EFFICIENCY OF NONLINEAR COMPENSATION FOR WDM-PON BASED OFDM USING OPTICAL BACK PROPAGATION

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Abstract: The Kerr nonlinearity is the main obstacle that limits the performance of the orthogonal frequency division multiplexing wavelength division multiplexing (OFDM-WDM) system. Moreover, the nonlinear compensation method that is feasible and adds no more complexity to the receiver is very necessary for the long-range passive optical network (LR-PON) applications. In this paper, we investigate the nonlinear and dispersion compensation efficiency in OFDM-WDM system using an advanced optical back propagation (OBP) approach based on split-step Fourier method. In the OBP, the real optical devices such as the high-nonlinear fiber (HNLF), fiber Bragg grating (FBG) and nonlinear waveguide are used as a nonlinear operator, a dispersive operator and phase conjugated media, respectively. The advanced OBP is located in the transmitter site that is very suitable for LR-PON applications. The compensation efficiency of the OBP in OFDM-WDM systems is evaluated by an analytical model and then Monte-Carlo simulations. The obtained results from both analytical evaluation and simulation show that the OBP can improve remarkably the system performance when the parameters of OBP such as dispersion and pump power are properly selected.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Wavelength Division Multiplexing (WDM), Nonlinear compensation, Optical Back Propagation (OBP), Long-range Passive Optical Network (LR-PON).

I. INTRODUCTION

The orthogonal frequency division multiplexing (OFDM) has become the promising solution for the WDM-based long-range passive optical networks (WDM LR-PONs) [1], [2]. The OFDM WDM LR-PON can be extended both the capacity and the range thanks to the advantages such as highly spectral efficiency, highly chromatic dispersion tolerance. Moreover, the systems can get the simple design and cost efficiency when the intensity modulation and direct-detection (IM-DD) method is employed [3]. However, a larger power budget or higher transmitting power is required to extend the range of LR-PONs. Therefore, the nonlinear Kerr effects become a critical concern in these networks, especially in WDM LR-PONs.

There are many solutions in the digital domain which have been proposed to compensate the nonlinearity of the systems [4-8]. Almost these techniques provide a good PAPR reduction to eliminate the nonlinearity in all parts of the system, the transmitter, fiber channel and the receiver. However, each nonlinear compensator can only applied to each channel so that they make the complexity and cost of the OFDM-WDM system increase exponentially.

Nonlinearity in the fiber, especially the Kerr effect, can be mitigated by mid-span spectrum inversion (MSSI) method in the optical domain [9]. The MSSI using optical phase conjugation (OPC) module can reduce significantly not only Kerr nonlinearities but also group velocity dispersion in WDM systems [10], [11]. However, this method requires the OPC module placed in the middle of transmission link to ensure the power symmetry that is not feasible in LR-PON. The optical back propagation (OBP) solution using dispersion compensation fibers (DCFs) and high nonlinear fibers (HNLFs), proposed by Kumar et al [12], is placed in the receiver site of the optical systems. The OBP addresses the main drawback about strict location requirement of MSSI. Moreover, this solution has been proposed in the single channel OFDM based LR-PON that demonstrated its nonlinearity compensation efficiency [13].

In this paper, we investigate the efficiency of optical back propagation technique in nonlinearity compensation for OFDM-WDM system. The OBP module is located at the transmitter site that is similar to that proposed in [13]. This OBP consists of HNLFs, fiber Bragg gratings (FBGs) and an OPC. The HNLF is the nonlinear operator to compensate the nonlinearity. The FBG is the linear operator to compensate the dispersion. The signal after HLNFs and FBGs is conjugated by the OPC to transmit via the standard single mode fiber to the receiver. A theoretical analysis model is also used to evaluate the efficiency of nonlinearity compensation in this study. Both analytical evaluation and simulation results show that our proposed OBP technique can improve remarkably the performance of the OFDM WDM system when the parameters of OBP module are properly selected. These

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achieved results also show that the advanced OBP is very suitable to deploy in OFDM WDM LR-PON.

The rest of this paper is organized as follows. Section 2 gives analytical descriptions of nonlinear wave mixing efficiencies of OFDM WDM systems that influence to the nonlinearity compensation efficiency of OBP technique. Simulations are discussed in section 3. Finally, section 4 concludes this paper.

