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Dispersion Estimation and Compensation Using FrFT and LMS Adaptive Methods for Reliable Optical Communication

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Abstract - In this paper, we propose a fractional Fourier transformation (FrFT) to blindly assess the third-order dispersion in optical fiber communication system. By measuring the chromatic dispersion (CD) at different wavelengths, this technique can estimate the dispersion slope and further it can calculate the third-order dispersion. The Least mean square adaptive method is also utilized at last for the compensation of dispersion effectively. The simulation results exhibit that the estimation error is less than 2% in 28GBaud dual polarization quadrature phase-shift keying (DP-QPSK) and 28GBaud dual polarization 16 quadrature amplitude modulation (DP-16QAM) system. Through simulations, the proposed third-order dispersion estimation method is appeared to be powerful against nonlinear and amplified spontaneous emission (ASE) noise. Moreover, to decrease the computational complexity, searching step with coarse and fine granularity is looked to search optimal order of FrFT.

Keywords* - *Energy convergence, Optimal order selection, Third order dispersion, Dispersion compensation, Reliable optic communication.

I. INTRODUCTION

Over the most recent couple of years, there has been immense increment of uses in media communications areas that require incredible measures of data transmission administrations, for example, intuitive mixed media, video conferencing and gushing sound which has made the limit of the current optical fiber frameworks deficient [1]. With the fast development of the data business all through the world, more consideration is being given to optical fiber correspondence systems having substantially higher speed and bigger limit [2].

Dispersion is the significant restricting component as the bit rate and the transmission separate increments [3]. Debasement of the execution of the framework happens because of expanded between tweet impedance and lessened optical power [4]. Chromatic dispersion (CD) is one of the disability factors restricting the execution of an optical fiber correspondence framework. Up and coming, numerous strategies have been looked into and conveyed to quantify or screen CD in optical strands [5-6]. In optical fiber correspondence framework, the signal transmission is liable to the impact of heartbeats widening caused by the dispersion [7-11]. Dispersion administration systems are expected to stifle beats widening. Regardless of whether the transmission bandwidth is constrained to a solitary channel, third-arrange dispersion (TOD) makes beats have trailing swells which debases the execution of the ultrahigh speed optical transmission frameworks. Hence, in such a high piece rate framework, it turns out to be progressively critical to precisely repay the second-arrange scattering, as well as the TOD or dispersion incline of the fiber [12]. The exact estimation of third-arrange dispersion and further pay can extraordinarily lessen the harm caused by third-arrange dispersion [13, 14].

Different methodologies of CD estimation in computerized lucid recipients have been exhibited [15-18]. One of the techniques depends on parameter extraction from equalizer taps. Because of a set number of channel taps in the collector, this arrangement may just be utilized to screen generally little CD. To help longer connections, CD examining is frequently utilized. The four unique measurements, in particular constant modulus algorithm (CMA) metric, mean signal control, Eigen esteem spread and recurrence range autocorrelation, were presented and tentatively checked in the transmission explore. As of late, a more effective system was proposed in [19] by taking note of that the previously mentioned seek process is commensurate to applying a quick Fourier transform (FFT) on the autocorrelation of the discrete spectrum [20].

II. RELATED WORK

Raffaele Corsini *et.al* [21]had proposed chromatic dispersion (CD) pay and estimation in lucid optical frameworks. The technique depended on a Frequency Domain Equalizer (FDE), a low unpredictability Time Domain Equalizer orchestrated in a butterfly structure (B-TDE) and an Optical Performance Monitoring (OPM) hinder in a circle design. The circle was that, the CD esteem repaid by the B-TDE at all emphases and assessed by the

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OPM was given to the FDE; as indicated by that estimation, in the ensuing cycle, the FDE remunerates additionally the amount. The system was rehashed until the point that the lion's share of CD was repaid by the FDE what's more, a little lingering amount was remunerated by a low unpredictability B-TDE with few taps. The strategy was stretched out to whole deal uncompensated connections abusing the data on the mean square blunder (MSE) gave by the B-TDE

Sheng Cui *et.al* [22] had proposed a novel symbol rate estimation (SRE) procedure using the clock tone (CT) got by Godard timing recuperation calculation was proposed. By this method, the known testing rate of the analog-to-digital converter (ADC) in advanced intelligent optical collectors can utilized as a kind of perspective to straightforwardly decide the obscure flag image rate. The effect of polarization mode dispersion (PMD) on the CT extent can be alleviated by utilizing the hybrid correlation function (HCF) comprising of both auto-correlation function (ACF) and cross-correlation function (XCF) of the got signal spectrum, while the chromatic dispersion (CD) effect can be moderated by versatile CD remuneration procedures

Chongjin Xie *et.al* [23] had proposed exhibited a visually impaired chromatic dispersion (CD) estimation strategy for single-transporter intelligible optical correspondence frameworks. They demonstrate that the peak-to-average power ratio(PAPR) of a signal was a decent pointer of the measure of CD the signal encounters and the base PAPR normally compares to zero aggregated CD. By examining CD estimations of a CD compensator in a sound beneficiary and observing the PAPR after the CD compensator, CD can be assessed precisely.

