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Performance Evaluation of Dispersion Compensation Fiber-based Coherent Optical OFDM-WDM for Long Haul RoF

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Keyword

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Abstract:

Demanding extra Bandwidth and high data rates has been meet by the integration both of wired and wireless communication systems. For that the Radio over Fiber (RoF) technology has gained a traction. In this article a Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) is proposed as the main wired system for transmitting data at high rates suffers from the polarization mode dispersion and chromatic dispersion of the optical channel which mitigates the data rates. Thus, to combat these limitations a Desperation Compensation Fiber (DCF) which adds negative attenuation to the optical signals transmitted in optical fiber is suggested. Moreover, the addition of Wavelength- Division- Multiplexing (WDM) to the system of transmission provides better bandwidth saving, high data rates, and better spectral efficiency, and power utilization. The efficiency of high data rate CO-OFDM integrated with RoF for long haul transmission between 100km and 450km with data rates up to 10 Gbps have been investigated in this article with SMF-DCF with 16 DPSK and 16-QAM modulations schemes respectively. The simulation results showed that the proposed system can achieve a high data rate up to 55 Gbps but when integrated with WDM, with a fiber link length can be increased to up to 6600 kilometers, with highest data rate up to 1.65 Tbps.

Keywords: DCF, WDM, CO-OFDM, MZM, OFDM

تقييم أداء تعويض التشتت البصري لنظام الموجات الرادوية عبر الألياف البصرية لمسافات طويلة باستخدام نظام *OFDM-WDM* البصري

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الخلاصة:

المطالبة بنطاق ترددي إضافي ومعدلات بيانات عالية يتم من خلال تكامل كل من أنظمة الاتصالات السلكية واللاسلكية. لذلك اكتسبت تقنية الراديو عبر الألياف (RoF) قوة دفع. في هذه المقالة ، يُقترح تعدد الإرسال بتقسيم التردد البصري المتعامد المتماسك (CO-OFDM) باعتباره النظام السلكي الرئيسي لنقل البيانات بمعدلات عالية يعاني من تشتت وضع الاستقطاب والتشتت اللوني للقناة الضوئية مما يخفف من معدلات البيانات. وبالتالي لمكافحة هذه القيود ، يُقترح استخدام ألياف تعويض اليأس (DCF) التي تضيف توهينًا سلبيًا للإشارات الضوئية المرسلة في الألياف الضوئية. علاوة على ذلك ، فإن إضافة الطول الموجي - التقسيم - المضاعفة (WDM) إلى نظام الإرسال يوفر أفضل عرض النطاق الترددي ، ومعدلات بيانات عالية ، وكفاءة طيفية أفضل ، واستخدام للطاقة. تم التحقيق في كفاءة معدل البيانات المرتفع CO-OFDM المدمج مع RoF للإرسال لمسافات طويلة بين ١٠٠ كم و٤٥٠ كم بمعدلات بيانات تصل إلى ١٠ جيجابيت في الثانية في هذه المقالة باستخدام SMF-DCF مع مخططات تعديل DPSK١٦ و١٦-QAM على التوالي. أظهرت نتائج المحاكاة أن النظام المقترح يمكنه تحقيق معدل بيانات مرتفع يصل إلى ٥٥ جيجابيت في الثانية، ولكن عند تكامله مع WDM ، يمكن زيادة طول ارتباط الألياف إلى ٦٦٠٠ كيلومتر ، مع أعلى معدل بيانات يصل إلى ١,٦٥ تيرا بايت في الثانية.

الكلمات المفتاحية: ألياف تعويض التشتت، إرسال متعدد بتقسيم طول الموجة، تعدد الإرسال بتقسيم متعامد بصري متماسك، المضمن البصري ماخ – مازندر، مضاعفة قسم التردد المتعامد.