II. THEORETICAL EVALUATION

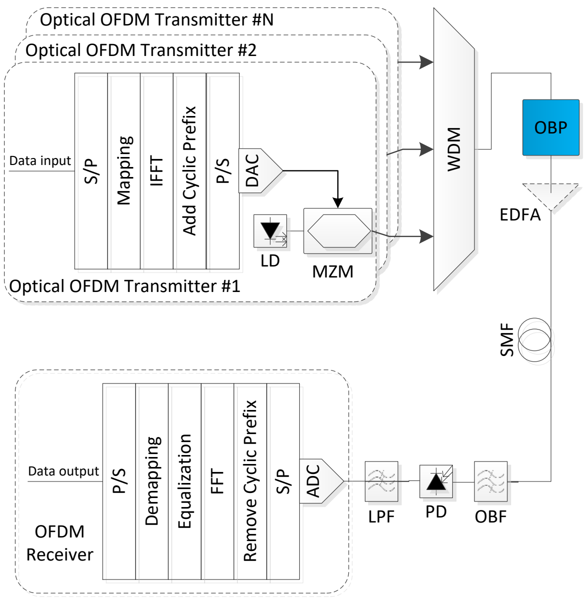


Figure 1. Block diagram of IM-DD OFDM WDM system using OBP as pre-compensation.

Fig. 1 shows the schematic of IM-DD optical OFDM WDM system where the OBP module is located at the transmitter site. The OBP module consists of steps of HLNF and FBG, an OPC module and an Erbium Doped Fiber Amplifier (EDFA) as described in details in [13]. With the advantages of system design and cost efficiency, the IM-DD OFDM WDM is the good solution for LR-PON applications. For the sake of simplicity, we assume that insertion loss of all components of the LR-PON is ignored. Here, our OBP plays a role as pre-compensation in optical domain of the LR-PON. The OFDM transmitted signals are multiplexed in wavelength domain before they propagates via the OBP section, and then it is phase conjugated before propagating in the transmission fiber link. The nonlinear and dispersion distortions of the OBP section are based on the split-step Fourier method in the optical domain [14]. The FBG is used as dispersive step because of its pros such as negligible nonlinearity and insertion loss, very compact size, and dispersive tunability. The HNLF is used as nonlinear step due to its very low dispersion distortion and negligible loss. The OPC using the nonlinear waveguide produces the conjugated signal by four-wave mixing (FWM) process to transmit along the single mode fiber (SMF) to the receiver site. The EDFA is used to control the signal input power of the SMF link. By using real photonic device, our OBP overcomes the cons of digital back propagation (DBP) method including the computational complexity and less-flexible configuration [8].

Nonlinear Kerr effects in the fiber including self-phase modulation (SPM), cross phase modulation (XPM), and four-wave mixing (FWM) are the dominant obstacle to extend the capacity and transmission distance of the multichannel optical communication systems [14]. In such systems, all the nonlinear effects such as XPM, SPM are considered as FWM between all subcarriers. Thus, the evolution of the FWM field (spectrally located at ω_F) resulting from the nonlinear wave mixing between three other optical waves (k, l, m such that $\omega_F = \omega_k + \omega_l - \omega_m$) can be expressed as [15]

$$E_F(L) = i\frac{\gamma D}{3}E_k(0)E_l(0)E_m^*(0)e^{i\beta L}\frac{e^{(-\alpha+i\Delta\beta)L}-1}{-\alpha+i\Delta\beta} \quad (1)$$

where $E_s(z)$ is the optical field spectrally located at ω_s measured at distance z, and L is the transmission fiber length. γ, α and β are nonlinear, attenuation coefficients and propagation factor of a fiber, respectively. D is the degeneracy factor of FWM. SPM is considered that three waves of FWM are coincided, $\omega_k = \omega_l = \omega_m$, and $D = 1$. While XPM is considered as degenerate FWM effect, in which two of mixing components have the same frequency, $\omega_k = \omega_l \neq \omega_m$, and $D = 3$. The remaining case that three mixing components are totally different, $\omega_k \neq \omega_l \neq \omega_m$, is called non-degenerate FWM or simply FWM, and $D = 6$. $\Delta\beta = \beta_k + \beta_l - \beta_m - \beta_F$ is the phase mismatch coefficient of the fiber, relates to the dispersion coefficient D_c as follows [15]

