarization multiplexed, 16-ary quadrature amplitude modulation (PM 16-QAM) can be used to achieve an increase in the spectral efficiency. For PM QPSK, two-level drive signals are required for the IQ optical modulator, while for PM 16-QAM, four-level drive signals are required. The four-level drive signals can be generated using either the RF combining of two two-level signals2 or a high-speed digital signal processor and digital-to-analog converters (DACs) [4]. The radio carrier frequency is exactly translated between the electrical and the optical domain despite the use of coherent reception without additional signal processing. Using a commercial off-thes helf EML device, a low error vector magnitude of 4.6% is achieved for radio-over-fiber transmission of 100-MHz 64-ary quadrature amplitude modulated orthogonal frequency division multiplexed radio signal over a 27.5 km reach, 1:128 split front haul network. Extension to 1-GHz wideband radio signals is investigated [5]. The multimode add/drop multiplexing nodes are built with commercially available narrowband multimode fiber Bragg gratings. The feasibility of the proposal is experimentally investigated with the distribution of 120-Mb/s 64 quadrature amplitude modulation radio signals at 24 GHz over a 4.4-km-long multimode fiber ring with multimode add/drop multiplexing nodes, achieving error vector magnitude values below 4.5% [6]. A novel optical fiber aided beam forming technique based on the fiber’s nonlinearity to be applied in cloud radio access network (C-RAN). In this technique, the PAA elements are fed by the phase-shifted signals introduced by our highly nonlinear fiber (HNLF) aided phase-shifting solution, which results in an angular beam steering range of around 90◦. This can be exploited by sectorization in cellular networks to reduce the co channel interference imposed. Furthermore, we exploit the proposed RoF-aided phase shifting technique in C-RAN, where our proposed system takes advantage of the centralized signal processing capability of the RoF system to conceive an all-optical processing based tunable beam forming system [7].

The performance of coherent optical fiber communication systems depends on the signal processing algorithms and on their implementation. Due to the high cost of developing an ASIC or FPGA based solution for receiver real-time processing at the symbol rates of interest, it is common practice in research to use a real-time sampling oscilloscope to perform the analog-to-digital conversion and off-line computer processing of the captured waveforms to perform the signal processing [8]. PM-16QAM transceivers, which double the signal's efficiency at the same symbol rate but exerting more pressure on the electronics, are already commercially available. As much as possible, minimize the distance between channels in optical fibers in order to enhance their capacity. Traditional modulated optical transmissions often have bandwidths of double the symbol rate. Root-increased cosine pulse shaping and high-speed DACs are used to modulate higher-order modulation schemes like PM-16QAM. The root-raised cosine's ideal pulse form is (0 a) [9]. For reasons such as laser frequency drift and difficulty in maintaining the same calibration across geographically dispersed devices, a small guard band is required in practice.

Using the intra-link optical network, the scheme of polarization multiplexed-quadrature phase shift keying (PM-QPSK) is employed to compare probabilistic as well as deterministic systems in this study. The proposed design is further validated using wavelength division multiplexing (WDM) radio over fiber (RoF) system. Additionally, to obtain more insight about the system characteristic, PM-16QAM (Polarization multiplexed-quadrature amplitude modulation) and PM-QPSK system margins are analyzed. The performance of polarization multiplexed - quadrature phase shift keying (PM QPSK) and polarization multiplexed -16-ary quadrature amplitude modulation (PM 16-QAM) is considered with an emphasis on the signal processing algorithms that compensate transmission impairments and implement key receiver functions.

2.WDM RADIO OVER FIBER (ROF) SYSTEM

In this work, two main parameters are considered to analyze the performance of the optical transmission system, which are the nonlinearity at the fiber link and the input power of the laser source. The model was setup in two parts: the transmitter and the receiver. RoF link consists of the direct modulation technique in which we use directly modulated laser at ~1550 nm wavelength with ~ 0 to 25 dBm power and 25 MHz line width. The pseudorandom bit sequence generator (PRBS) generate baseband signal which is used with 10 Gbps to modulate a high frequency RF. The last is the frequency carrier that uses electrical modulation which will shift this spectrum of data signal to frequency. Differential Phase-Shift Keying (DPSK) is proposed for this electrical modulation, which is a non-coherent version of PSK; it eliminates the need for a coherent reference signal at the receiver. Two amplifiers of 45 dB and 31 dB gains are used within a signal mode fiber of 100 km length with 0.2 dB/km attenuation. At the receiving side PIN photodiode uses an optical detector with responsivity of 1 A/W & Dark Current of 1 nA. The input signal is m-QAM and m-DPSK signal; the Directly Modulated Laser Measured Wavelength is from 1550 nm until 1553 nm. The QAM and DPSK transmitter signals are generated by M-array pulse generator, QAM and DPSK modulators, and QAM and DPSK sequence generators. The QAM and DPSK modulated signal will be transmitted through radio over fiber. The QAM and DPSK demodulator are used for detection. Simulation results are analyzed using oscilloscope visualize, electrical cancellation, optical power meter, and electrical power meter. Figure 2 shows the schematic simulation diagram of RoF system with PM-QPSK modulation schemes considered in the system modeling using the advanced tools of Optical system 7.0.