Xiang Li *et.al* [24] had proposed the channel adjustment procedure for rational optical fiber transmission frameworks in independent component analysis (ICA). The rule of ICA for daze source partition was presented. The ICA based channel adjustment after both single-mode fiber and few-mode fiber transmission for single-transporter and orthogonal frequency division multiplexing (OFDM) tweak positions were explored, separately.

Mahdi Nouri *et.al* [25] had proposed a kernel least mean square (KLMS) algorithm with partially divided equalizing structure for the compensation of chromatic dispersion (CD) and nonlinear phase noise (NLPN) in a dual polarization optical communications system with coherent detection. They considered the single mode fiber channel. At the receiver, the additive optical noise was represented as additive white Gaussian noise. Phase modification was utilized at high signal powers to maintain the validity of Gaussian model of noise. They considered the QAM and PSK modulations and evaluate the performance of the proposed method in terms of error rate, phase error, and error vector magnitude (EVM).

III. DISPERSION ESTIMATION AND COMPENSATION USING FrFT AND LMS ADAPTIVE METHODS

The dispersion in optical fiber link will cause the optical pulse signal to become the chirp signal. As indicated by the energy convergence effect of the chirp signal in FrFT, the optimum order of the chirp signal after FrFT can be found to compute the dispersion at various wavelengths with a specific end goal to quantify third-order dispersion. Further least mean square (LMS) adaptive method is utilized for the dispersion remuneration. The steps of dispersion estimation and compensation using FrFT and LMS adaptive methods is given in figure 1,

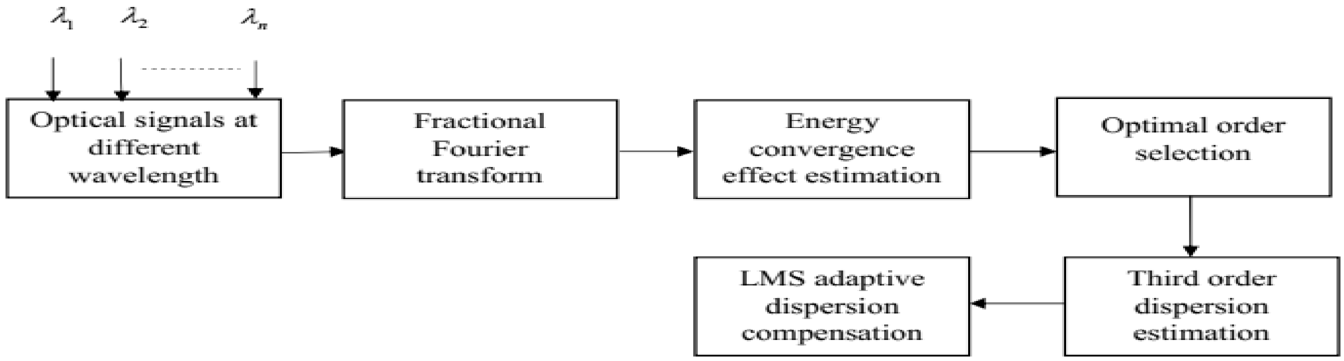

Figure 1: Block diagram of proposed method

3.1 Energy convergence effect estimation using FrFT

The FrFT is the general of traditional Fourier transform (FT). The FrFT is appeared to instigate order dependent rotation in time-frequency transform in figure 2, which can be translated by the short-time Fourier transform. The rotation angle α of time-frequency distribution is related to the order p of FrFT, which is $p = 2\alpha/\pi$. The FrFT characterized with the assistance of the transformation kernel as:

$$K_\alpha(v,t)=\begin{cases} A_\alpha \exp\left[j\left(\tfrac{1}{2}v^2\cot\alpha - vt\csc\alpha + \tfrac{1}{2}t^2\cot\alpha\right)\right], & \alpha = n\pi \\ \delta(v-t), & \alpha = 2n\pi \\ \delta(v+t), & \alpha = (2n\pm 1)\pi \end{cases} \tag{1}$$

$$\text{With } A_\alpha = \sqrt{1-j\cot\alpha / 2\pi}\,,\quad \alpha = \frac{\pi}{2}\cot p \tag{2}$$

Where, n is the integer and the FrFT of $x(t)$ is defined using the kernel and denoted by $X_p(v)$:

$$X_p(v)=\int_{-\infty}^{\infty} K_\alpha(v,t)x(t)dt \tag{3}$$

The best order of FrFT can be calculated by a statistical parameter $E_c(p)$ which can be used to describe the energy concentration of the signal in different order p :

$$E_c(p)=\int_{-\infty}^{\infty}\left|X_p(v)\right|^4 du \tag{4}$$

Where, $X_p(v)$ is the FrFT of the signal $x(t)$. By searching the maximum or minimum of $E_c(p)$, we can get the optimum fractional order of FrFT.