1. INTRODUCTION:

As the internet's data traffic grows, data transmission rates over optical fiber networks must increase, from 1-Gb/s to 10-Gb/s to today's 1 Tb/s. The internet has been steadily expanding, and to meet the demand for bandwidth [1]. To overcome losses in a transmission medium, scientists developed a medium with low attenuation and no electromagnetic interference by adding DCF because it’s ability to combat the chromatic dispersion and polarization mode dispersion problems. To combat the problem of long-haul transmission the CO-OFDM is suggested. In addition, the use of WDM is to increase the bandwidth utilization. As a result, the first goal of this article is to investigate the performance of integrated CO-OFDM with RoF framework for a single user[2]. The second goal is to determine the best form of dispersion compensation fiber (DCF) to compensate for fiber connection losses, and the third goal is to achieve long-haul transmission over a distance up to 6600 kilometers based on pervious system elements described in the first and second goals based on Opti system 14 software. Finally, the fourth goal is to look into the rendering of the proposed CO-OFDM WDM system along to RoF for long haul transmission over distances of up to 6600km and data rates of up to 1.65Tbps. The analysis of the comprehensive proposed system is based on the construction of a constellation diagram for both transmitter and receiver, along with studying the relationship between Q - Factor and input power, as well as finding the relation between RF signal power and optical fiber length. Furthermore, the influence of optical fiber length on the Optical Signal to Noise Ratio (OSNR) and Bit Error rate (BER) were depicted. The literature review begins with a transmitted OFDM modulated radio signal over SMF (Wong 2012). (Single Mode Fiber). Then, using CO-OFDM and WDM RoF, multiple RF signals were modulated and multiplexed. The device is capable of transmitting data at up to 10 Gbps using 4-QAM (2-bits per symbol for each channel) and OFDM. Wong demonstrates that as the higher the fiber transmission distance, the transmitted signal power is reduced[3]. On the other side, Almasoudi in 2013, looked at high data rates of RoF for long-haul optical fiber. It has been demonstrated that RoF is a powerful tool for mitigating chromatic dispersion, polarization mode, and modal dispersion, resulting in increased versatility and coverage area with reasonable device complexity and expense, as well as high data rates up to 1.4 Tbps and transmission distances of 6600 km [4]. Atta Takhum Jaber and colleagues, in 2020. For long path transmissions, a comprehensive solution of higher data rates using Direct and CO-OFDM was proposed. In this study a single user was investigated, along with multiusers by integrating OFDM – WDM which leads to attain a data rate up to 100 Gbps. The Opti system simulation tool was used for the system's design and implementation. The OFDM signal is modulated with QAM, and I/Q modulation was used, with Coherent and Direct detection used at the receiving end. Saifur Rahman et al. in 2020 stated (RoF) transport-based fronthaul as efficient candidate for C-RAN framework, but the related issues of nonlinear impairments (NLIs) from power amplifiers, linear distortions (LDs) from modulating lasers, and high peak to average power ratio (PAPR) of (OFDM) signals must be Alatawi et al. in 2013tackled. Thus a variety of input power values, different (QAM) formats for the OFDM signal, high accuracy filtering at the receiver end, and varying channel spacing among the optical WDM channels have been employed[5]. Adnan Hussein et al in 2019, proposed in their article uses an integrated CO-OFDM and WDM schemes to transmit and receive data streams across a long distance through the optical fiber and optimized the constellation diagram by testing various modulation schemes[6]. Alatawi et al. in 2013 proposed a study for the performance of direct detection optical orthogonal frequency division multiplexing (DD-OFDM) along with (WDM) was proposed by [7]. The proposed system succeeded to attain 1050 Tb / s over distance of 3600 km using a Single Mode Fiber (SMF) by multiplexing 30 signals of OFDM, each with 35 Gb / s. Almasoudi et al, in 2013 used RoF in the case of Passive Optical Network (PON) with SMF in the last mile of a wireless system with 100 km, 140 km, and 288 km[8]. Almashhadani et al 2017, pointed out the influence of the cyclic prefix and the length of the cyclic prefix on the OFDM system. Also, compared the system's performance with and without the cyclic prefix. The simulations ran on AWGN and Rayleigh fading channels marked the importance of cyclic prefix[9]. Aloff in 2014 had simulate (CO-OFDM). compared the two systems by simulating the (DD- OFDM) and (CO-OFDM) using the same parameters as before. Then, he realized that increasing optical fiber length must be done by using Dispersion Compensating Fiber (DCF)[10].By multiplexing four 12Gbps OFDM channels over more than 80km from (SMF), Das and Zahir in 2014 investigated a hybrid system made up of (CO-OFDM) and (WDM-RoF) with DCF technique to achieve a 48Gbps for a distance up to 80km from (SMF). A Fiber Bragg Grating (FBG) has been applied to this device proposal to counteract the effect of dispersion. By comparing the Q-factor, BER, and constellation diagram of CO-OFDM/WDM-RoF systems with and without FBG, it was determined that using FBG in the CO-OFDM/WDM-RoF system dramatically improves system efficiency[11]. Sarup and Gupta in 2014 showed how to use the RoF method in synchronism with the dense wavelength division multiplexing (DWDM) technique to increase the system band width and achieve ultra-high-speed communication. With a 40-channel DWDM-RoF system, each channel transmits 25 Gbps, and hence the overall speed attained is 1Tbps with different wavelengths of 0.1 nm and 0.2 nm. The Erbium Doped Fiber Amplifier (EDFA) and Semiconductor Optical Amplifier (SOA) were used to achieve highly narrow channel spacing. When used as a post amplifier, SOA is found to perform linearly and better than EDFA[12]. Abdul-Rahaim, Murdas, et al. in 2015 demonstrated a Polarization Division Multiplexing Coherent Optical Orthogonal Frequency-Division Multiplexing (PDM CO-OFDM) scheme with the modulation formats of (QPSK and 16-QAM) at bit rates of 40 and 100 Gb/s. To investigate the output, the device is essentially simulated assuming a single channel. After that, 8 WDM channels with 50 GHz channel spacing were simulated. PDM CO-OFDM QPSK was recommended for high-capacity networks because of its superior efficiency. Because of the advantages of PDM CO-OFDM 16-QAM (improved spectral performance, reduced electrical bandwidth), the optimal input power is reduced. At a maximum distance of 1760 km, the single channel's optimum input power was -4dBm and -1dBm. The 8-WDM system's optimum input power was between -8dBm and -4dBm**[13]**. Sinan M. Abdul Satar, in 2015 investigate the use of a (CO-OFDM) system with (DWDM) and the achievement of 1.60 Tb/s data rates over a 4500 km SMF by multiplexing 16 CO-OFDM signals, each of 100 Gb/s**[14]**. According to Pawar and Umbardand in 2016), a rate of 100Gb/s for fiber length of 360 km using (SMF), can be achieved when (CO-OFDM) combined with Dual –Polarization Quadrature Phase Shift Keying (DP-QPSK) modulation**[15]**. M. Sofien et al. in 2018 have examined many regression methods for fiber non-linearity mitigation**[16].** The remainder of this work is structured as follows. Section 2 Proposed WDM CO-OFDM-ROF with Dispersion Compensation Fiber; Section 3 Results and Calculations; Section 4 Comparison with peer Literatures ; Finally, conclusions are brought in Section 5.