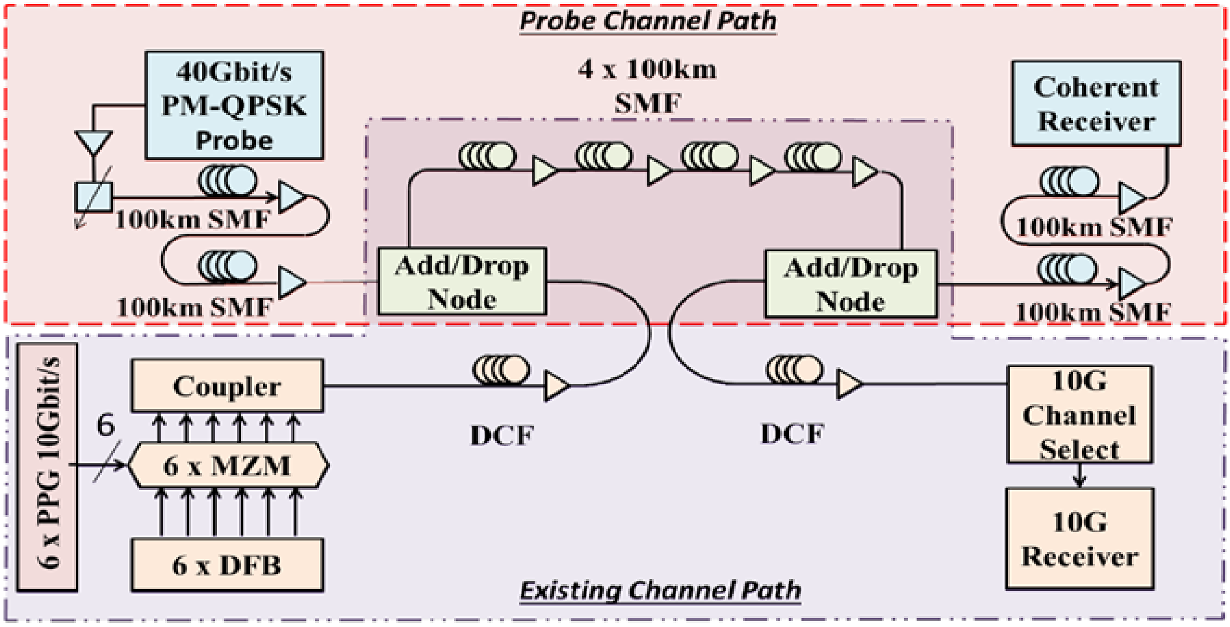

Figure 2: Setup for WDM RoF with PM-QPSK scheme

An additional 40 Gbit/s of PM-QPSK test data was sent across 800 kilometers of conventional single-mode fiber using the line card (SMF). Six 10 Gbit/s OOK aggressor channels were introduced after the installation of 200 km of SMF by a ROADM, with each modulator being controlled by a 10 Gband PRBS. The combined optical signal is received by a second ROADM and sent via single mode fiber (SMF) for an additional 400 kilometers by a third ROADM. All of the possible 10 Gbit/s OOK channels had to be eliminated before one could be selected for reception. Figure 2 shows the line card receiving the 40 Gbit/s channel after it had been sent via a further 200 km SMF path. Pre-compensation for 50% of the dispersion in the 10 Gbit/s channels was done with dispersion compensating fiber (DCF) prior to combining with the 40 Gbit/s probe to avoid increasing the non-linearities on probe channel non-linearities by in-line dispersion compensation, with the remaining 50% of chromatic dispersion being compensated.