$$\Delta\beta = \frac{2\pi\lambda^2}{c}D_c\Delta f^2(k-m)(l-m) \quad (2)$$

where Δf is channel spacing. It can be obviously seen from Eq. 1 that the amplitude of FWM field depends much on channel spacing. To evaluate how the OBP could compensate the nonlinearity of the OFDM WDM LR-PON, the powers of FWM field in two cases a link with OBP and a link without OBP are compared. Thus, Eq. 1 describes the FWM field in case of the OFDM WDM LR-PON link without OBP. The total power of nonlinear product $|E_F(L)|^2$ with assumption that the signal powers in all channels are equal can be written as [16]

$$P_F(L) = \frac{D^2\gamma^2}{9}P^3\left[\frac{\alpha^2 L_{eff}^2}{\alpha^2+\Delta\beta^2}\right]\left[1+\frac{4e^{-\alpha L}sin^2(\Delta\beta L/2)}{(1-e^{-\alpha L})^2}\right] \quad (3)$$

where P is the power of each mixing component launched into the fiber and $L_{eff} = (1-e^{-\alpha L})/\alpha$ is the effective length.

We next consider the nonlinear Kerr power in OBP-assisted OFDM WDM LR-PON link. The link can be divided into two segments, OBP segment and SMF segment. The OFDM signal first is sent through the OBP segment, phase conjugated at OPC and then transmitted via the SMF segment. The nonlinearity arisen in the OBP segment will be compensated in the SMF segment. Given that after two segments all dispersion effect are compensated, so the total FWM field in this case will be

$$E_F(L) = E_F(SMF) + [E_F(OBP)]^* e^{i\beta L} \quad (4)$$

Applying the Eq. 1 for the OBP segment, the nonlinear field can be obtain as

$$E_F(OBP) = i\frac{\gamma_{OBP}D}{3}E_k(0)E_l(0)E_m^*(0)e^{i\beta_{OBP}L_{OBP}}\frac{e^{(-\alpha+i\Delta\beta_{OBP})L_{OBP}}-1}{-\alpha+i\Delta\beta_{OBP}} \quad (5)$$

In the OBP segment, both the loss of HLNFs and FBGs is negligible so that the attenuation coefficient of OBP can be omitted. To ensure that the dispersion arisen in the OBP segment is fully compensated in the SMF segment, $\beta_{OBP}L_{OBP} = \beta L$ or $\beta_{FBG}L_{OBP} = \beta L$. For more convenient in calculation, we define $K = \beta_{FBG}/\beta$. Hence, the nonlinear field from the OBP segment can be reduced as

$$E_F(OBP) = i\frac{\gamma_{HLNF}D}{3}E_k(0)E_l(0)E_m^*(0)e^{i\beta L}\frac{e^{i\beta L}-1}{iK\Delta\beta} \quad (6)$$

By the end of the OBP segment, the mixing fields (k, l and m) are phase shifted due to the accumulation of dispersion along the OBP segment $e^{i(\Delta\beta_{OBP}+\beta_{OBP})L_{OBP}} = e^{i(\Delta\beta+\beta)L}$. Then they are conjugated to propagation via the SMF segment that results the following nonlinear field

$$E_F(SMF) = i\frac{\gamma D}{3}E_k^*(0)E_l^*(0)E_m(0)e^{-i\Delta\beta L}\frac{e^{(-\alpha+i\Delta\beta)L}-1}{-\alpha+i\Delta\beta} \quad (7)$$

Substituting Eq. (6) and Eq. (7) into Eq. (4), we can obtain the total nonlinear field generated by the OBP-assisted OFDM WDM LR-PON link as follow

$$E_F(L) = i\frac{D}{3}E_k^*(0)E_l^*(0)E_m(0)\left[\gamma e^{-i\Delta\beta L}\frac{e^{(-\alpha+i\Delta\beta)L}-1}{-\alpha+i\Delta\beta} - \gamma_{HNLF}\frac{e^{-i\beta L}-1}{-iK\Delta\beta}\right] \quad (8)$$