2. Proposed WDM CO-OFDM-ROF with Dispersion Compensation Fiber

Fig. 1. shows the proposed system named WDM CO-OFDM RoF with SMF-DCF. The First stage from the proposed scheme is pseudo random binary sequence (PRBS) which generates semi-random binary data stream which modulated using QAM modulator. The modulated signal is then converted from serial to parallel to frame of 512 subcarriers and 1024 Fast Fourier Transform (FFT) points OFDM modulator. Then the output of OFDM modulator include two types of signals, the in - phase(I) and quadrature phase(Q) signals are modulated by optical I/Q modulator which consists of two Mach-Zehnder (MZM) lithium Niobate (LiNb) modulators using an optical carrier. The output of each CO-OFDM system is then transmitted via one of the available channels of (WDM). Thus, the capacity of the overall is improved. The WDM maps the optical spectrum into smaller channels, employed to transmit and receive data simultaneously. Due to available very high-speed electronics, the WDM can support up to 55Gbps for each channel. The multiplexed optical signal resulted from WDM MUX is transmitted via SMF-DCF. In the optical channels, DCF can be used for fiber dispersion compensation, and an (EDFA) is being used for the signal amplification and for compensate the losses. At recover side the WDM DEMUX is split the received optical signal through the

optical fiber into multiple wavelengths and make each wavelength is manipulated by its receiver which is to be designed. The signals that resulted from the MZMs (optical demodulators) are then provided to the OFDM demodulator before it demodulated by QAM demodulator. Eventually the original digital signals are reconstructed. The parameters used in this article simulation have to be summarized in the next part. Thus, the optical link used in this research is SMF with the nonlinearity coefficient of 2.6 * 10–20 and 0.2dBm/km the attenuation per kilometer.