To analyse the performance of a basic optical system that transmits straight from the transmitter to the receiver, the BER may be readily calculated by counting the number of error bits. However, it does not cover the whole performance spectrum of the transceiver. Optical noise loading is often used to test the performance range in this B2B arrangement. Noise power is progressively added to the signal, and the BER is measured at each incremental value. Over a bandwidth of 12.5 GHz, the OSNR is measured using an OSA.

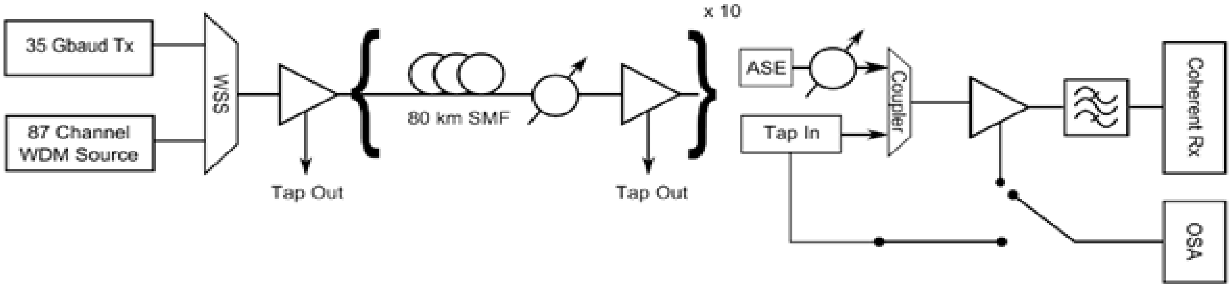

Figure 3: C-band 35 Gband flexible PM-QPSK/16QAM transceivers

Since back to back (B2B) configurations are most efficient, this transceiver characterization serves as the foundation of optical network design. An optical telecommunication system safety margin may be calculated using the BER and OSNR at the receiver. In order to re-amplify the optical signal back to a power level that can be recognized by the receiver, an increasing number of optical amplifiers are required.

$$OSNR_{dB} = 58 + P_{out} - L_{span} - NF - 10\log_{10}(N_{span}) \quad (1)$$

P_{out} is the output power of the transmitter, L_{span} is the loss of a fiber span in dB, NF is the optical amplifiers noise figure, and N_{span} represents the number of fiber spans. Assuming all fiber spans are identical in length, then this equation assumes for all optical transmission networks.

A linear system margin in terms of OSNR can be calculable at a certain transmission distance from the expression

$$Margin_{OSNR_{dB}} = OSNR_{span} - ROSNR_{B2B} \quad (2)$$

Since the margin for one of modulation format may be calculated from the margin for another, for example, PM-16QAM margin estimation can be done using PM-QPSK as

$$Margin_{PM-16QAM} = Marign_{PM-QPSK} - \left(ROSNR^{B2B}_{PM-16QAM} - ROSN^{B2B}_{PM-QPSK}\right) \quad (3)$$

The optical fiber capacity is limited by the non-linear Kerr effect, which occurs during propagation via the non-linear transmission medium. It is possible to represent this Kerr non-linearity as an additive noise factor with a variance proportional to the signal power squared. The received optical SNR (ROSNR) is reduced by this non-linear noise factor. The signal has an effective signal to noise ratio is expressed as

$$SNR_{eff} = \frac{P_{sig}}{P_{ase} + P_{nl}} \quad (4)$$

where P_{sig}, P_{ase} and P_{nl} are the powers of the optical signals, ASE noise and nonlinear noise respectively. From the above equation (4), the system designer can be raise the optical power to optimize the OSNR margin with increase the launch power as well as enhance the OSNR.

The above equation is due to the non-linear noise power being a function of how strong an optical signal is, and it will be consistent across all fiber spans of a given type if the optical amplifier is able to compensate precisely for the span loss. As shown in Figure 3, the non-linear noise accumulation may be modeled as incoherent and as a result, additive. This suggests that fig. 4, when applied to the example system shown in Figure 5., might be up to 0.8 dB off. The shorter Euclidean distance between constellation points belonging to PM-16QAM may cause an even greater error in Equation 6. Eqn. 7 must incorporate an extra non-linear penalty component if the modulation formats and the number of spans are inconsistent.