Deploying lossless for the SMF segment ($\alpha = 0$), the signal power symmetry for the link with OBP can be satisfied. In this case, Eq. (8) shows that the fully nonlinear compensation will be attained in the OBP-assisted OFDM WDM LR-PON link with fully dispersion management. Unfortunately, the attenuation coefficient of the SMF fiber cannot be omitted that breaks the power symmetric condition. This reduces the efficiency of the OBP in nonlinear compensation in comparison with MSSI technique. Thence, the total FWM power of the OBP-assisted OFDM WDM LR-PON link is given as

$$P_F(L) = \frac{D^2}{9}P^3\left[\frac{\gamma^2\alpha^2L_{eff}^2}{\alpha^2+\Delta\beta^2}\left(1+\frac{4e^{-\alpha L}sin^2(\Delta\beta L/2)}{(1-e^{-\alpha L})^2}\right) + \frac{\gamma_{HLNF}^2}{K^2\Delta\beta^2}4sin^2\left(\frac{\Delta\beta L}{2}\right) - \frac{4}{K\Delta\beta}\frac{\gamma\gamma_{HLNF}}{(\alpha^2+\Delta\beta^2)}\sin\left(\frac{\Delta\beta L}{2}\right)\left[\alpha(1-e^{-\alpha L})cos\left(\frac{\Delta\beta L}{2}\right) + \Delta\beta(1+e^{-\alpha L})\sin\left(\frac{\Delta\beta L}{2}\right)\right]\right] \quad (9)$$

The first term of Eq. 9 describes the nonlinear FWM power arisen in the SMF segment, which only depends on the SMF coefficients. The second term in Eq. 9 is the added nonlinear FWM power because of the presence of the OBP, which only depends on the OBP coefficients. The third one is the mixing nonlinear power that compensates for nonlinearities of the both SFM and OBP segments. Therefore, the compensation efficiency of the OBP will increase when the third term is larger than the second term. And this depends much on the factor K and the coefficients of both segments.

Figure 2 demonstrates the dependent of nonlinear Kerr power in the OBP-assisted OFDM WDM LR-PON link on the factor K with the channel spacing of 12.5 GHz and the fiber link length of 80 km. As can be seen from the figure, when K is small, the phase mismatch of the OBP is small that makes the nonlinear effect arisen by OBP become too strong. At the value of K is smaller than 5, the nonlinear power in the link with OBP evenly exceeds that in the link with our OBP. When K increases, the nonlinear Kerr power of the OBP reduces remarkably. However, under the asymmetry power condition, the OBP cannot compensate perfectly the nonlinearity of the SMF. That's why the residual nonlinear FWM power in the case of using OBP become saturation when K is very large although this value is always smaller than the FWM power in the case of not using OBP. Consequently, there is an optimum value of K where the nonlinear Kerr power in the link with OBP is minimum.

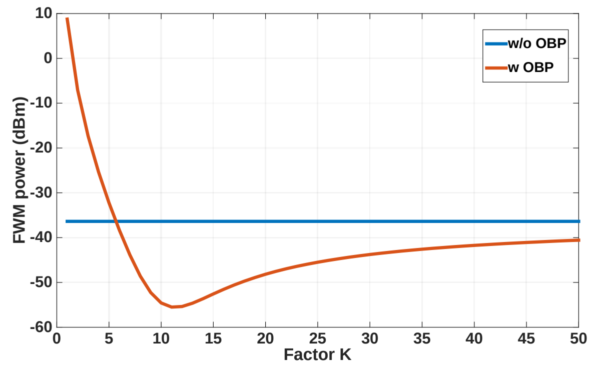


Figure 2. FWM power as a function of factor K with the channel spacing of 12.5 GHz and the SMF fiber length of 80km.

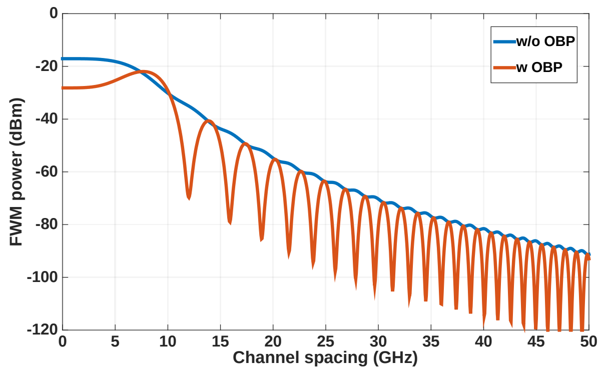


Figure 3. FWM power as a function of channel spacing with the factor K of 12 and the SMF fiber length of 80km.