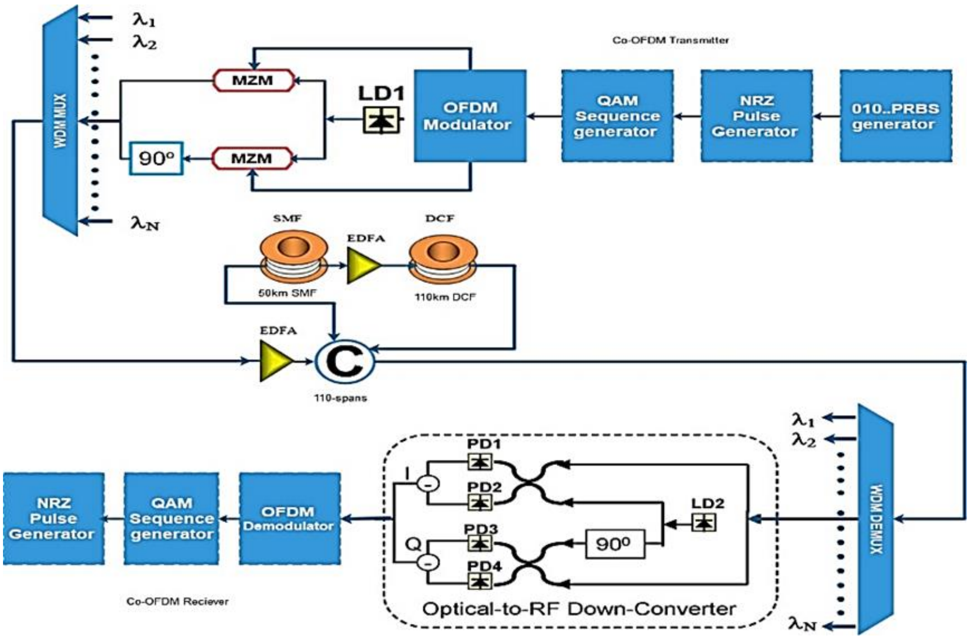

Fig. 1: CO-OFDM WDM RoF system with SMF-DCF (Block diagram).

The dispersion factor is 16 ps/nm/km with slope of 0.08ps/nm ^{2}/km while the DCF attenuation is assumed to be 0.4dB/ km. To amplify the optical power signal, the (EDFA) can be employed on the SMF link. The resulting filtered optical signals from the two LiNb MZM are Subsequently transmitted via SMF-DCF. Thus, a 50 km length SMF fiber will result in a dispersion of 16 × 50 = 800ps/nm. Consequently, a 10 km long of DCF with a dispersion factor -80 ps / nm / km is required to combat the dispersion of 50 km SMF length yielding a dispersion of 80 × 10 = 800ps/nm. An EDFA employed has a power gain of 20 dB power. Then a pair of local oscillators (LO) behave as a balanced coherent detector exploited for I/Q optical- to electrical conversion and for canceling the noise of the optical signal contaminated. Each detector is made up of pair of couplers with pair of PIN photodetectors with a 10 nA of the current, 1 A/W responsively, and 10×10^{-24}W/Hz of the thermal noise. In the proposed system, up to 1.65Tbps rate has been attained by multiplexing thirty CO-OFDM channels. The optical carrier which has a laser frequency begins from 193.05 until 194.5 THz. It's up to1.65 Tbps generated by multiplexing thirty OFDM channels and optical carrier with laser frequency begins from 193.05 until 194.5 THz. **Fig 2.** shows the structure of each OFDM channel while **Fig.3** shows the multiplexed CO-OFDM channels spectrums (after being multiplexed by WDM). The spectrum starts at 193.05 THz up to 194.5 THz with 50GHz of the channel guard band.