$$\begin{aligned} Margin_{PM-16QAM} &= Margin_{PM-QPSK} \\ &- \Big(ROSNR^{B2B}_{PM-16QAM} - ROSNR^{B2B}_{PM-QPSK} \\ &+ N_{span} \times \big(NLPenalty_{PM-QPSK} - NLPenalty_{PM-16QAM}\big)\Big) \end{aligned} \tag{5}$$

where $Margin^{B2B}_{PM-16QAM}$ is the estimated $PM-16QAM$ margin, $Margin_{PM-QPSK}$ is the measured $PM-QPSK$ margin, $ROSNR^{B2B}_{PM-16QAM}$ is the received optical signal to noise ratio for $PM-16QAM$ in back to back (B2B) system, $ROSNR^{B2B}_{PM-QPSK}$ is the ROSNR for B2B $PM-QPSK$ performance, N_{span} is the number of fiber spans. $NLPenalty_{PM-QPSK}$ and $NLPenalty_{PM-16QAM}$ are non-linear penalties to the ROSNR per fiber span for PM-QPSK and PM-16QAM, respectively.

$$\begin{aligned} Margin_{PM-16QAM} = Margin_{PM-QPSK} - \big(ROSNR^{B2B}_{PM-16QAM} - ROSNR^{B2B}_{PM-QPSK}\big) \\ + \Big(NLPenalty^{N_{span}}_{PM-QPSK} - NLPenalty^{N_{span}}_{PM-16QAM}\Big) \end{aligned} \tag{6}$$

where $NLPenalty^{N_{span}}_{PM-QPSK}$ and $NLPenalty^{N_{span}}_{PM-16QAM}$ are the accumulated non-linear penalties after N number of spans in the transmission system for PM-QPSK and PM-16QAM, respectively.

3.RESULTS AND DISCUSSION

The received optical SNR (ROSNR) is a function of the number of propagated spans. Figure 4 shows the performance of ROSNR for PM-QPSK and PM-16QAM over a range of optical launch powers of 0 dBm, 1.5 dBm and 3 dBm. From the figure 4 it is noticed that the PM-16QAM constellation points are more susceptible to non-linear distortion than PM-QPSK. Therefore the accumulation becomes quadratic rather than linear at 3 dBm. There is a linear rise in the ROSNR value with distance increases for each modulation type.

The optical power launch per channel may be swept from 0 to 4 dBm in 0.5 dB increments in the proposed design. The received OSNR is measured using an OSA with a resolution of 0.03 nm in order to determine the ROSNR for 3.4 percent of BER as shown in figure 5. It is difficult to determine even small changes in OSNR due to the inherent unpredictability of the setup.

The ROSNR of each span is multiplied by seven to calculate a non-linear penalty of each span. These models, which span a range of nine optical launch powers, may be used to anticipate the OSNR margin for the PM-16QAM signal. With and without non-linear modification, a linear accumulation assumption is shown in figure 6. Including these assumptions, it is possible to examine how the probability distribution changes over quadratic assumption with larger powers.