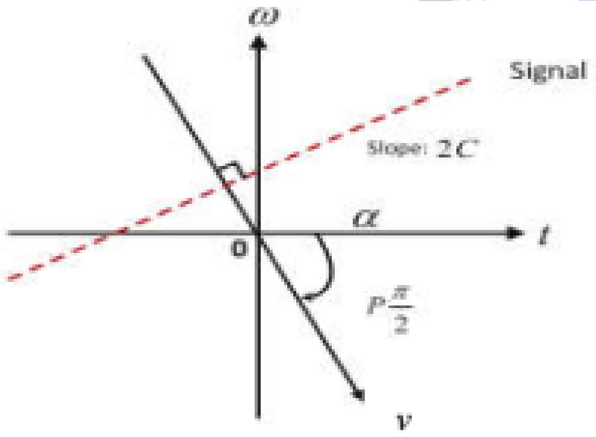

Figure 2: Time-frequency plane and a set of coordinates (v,w) rotated by an angle α relative to the original coordinates (t,ω)

3.2 Optimum order selection using FrFT

Chirp signal in the time domain can be expressed as:

$$x(t)=a(t)\exp(i\omega_0 t + iCt^2 + \phi_0) \tag{5}$$

Where, C is the chirp parameter.

$$\omega(t)=\omega_0 + 2Ct \tag{6}$$

Where, $\omega(t)$ is the frequency of the chirp signal, which is linearly increased with time.

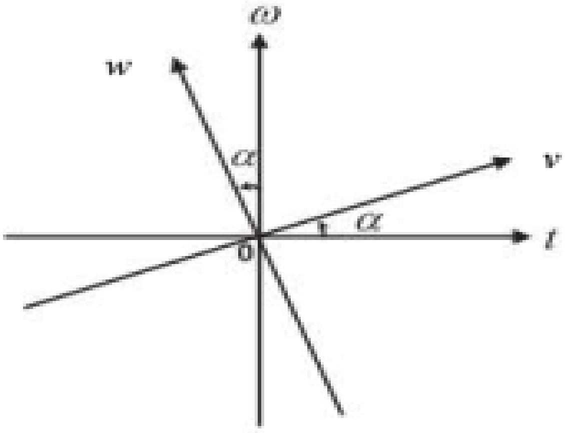

Figure 3: The projection of chirp signal in time-frequency plane

From figure 3, we can get the relation between p and C as:

$$\tan\left(p\,\pi/2\right) * \frac{2C}{d\omega/dt} = -1 \tag{7}$$

Where, dt and $d\omega$ are sampling interval in the time and frequency domain. We can locate the ideal FrFT order, subsequently the signal can be localized mostly in rotated time-frequency coordination, as appeared in figure 2, which decides C as takes after:

$$p\left(\pi/2\right) = arc\cot\left(-2C\, dt/d\omega\right) \tag{8}$$

The dispersion in optical fiber connection will cause the optical pulse signal to become the chirp signal. As per the energy convergence effect of the chirp signal in FrFT, the optimum order of the chirp signal after FrFT can be found to compute the dispersion at different wavelengths in order to measure third-order dispersion. A CD estimation method based on measuring the chirp of CD in frequency domain. In this manner, the chromatic dispersion (CD) in an optical fiber can be obtained from the optimum order of the FrFT as:

$$\beta_2 z = -\frac{dt}{d\omega}\tan\left(p_{opt}\frac{\pi}{2}\right) \tag{9}$$

Where, the second-order dispersion β_2 describes the group velocity dispersion which is related to the CD parameter D; z is the transmission distance and p_{opt} is the optimum fractional order.