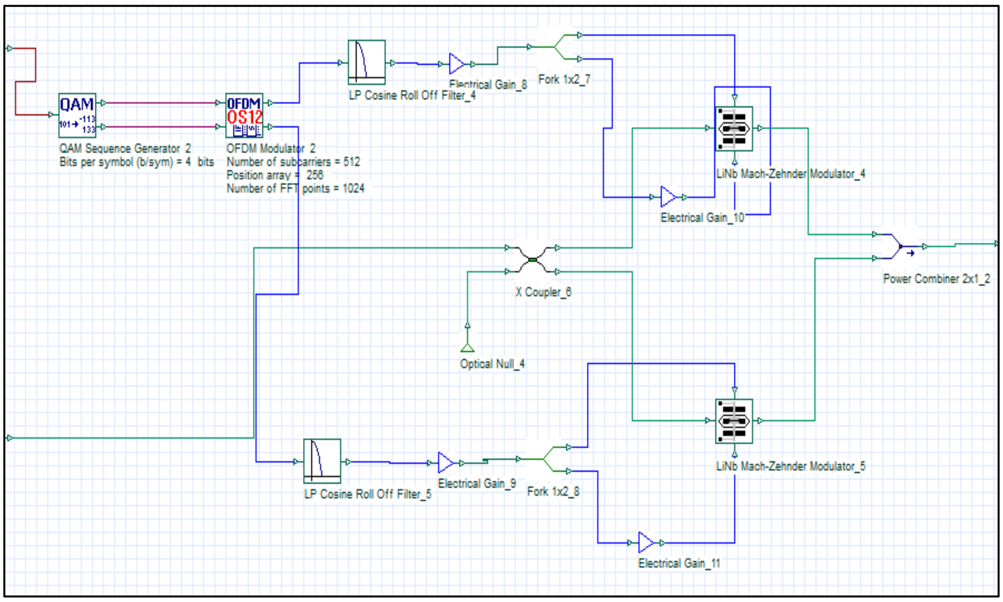

Fig.2: CO-OFDM Channel structure.

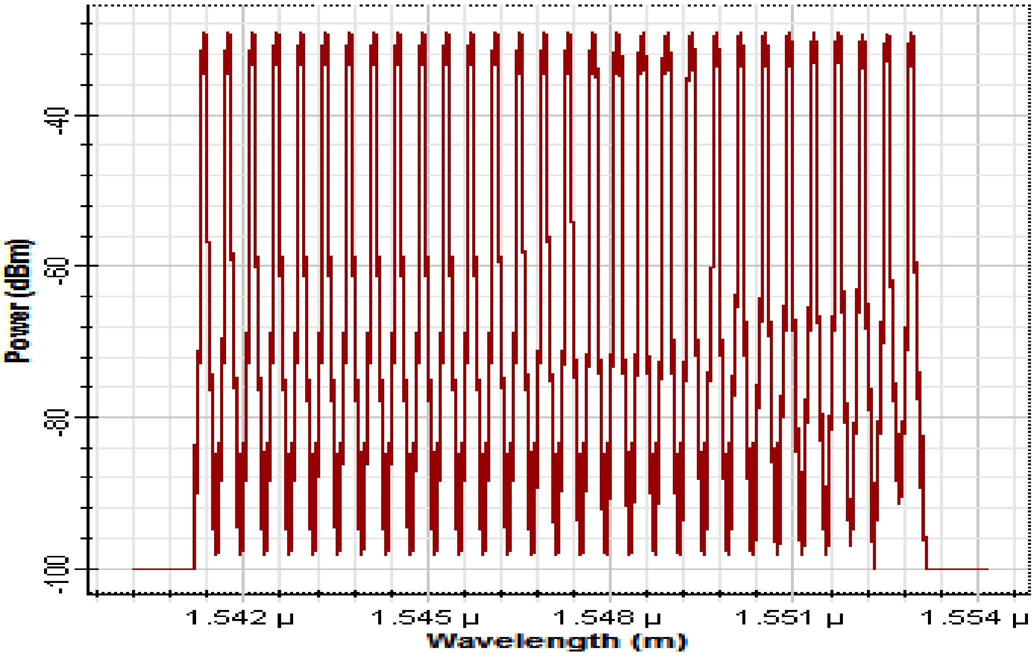

Fig. 3: A 30 CO-OFMD multiplexed channel spectrum at the output of WDM.

3. Results and Calculations

The simulation results are mainly divided in to two parts: the first part depicts the results of CO-OFDM RoF with dispersion compensation fiber. Whereas the second part illustrates the results of the proposed system.

Part A

Fig 4 shows the relation between input power in dBm and the Q-factor. It's clear that input laser power, and Q-factor values are directly related, hence the signal power increased at the receiver end, but after exceeding 5dBm (input power at which the Q-factor is maximum) the system performance begin to decline with grow happened in input power.

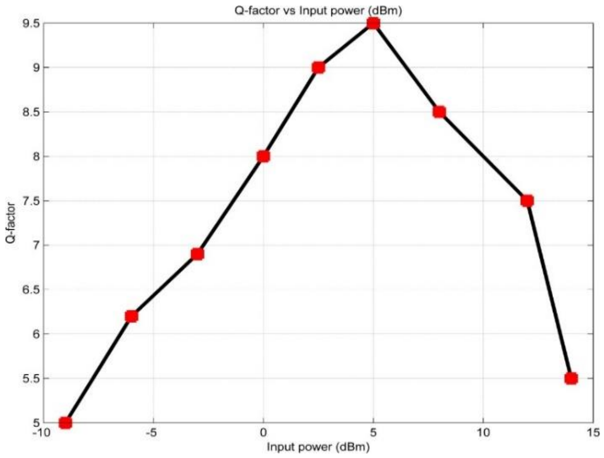

Fig. 4: Input power vs to Q-Factor.