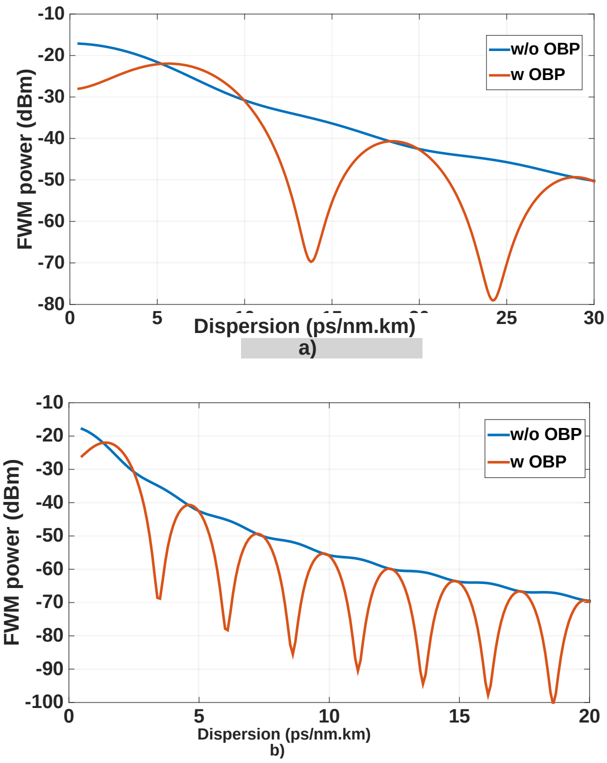
Figure 3 shows that not only the FWM power depends on the channel spacing but also the compensation efficiency of the OBP does. The increase in channel spacing causes the increase in the phase mismatch that makes the average FWM power decrease. However, in case of the OBP-assisted OFDM WDM LR-PON link, the power of the FWM varies with the channel spacing as an oscillation but it is always smaller than or equal to the Kerr nonlinear power in case of not using OBP.

Dependence of the mixing power on the dispersion at different channel spacing is shown in Figure 4. The dispersion dependence of the mixing power has a similar tendency to the channel spacing dependence. The oscillation of the mixing power dependent on dispersion can be observed and shows a reduction of the mixing power in the OBP-assisted OFDM WDM LR-PON link compared to that in the OFDM WDM LR-PON link without OBP.

In the OFDM WDM system, the Kerr nonlinear noise imposed on each subscriber of OFDM signals results from two main sources:

(i) FWM effect between subcarriers of each OFDM channel. The Kerr nonlinear powers in the link with and without OBP caused by OFDM subcarriers, $P_F^{OFDM}(L)$, are derived from Eq. 3 and Eq. 9, respectively in which P is the power of each OFDM subcarrier and Δβ is dependent on channel spacing between OFDM subcarriers, and

(ii) FWM effect between optical channels of WDM system. The Kerr nonlinear powers in the link with and without OBP caused by WDM optical carriers, $P_F^{WDM}(L)$, are also derived from Eq. 3 and Eq. 9, respectively in which P is the power of each optical channel and Δβ is dependent on the channel spacing of WDM system.



Figur 4. FWM power as a function of dispersion at different channel spacing: (a) 12.5 GHz, (b) 25 GHz.

Therefore, the total FWM power on each subcarrier in case of using or not using OBP has the following form:

$$P_F^{total}(L) = P_F^{WDM}(L) + P_F^{OFDM}(L) \qquad (10)$$

Let's consider the FWM effect caused by subcarriers of an OFDM signal. Because the number of subcarriers of an OFDM is quite large, the power of each subcarrier is small but the channel spacing is very small too. Thus, the FWM power caused by subcarriers of an OFDM signal cannot be negligible. It can be seen that from Fig. 3, if channel spacing is smaller than 5GHz, the Kerr nonlinear power in the case of using OBP is always 10 dB smaller than that in the case of not using OBP. Fortunately, channel spacing of an OFDM signal is much smaller than 5 GHz. For example, if the OFDM signal in the OFDM WDM LR-PON at the very high bitrate of 100 Gb/s using 64QAM and DCO-OFDM scheme has 190 data subcarriers and 66 zero-padded subcarriers, the channel spacing is about 0.18 GHz. Thus, the OBP can compensate the Kerr nonlinearity caused by OFDM subcarriers in the OFDM WDM LR-PON. When channel spacing is larger than 5 GHz, which is the range of the channel spacing of WDM systems, the Kerr nonlinear power in case of using OBP fluctuates with large amplitude. By choosing suitable value of K and channel spacing, the OBP can compensate significantly the Kerr nonlinearity caused by optical channels in the OFDM WDM LR-PON. The performance improvement of the OFDM WDM LR-PON thanks to OBP will be clarified by Monte- Carlo simulation in the next section.