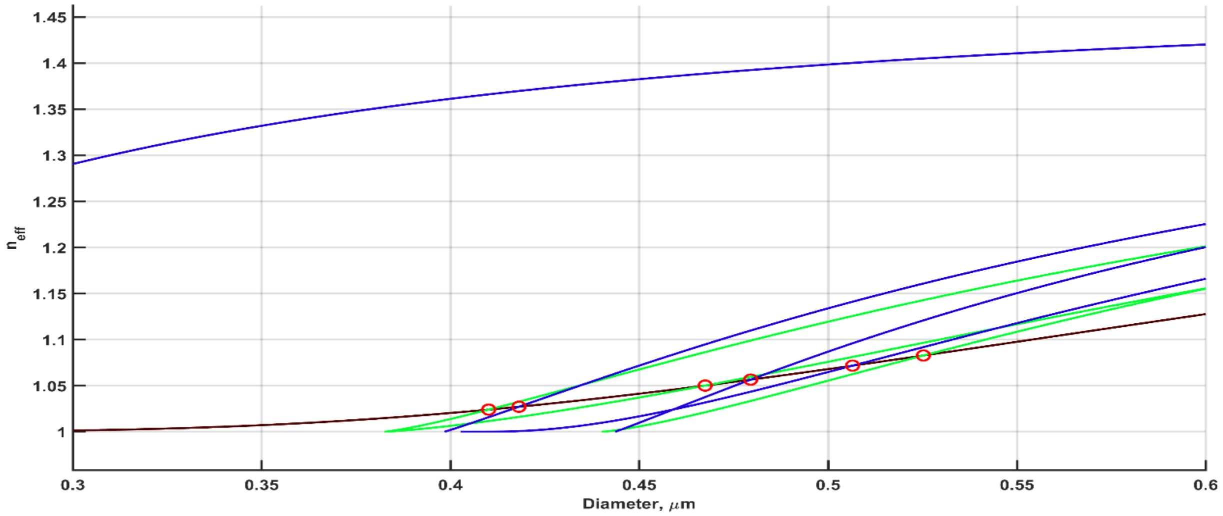

Figure 3: ROSNR for PM-QPSK and PM-16QAM over a range of optical launch powers

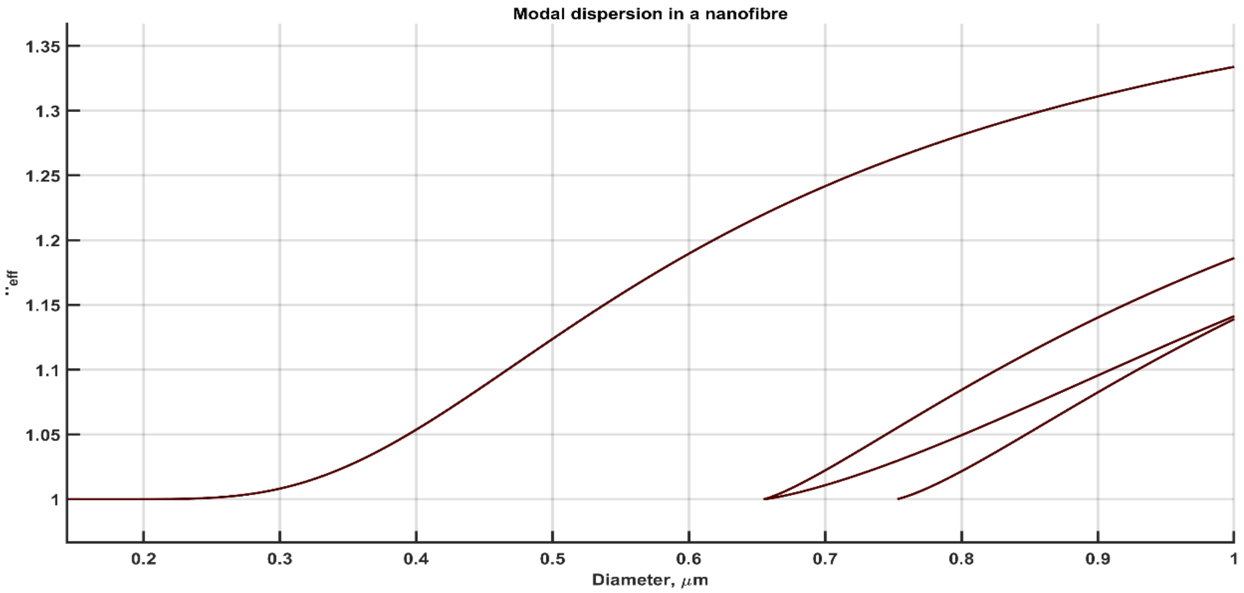

Figure 4. OSNR margin for the PM-16QAM signal

When transmitting up to ten spans of 80 km single mode fiber at 35 Gband, the performance margin of PM-16QAM signal based on PM-QPSK signal performance is plotted in figure 6.

It is observed that the optical launch power range of 4 dB has a maximum inaccuracy of 0.4 decibels. In addition, the coherent WDM optical system up to 6 dB dispersed link are analyzed across 1000 discrete instantiations of PM-QPSK and PM-16QAM schemes using polarization dependent loss (PDL) measurement. Over a 6 dB range of launch optical powers, the system gives less than 1 dB of signal-to-noise ratio (SNR) loss as shown in figure 7.