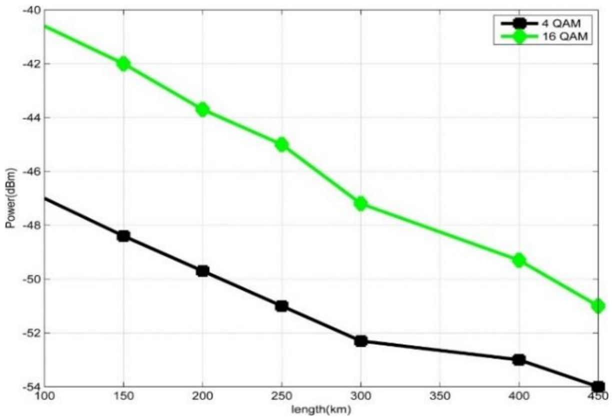

Fig. 5: Power versus the length of optical fiber.

The received power for 4-QAM and 16-QAM respectively with OFDM technique versus fiber length is depicted in **Fig. 5**. As the length of fiber increases the RF power decreases. The RF signal power with 16-QAM is higher than the RF signal power for this system using 4-QAM. It can be concluded that There is a direct relation between the RF signal received power value with the level M-ary QAM selected for the same bit error rate. **Fig 6** shows that both of symmetrical and post configuration give a comparable result in case of relatively short fiber distance but as distance increases above 100km (long distance) post configuration is preferable. Using DCF along with SMF mitigates the distortion level on the propagated optical signal for a longer SMF length. By investigation **Fig. 6** which depicted the relation between Q –factor and fiber length for different DCF types. It's clear that the quality factor (Q-factor) of 12 can be achieved at fiber length doesn't exceed 50 km without using fiber while the same Q-factor can be achieved at fiber length of 140km, 200 km,225 km corresponding to pre DCF, symmetrical DCF, post DCF respectively before noticing any reduction in Q-factor values.

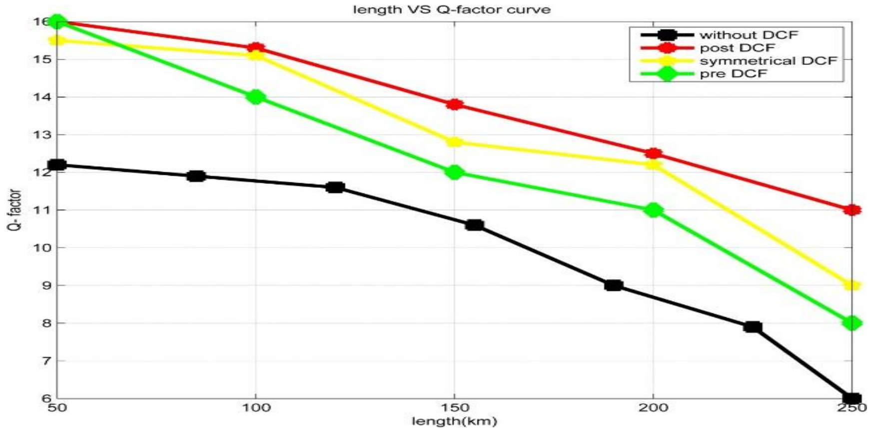

Fig. 6: The Variation in Q-Factor.

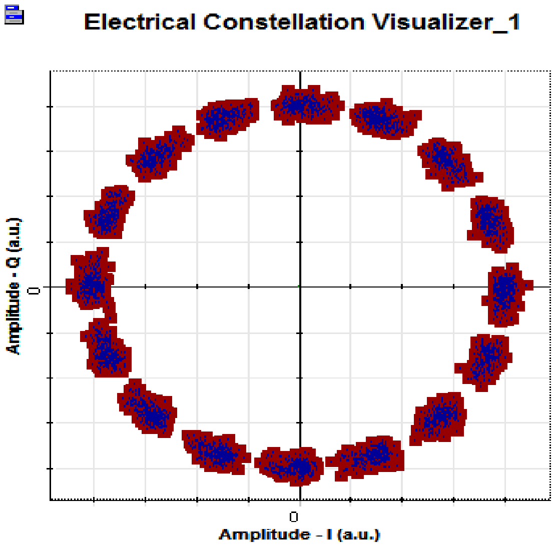

Fig. 7: Constellation diagram of 16-DPSK.