III. SIMULATIONS AND RESULTS

A MATLAB based simulation model of IM-DD OBP assisted OFDM WDM LR-PON is developed to investigate the nonlinear compensation efficiency of proposed OBP method. The simulation setup of the system is similar to the block diagram described in Figure 1 that includes three main components: optical transmitter, transmission link and optical receiver. The DCO-OFDM signal is generated from the OFDM modulator in digital domain that consists of 190 data subcarriers and 66 zero-padded subcarriers. The MZM is used to optically modulate the OFDM signal before launching into the OBP. After pre-compensating at the OBP, the signal is sent to the receiver via the transmission link of 80 km standard single mode fiber (SSMF). Here, the data is recovered with the reverse process of the transmitter. The important system parameters and constants used in our simulation are shown in Table 1.

Table 1. Simulation parameters

Name	Symbol	Value
SMF parameters		
Attenuation coefficient	α_{SMF}	0.2 dB/km
Dispersion coefficient	D_{SMF}	17 ps/nm.km
Nonlinear coefficient	γ_{SMF}	1.4 $W^{-1}.km^{-1}$
Fiber length	L_{SMF}	80 km
HNLF parameters		
Attenuation coefficient	α_{HNLF}	0.5 dB/km
Dispersion coefficient	D_{HNLF}	1.7 ps/nm.km
Nonlinear coefficient	γ_{HNLF}	6.9 $W^{-1}.km^{-1}$
Fiber length	L_{HNLF}	150 m
NW parameters		
Attenuation coefficient	α_{NW}	50 dB/m
Dispersion coefficient	D_{NW}	28 ps/nm.km

Nonlinear coefficient	γ_{NW}	10^4 W^{-1}.km^{-1}
Waveguide length	L_{NW}	7 cm
System parameters		
Optical signal frequency	f_s	193.1 THz
PD responsivity	R	0.6 A/W
Dark current	I_d	0.2 nA
Thermal noise PSD	S_T	2x10^{-23} A/(Hz)$^{1/2}$
M-ary	M	64
Data rate	R_b	100 Gbit/s
Pump power	P_p	450 mW
Optical pump frequency	f_p	193.3 THz

In the OBP, the OFDM signal after nonlinear and dispersion pre-compensating is phase conjugated by an OPC before transmitting via SSMF to the receiver. Thus, the quality of the conjugated signal through FWM process in the OPC plays an important role in the performance of the OBP. In our simulation, the pump power and the input power of the OPC are chosen carefully to ensure that the conjugated signal does not add any more impairment to the performance of the system [13]. The parameters of the OFDM modulator need to be fixed to keep the data bitrate of each optical channel of 100 Gbps. Hence, the channel spacing between OFDM subcarriers is constant in all simulations, only the channel spacing between optical WDM channels is varied to examine the system's performance.

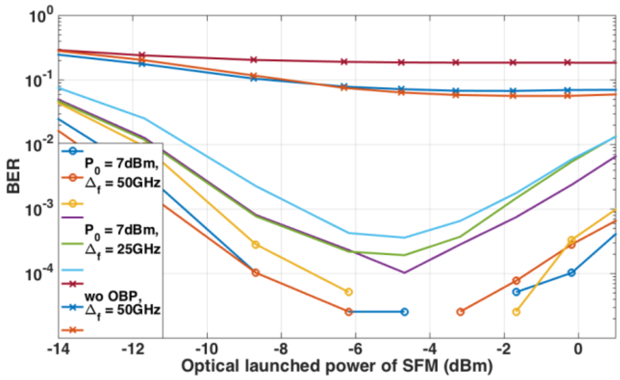


Figure 5. BER vs optical launched power of SMF in each optical WDM channel with different channel spacing.