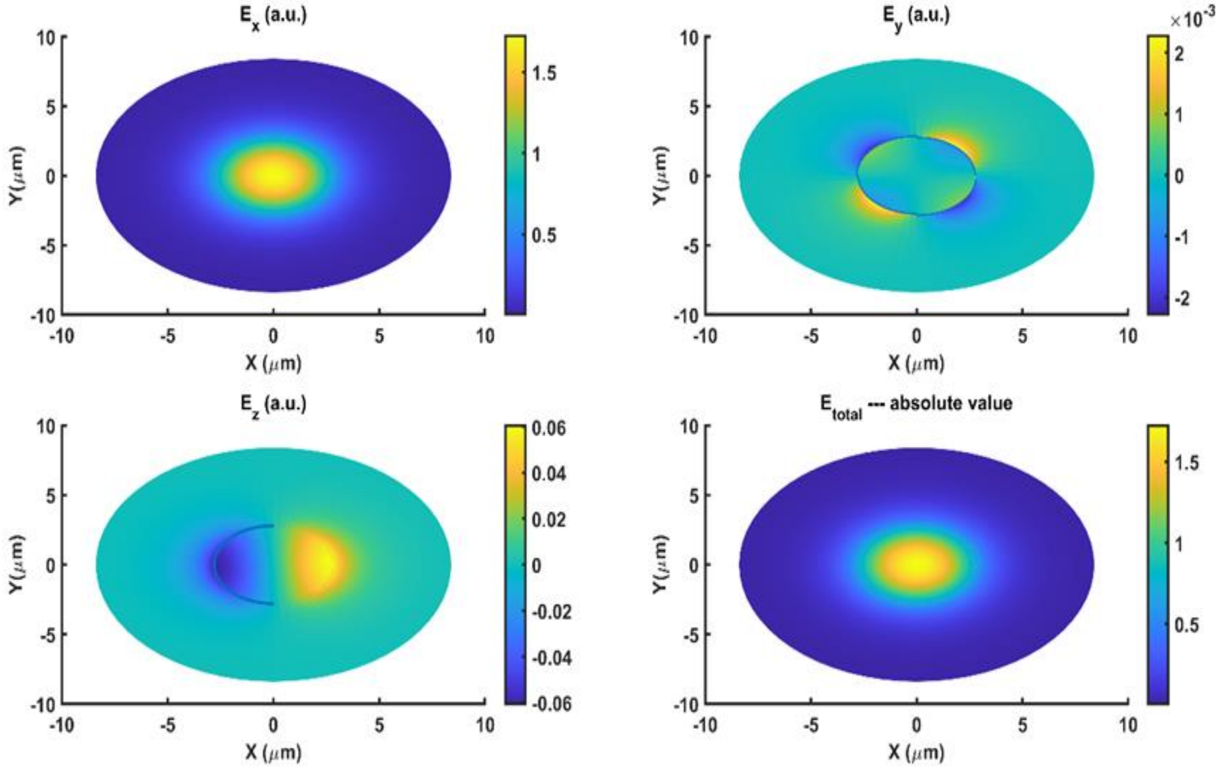

Figure 5: PM-QPSK signal performance

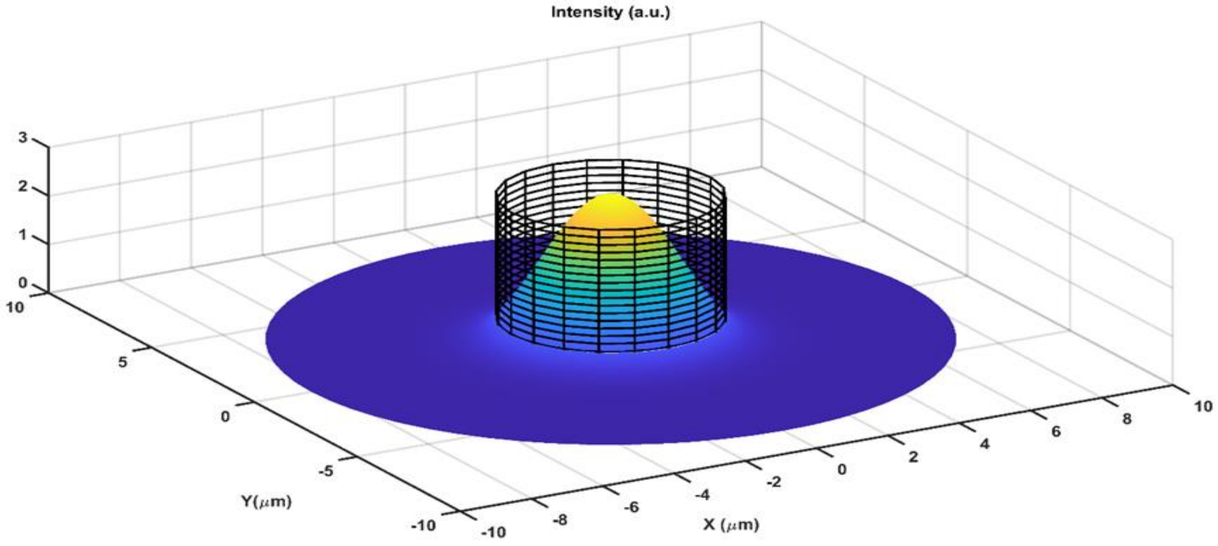

Figure 6: 16 PM-QPSK signal performance

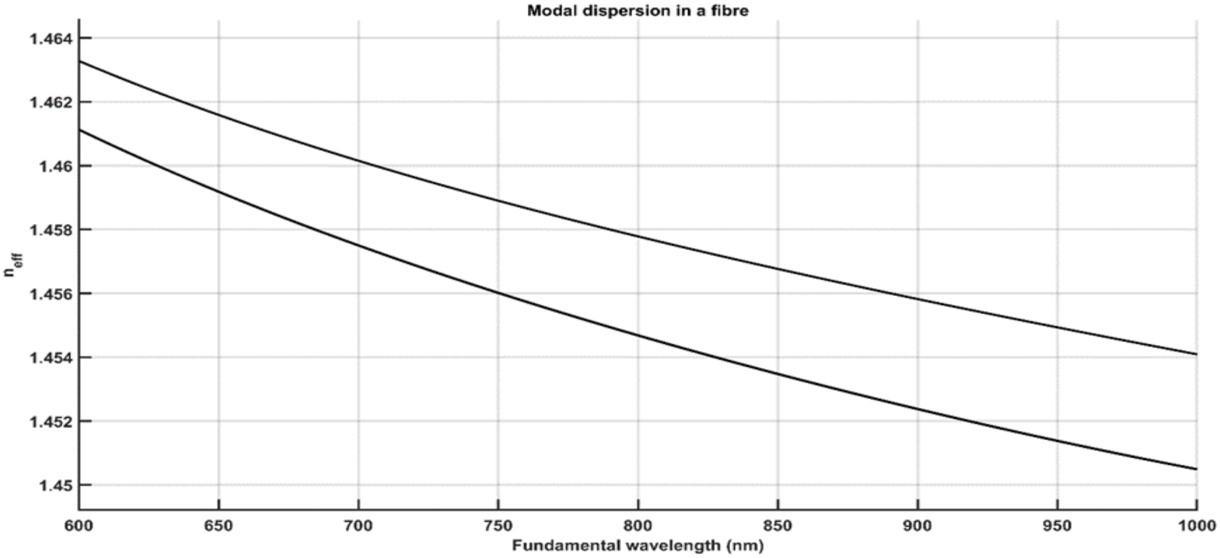

Figure 7: Model Dispersion in a Fiber

4.CONCLUSION

The spectral occupancy of the desired wavelength has been determined by the use of the PM-QPSK and PM-16QAM approaches. A pre-calibrated LUT is used to test the probe's performance and estimate the power of the adjacent channels to obtain an optimal provisioning point. In order to test the probabilistic design process, we perturbed each span of the optical power profile to introduce randomness. Results show for the performance of the transceivers in a disturbed system may be reliably predicted using PM-QPSK and PM-16QAM systems. An estimation approach for the performance margin of a PM-16QAM and PM-QPSK systems are analysed. It is noticed that the optical launch power range of 4 dB has a maximum inaccuracy of 0.4 decibels. In addition, the coherent WDM optical system up to 6 dB dispersed link are analysed across 1000 discrete instantiations of PM-QPSK and PM-16QAM schemes using polarisation dependent loss (PDL) measurement. Over a 6 dB range of launch optical powers, the system gives less than 1 dB of signal-to-noise ratio (SNR) loss. In addition, we noticed that WDM PM-16QAM with probabilistic design seems to be superior to traditional design.

REFERENCE

[1] Cisco, “Cisco Visual Networking Index: Forecast and Methodology, 2014–2019”, White paper technical report, Cisco, 2016.

[2] D Lavery and S J Savory, “Digital Coherent Technology for Long-Reach Optical Access”, Optical Fiber Communication Conference, pp. 2-4, 2014.

[3] G. P. Agrawal, “Fiber-Optic Communication Systems” Wiley inter-Science 4th Ed., 2002.