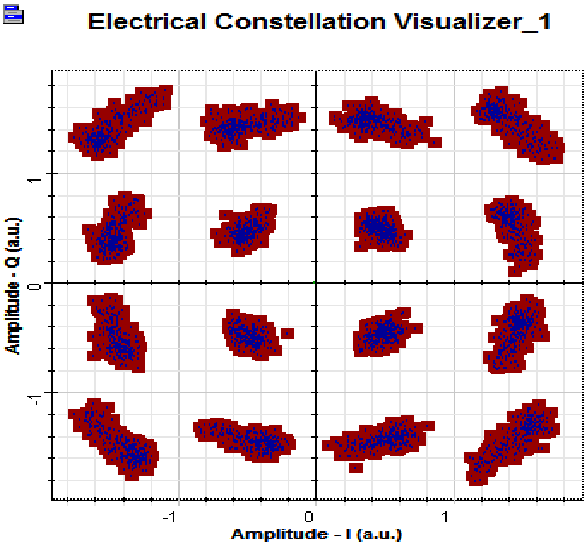

Fig. 8: Constellation diagram of 16-QAM

Part B

In this part, the performance CO-OFDM-RoF integrated with WDM and DCF would be investigated. From simulation results it's found that the maximum data rate of 1.65 Tbps can be attained over 6600 SMF- DCF, considering 16-DPSK, and 16-QAM modulation schemes. Thus, **Fig.7** illustrates the constellation diagram of 16-DPSK based system taking place on the receiver side for 6600 km fiber length with SMF-DCF, whereas **Fig.8** depicts that the constellation diagram of 16-QAM based system revived signal with 6600 km fiber length employing SMF-DCF. From these two **Figures (7,8)** it's obvious that achieving a 1.65Tbps rate it was possible by using 30-channels (Dense Wavelength Division Multiplexing) DWDM integrated with 16-QAM modulation which outperform the 16-DPSK modulator by reducing the noise and distortion levels. **Fig.9** shows the relation between BER with different transmission distances. It's clear from **Fig.9,** that the BER has been declined as increasing the transmission distance, hence increasing the fiber length to cover longer distance come with the cost of increasing fiber loss. **Fig.10** demonstrates the behavior of the BER related with the OSNR considering different distances of transmission. From this figure an inverse relation between the OSNR and the BER has been discovered, so to attain a BER less than 10−13, the OSNR must be raised to 55 dB with transmission distance 6600 km while for transmission distance of 3120 km OSNR must be greater than 46dB which is 16 dB less than transmission distance 6600 to achieve BER less than10−14. However, the OSNR increment must be compromised with the input power increment, because any increase in the input power will results of increasing in the nonlinear effect of the fiber which lead to detritions in system

performance.

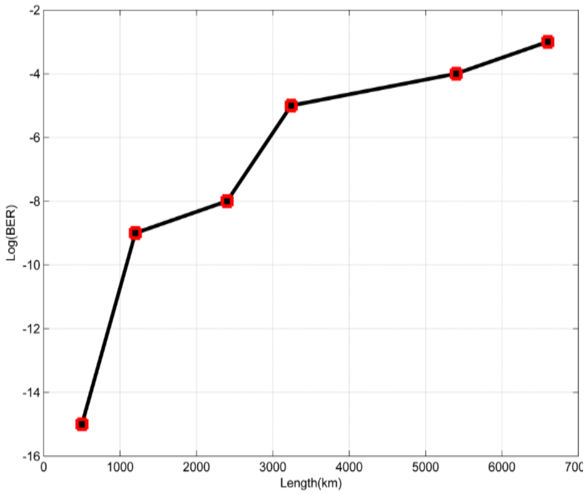

Fig.9: BER vs. transmission distance for 1.65Tbps data rate.