Figure 5 demonstrates that the OBP can improve significantly the performance of the OFDM WDM LR PON. By adjusting the EDFA gain properly, the optical power at the input of the SMF is always varied in the range from -14 dBm to 2 dBm. At the given power of the OBP, the best efficiency of the OBP is obtained at the power range of the SMF that reaches to the system's power symmetry at any channel spacing. When the power of the SMF is too small or too high, the residual FWM power after two segments of the link is large that degrades the efficiency of the OBP. In the case of the channel spacing of 50 GHz, the BER is always lower about one order of magnitude than that in the case of 25 GHz because nonlinear Kerr power is inversely proportional to channel spacing. At the optimum power range of SMF in each optical WDM channel from -6 dBm to -2 dBm, the OBP can improve the BER performance of the OFDM WDM LR-PON up to 4 orders of magnitude at channel spacing of 50 GHz.

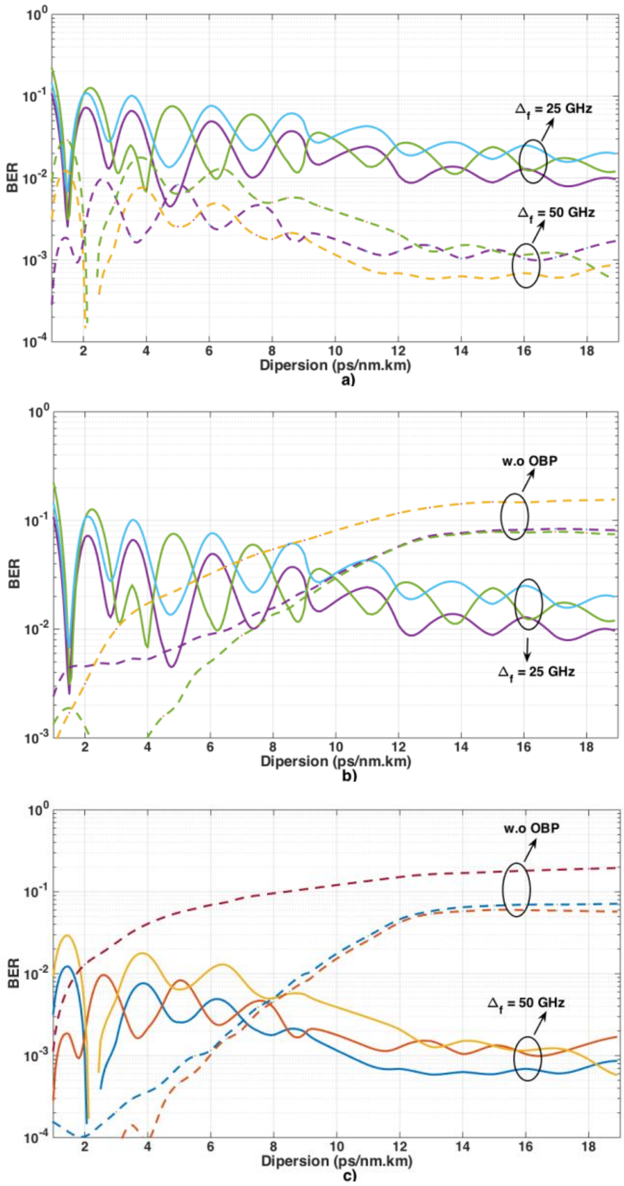


Figure 6. BER vs dispersion of SMF in each optical WDM channel: a) with different channel spacing, b) with and without OBP at channel spacing of 25GHz, c) with and without OBP at channel spacing of 50GHz.