[4] K. Kikuchi, T. Okoshi, and J. Kitano, “Measurement of bit-error rate of heterodyne type optical communication system - a simulation experiment”, IEEE Journal of Quantum Electronics, 17(12), pp. 2266–2267, December 1981.

[5] B. Schrenk, “The EML as Analogue Radio-Over-Fiber Transceiver—A Coherent Homodyne Approach”, Journal of Lightwave Technology, Vol. 37, No. 12, June 15, 2019.

[6] M. G. Larrodé, A. M. J. Koonen, “All-Fiber Full-Duplex Multimode Wavelength-Division-Multiplexing Network for Radio-Over-Multimode-Fiber Distribution of Broadband Wireless Services”, IEEE Transactions on Microwave Theory and Techniques, Vol. 56, No. 1, January 2008.

[7] Y Li, S Ghafoor, K Satyanarayana, M El-Hajjar, “Analogue Wireless Beam forming Exploiting the Fiber-Nonlinearity of Radio Over Fiber-Based C-RANs”, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 68, NO. 3 MARCH 2019.

[8] B. A. Ahmed, O. Aghzout, M. Chakkour, F. Chaoui, A. Naghar, “Transmission performance analysis of WDM RoF technology for next generation long-haul optical networks”, Hindawi International Journal of Optics, 2019.

[9] J. C. Cartledge, J. D. Downie , J. E. Hurley , A. S. Karar , J. H. Ke , I. Roudas , and K. Roberts, “Performance of PM QPSK and PM 16-QAM coherent optical fiber communication systems”, Next-Generation Optical Communication: Components, Sub-Systems, and Systems, Proc. of SPIE Vol. 8284, 2012.

[10] R. S. Vodhanel, A. F. Elrefaie, M.Z. Iqbal, R.E. Wagner, J. L. Gimlett, and S. Tsuji, “Performances of directly Modulated DFB Lasers in 10-Gb/s ASK FSK, and DPSK Light wave Systems”, Journal of Lightwave Technology, 8(9), pp. 1379–1386, September 1990.

[11] International Telecommunication Union, “Spectral grids for WDM applications: DWDM frequency grid. ITU-T Recommendation”, 2012.

[12] D. Lavery, C. Behrens, S. Makovejs, D.S. Millar, R.I. Killey, S.J. Savory, and P. Bayvel. “Long-haul transmission of PS-QPSK at 100 Gbps using digital back propagation”, IEEE Photonics Technology Letters, 24(3), pp. 176–178, Feb 2012.

[13] M A Reimer, S O Gharan, A Shiner, A. Ghasemi, and M. O’Sullivan, “Performance optimized modulation formats in 4 and 8 dimensions”, Signal Processing in Photonic Communications, Optical Society of America, 2015.

[14] S. J. Savory, “Digital filters for coherent optical receivers”, Optical Express, 16(2), pp. 804– 817, 2008.

[15] I. Ezra, A. P. T. Lau, D. J F Barros, and J. M. Kahn, “Coherent detection in optical fiber systems”, Optics express, 16(2), pp. 753–791, 2008.

[16] Q. Zhuge, M. Reimer, A. Borowiec, M O’Sullivan, and D V Plant, “Aggressive Quantization on Perturbation Coefficients for Nonlinear Pre-Distortion”, Optical Fiber Communication Conference, 2014.

[17] D. Lavery, D. Ives, G. Liga, A. Alvarado, S. J. Savory, and P. Bayvel, “The Benefit of Split Nonlinearity Compensation for Optical Fiber Communication”, arXiv, pages 1–4, 2015.

[18] K. Roberts, S. H. Foo, M. Moyer, M. Hubbard, A. Sinclair, J. Gaudette, and C. Laperle, “High-Capacity Transport at 100G and Beyond. Journal of Lightwave Technology”, 33(3), pp. 563–578, 2015.

[19] D. Ives, P. Bayvel, and S. Savory, “Adapting Transmitter Power and Modulation Format to Improve Optical Network Performance Utilizing the Gaussian Noise Model of Nonlinear Impairments”, Journal of Light Technology, 32(21), pp. 3485–3494, 2014.

[20] Open Networking Foundation. Software-defined networking: the new norm for networks. ONF White Paper, 2012.

[21] M Yoshida, T Hirooka, K Kasai, and M Nakazawa, “Adaptive 4~64 QAM real-time

coherent optical transmission over 320 km with FPGA-based transmitter and receiver", Optical Express, 22(13), pp. 16520–27, June 2014.