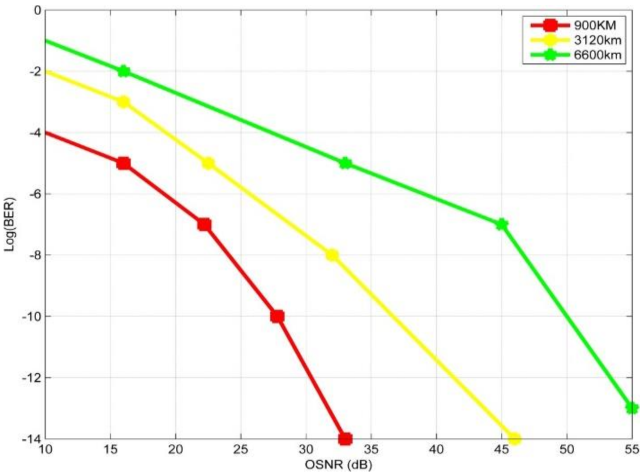

Fig 10: BER vs. OSNR for different transmission distances at 1.65Tbps data rate.

4. Comparison with peer Literatures:

To compare the proposed system model with other articles such as the thesis of khaled alatawi **[5]**. Our proposed system successes to transmit data up to 6600 km rather than that proposed by alatawi which was 6000 km, using 16-QAM compared to alatawei he had used 4-QAM. The proposed system has obtained higher data rate of 1.65Tbps, while in Khaled Alatwi's article only 1Tbps has been attained. Table 1 shows the distance gain and rate gain proposed by the proposed model compared to alatawei.

Table 1: Comparison present work to other articles

Author/year	Types of QAM	Types of OFDM	Maximum transmission distance	Maximum data rate
Ass. Prof. Dr. sinan	16 QAM	CO-OFDM	6600 km	1.65 Tbps
M. Abdul Satar/2015	64 QAM	CO-OFDM	4500 km	1.6 Tbps
Aloff, N.M.A,2014	4 QAM	CO-OFDM and OOFDM	6600 km	48 Gbps
Fahad Mobarak Almasoudi/2013	4 QAM	DD-OFDM	6600 km	1.4 Tbps
Alatawi. K. S. (2013)	4 QAM	CO-OFDM	6000 km	1 Tbps
Alatawi, Almasoudi et al.2013)	4 QAM	CO-OFDM	1800 km	1 Tbps

5. Conclusions

In the case of a single user system, it is concluded that rising the input the power from -9dBm to 5 dBm leads to distortion mitigation and hence improving the Q-factor of received signal. But after 5dBm the relation is inversed such that a deterioration of the transmitted signal has been observed which corresponds to disprove in Q-factor. There is a direct relation between the positive dispersion is and the transmission distance. Increasing the number of spans till 450km leads to increasing received signal distortion due to broadening of the sent signal caused by signal dispersion for long distance besides the increasing fading due to channel attenuation. With transmission distance up to 550 km SMF employing EDFA power of 60 dB and in case if the power gain of EDFA is increased beyond 60 dB, the received signal distortion level doesn't improve. Thus, the power gain of the EDFA cannot improve the quality of the signal over SMF length beyond 550km since it cannot compensate for the power loss. It's observed that the amount of distortion in the transmitted signal is decreased using DCF as compared to the case of without DCF; also, the type of DCF has its effect on transmitted signal distortion. It's clear from the results that post compensation gives better results as compared to pre or symmetrical compensation. Symmetrical and post configuration gives a comparable result in case of relatively short distance but as distance increases above 100km (long distance) post configuration is preferable. By using DWDM (Multiuser system), in applying 16-QAM the data rate of the system is improved from 10 Gbps to 55 Gbps whereas in using of 4-QAM the high data rate of 55 Gbps cannot be supported. The signal is distorted and corporate due to the high data rate even if the EDFAs power is increases. So, the signal does not improve. Using DWDM is the main reason for increasing the system capacity and attaining high rate up to 1Tbps compared with a single user rate which is less than 65Gbps. Therefore. In this research, a data rate of 1.65 Tbps over 6600 km has been achieved by multiplexing 30-channel. These results showed a good performance curve between OSNR and BER. The system gives superior performance in term of very low BER of 10^{-13}at OSNR of 55 dB. Finally, the resulting data verified the superiority in the performance of CO-OFDM WDM-RoF in attaining higher data rates. The proposed system successes to transmit data up to 6600 km rather than that proposed by Alatawi **[17]**which was 6000 km, using 16-QAM compared to alatawei he had used 4-QAM.We achieve higher data rate up to 1.65 Tbps while in khaled alatwi the maximum rate was 1Tbps. Also, the proposed system outperforms the results conducted by Dr. Sinan M. Abdul **[14]**which was attained a data rate 1.6 Tbps but with shorter transmission length of 4500 km.

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