The BER performance in each optical WDM channel of OFDM WDM LR-PON versus dispersion of the SMF is plotted in Fig. 6 in three cases: a) using OBP with different channel spacing, b) with and without OBP at channel spacing of 25 GHz, and c) with and without OBP at channel spacing of 50 GHz. In these simulations, the power of OBP and the power of the SMF are kept unchanged at the value of 3.7 mW. It can be seen from the Fig. 6a that the BER varies with the dispersion coefficient of the SMF as an oscillation. This oscillation is attributed by the dependence of the FWM efficiency on the phase mismatch as indicated in the analytical evaluation. Because the Kerr nonlinearity occurs strongly at the small value of dispersion so that the BER curve fluctuates with large magnitude. When the dispersion increases, the magnitude of the oscillation reduces as results of large phase mismatch. Thus, the average BER also decreases gradually with dispersion of the fiber. In the case of not using the OBP, the BER performance of the OFDM WDM system in the range of small dispersion is better than that in the higher dispersion value. At the small value of dispersion, the BER performance suffers dominantly from the nonlinear noise and can ignore the dispersive noise. However, at the high value of dispersion, both nonlinear and dispersive noises and their mutual interactions that deteriorates sharply the system's performance. Fig. 6b and Fig. 6c show that by employing the OBP for the OFDM WDM system, OBP exposes its very good efficiency at the high value of dispersion. When the dispersion coefficient of the fiber is small, the fiber becomes a high nonlinear media. Under the power asymmetry between two high nonlinear segments of the link, the nonlinear power of each segment is exceeded the nonlinear mixing power that downgrades the overall performance of the system. However, when the dispersion of the fiber increases, the nonlinear power of SMF segment is small that can be compensated by the mixing nonlinear power. At the channel spacing of 50 GHz, the OBP can expose its efficiency for the fiber with dispersion coefficient above 8 ps/nm.km. While this value reaches to 11 ps/nm.km in case of channel spacing of 25 GHz.

IV. CONCLUSIONS

We have investigated the distortion compensation efficiency for the OFDM WDM LR-PON using an advanced OBP, in which the OBP is positioned at the transmitter site. This OBP consists of real optical devices such as HNLFs, FBGs and the nonlinear waveguide. A model of theoretical analysis is also used to evaluate the efficiency of this technique and show that the OBP can compensate significantly the Kerr nonlinearity in the OFDM WDM system by choosing suitable parameters. The simulation model of the OBP-assisted OFDM WDM LR-PON at 100 Gbps is setup to validate the efficiency of the proposed compensation method in real conditions. The obtained results show that the BER performance of the system can be improved many orders of magnitude compared with that of the system without OBP. Consequently, the implementation of the OBP-assisted OFDM WDM LR-PON with very high bitrate of 100 Gbps is feasible in real conditions.

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GIẢI PHÁP BÙ PHI TUYẾN DỰA TRÊN KĨ THUẬT TRUYỀN NGƯỢC TRONG MIỀN QUANG ỨNG DỤNG CHO HỆ THỐNG OFDM-WDM

Abstract: Hiệu ứng phi tuyến Kerr là một trong các yếu tố chính giới hạn hiệu năng của hệ thống OFDM-WDM. Hơn nữa, có một giải pháp bù phi tuyến khả thi mà không làm tăng thêm độ phức tạp cho phía thu là rất cần thiết cho các ứng dụng của mạng quang thụ động khoảng cách dài (LR-PON). Trong bài báo này, chúng tôi đề xuất một mô hình bộ truyền ngược trong miền quang (OBP) cải tiến, dựa trên phương pháp Fourier tách bước, để bù lại ảnh hưởng phi tuyến và tán sắc trong hệ thống OFDM-WDM. Bộ OBP đề xuất gồm các phần tử quang có sẵn trong thực tế, trong đó sợi quang phi tuyến lớn (HNLF) đóng vai trò toán tử phi tuyến, cách tử Bragg sợi (FBG) đóng vài trò toán tử tuyến tính và ống dẫn sóng phi tuyến đóng vai trò phần tử liên hợp pha và được đặt tại phía phát nên rất phù hợp cho các ứng dụng LR-PON. Hiệu quả của bộ OBP đề xuất trong hệ thống OFDM-WDM được đánh giá dựa trên các tính toán lý thuyết và kiểm chứng dựa trên mô phỏng Monte-Carlo. Các kết quả thu được từ phân tích đánh giá và mô phỏng đều cho thấy bộ OBP đề xuất cải thiện đáng kể hiệu năng của hệ thống khi mà các tham số như hệ số tán sắc và công suất bơm được lựa chọn thích hợp.

Keywords: Ghép kênh phân chia theo tần số trực giao (OFDM), Ghép kênh phân chia theo bước sóng (WDM), Các giải pháp bù phi tuyến, Truyền ngược trong miền quang (OBP), Mạng quang thụ động khoảng cách dài (LR-PON).

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