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3.3 Third-order dispersion measurement based on FrFT

The dispersion parameter D_λ is commonly used in fiber-optics to replace the group velocity dispersion (GVD) parameter β_2. The relationship is as following:

$$D_\lambda = \frac{d\beta_1}{d\lambda} = -\frac{2\pi c}{\lambda^2}\beta_2 \tag{10}$$

Where, λ is the wavelength and c is the light speed. Taking equation (10) into equation (9), we can get:

$$D_\lambda z = \frac{2\pi c}{\lambda^2} * \frac{dt}{d\omega}\tan\left(p_{opt}\frac{\pi}{2}\right) \tag{11}$$

The third-order dispersion β_3 is the second order GVD slope, and is related to the dispersion parameter slope S_λ as follows:

$$\beta_3 = \frac{\lambda_{ref}^2}{(2\pi c)^2}\left(\lambda_{ref}^2 S_\lambda + 2\lambda_{ref} D_\lambda\right) \tag{12}$$

$$S_\lambda = \frac{dD_\lambda}{d\lambda} = \frac{d(D_\lambda z)}{d\lambda} \tag{13}$$

Where, $D_\lambda z$ is the accumulated *CD* at different wavelengths and therefore, $D_\lambda z$ should be measured in optical fiber system in order to estimate β_3.

3.4 Least mean square adaptive dispersion compensation

The LMS CD equalization is likewise executed by utilizing the convolution between the digital filter and the received symbols, while it requires an iterative and progressive correction on the tap weights vector to accomplish the minimum mean square error. The tap weights vector LMS in the LMS equalization can be expressed as follow,

$$W_{LMS}(t) = W_{LMS}(t-1) + \mu_{LMS}x(t)e^*_{LMS}(t-1) \tag{14}$$

$$e_{LMS}(t-1) = d_{LMS}(t-1) - W^H_{LMS}(t-1)x(t) \tag{15}$$

Where, $x(t)$ is the received symbol vector, LMS is the step size, $d_{LMS}(t)$ is the desired output symbol, $e_{LMS}(t)$ is the estimation error that is β_3, H is the Hermitian transform, and $*$ is the conjugate operation.

Firstly, we should find $E_c(p)$ of the received signals in optical fiber framework by condition (4) to look through the optimum order of signals at different wavelengths after FrFT. At that point the gathered CD can be measured by equation (11). Next, we can get the $CD_\lambda - \lambda$ lots to fit the slope of the curve according to equation (13). At long last, we can assess β_3 by equation (12). Basing on above investigating, the dispersion slope and the third-order dispersion can be investigating, the scattering slant and the third-arrange scattering can be evaluated FrFT. Finally the dispersion compensation is performed by utilizing LMS equalization as indicated by equation (14).

IV. SIMULATION RESULTS & DISCUSSION

The proposed third order dispersion estimation and compensation utilizing FrFT and LMS adaptive techniques in optical signals at different wavelengths is performed in MATLAB platform. To check the feasibility of proposed method to assess third order dispersion and compensation, we conducted simulation for 21 channels with 28GBaud DP-QPSK and 28GBaud DP-16QAM signals per channel. Distinctive channels have diverse wavelengths corresponding to emission frequencies are set from 192 THz to 194 THz and channel spacing is 100 GHz in the optical fiber system. The amplified noise is considered by setting Optical signal to noise ratio (OSNR) straightforwardly which is set to 20 dB.

In simulation, the data with length of 1024 samples after signals sampled at twice symbol rate are utilized for evaluating CD in each sub-channel. The E_c(p) of data is ascertained by quick FrFT algorithm firstly, which has a similar intricacy with FFT. At that point we examine the order with $\Delta = 0.001$ step size in a particular range of FrFT order [1, 1]. The optimum order can be controlled by peak search and relating gathered CD can be calculated according to equation (11). The dispersion slope measured in an optical fiber interface with FrFT based strategy for QPSK and 16QAM is shown in figure 4,

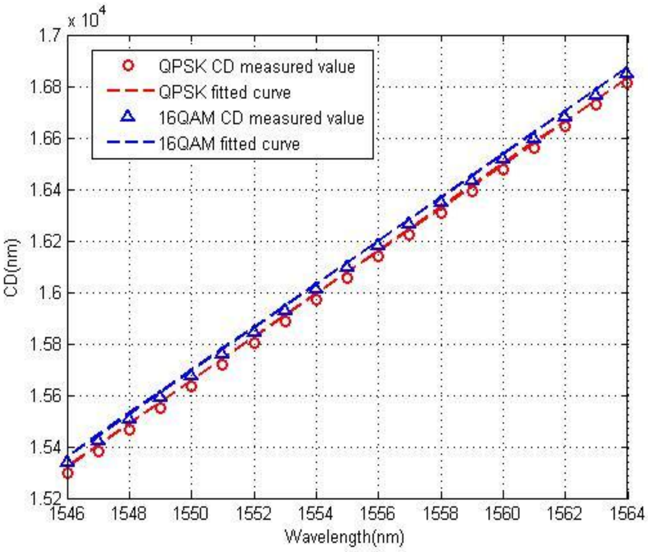

Figure 4: Dispersion slope measured in an optical fibre link with FrFT based method for QPSK and 16QAM

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In figure 4, we can see the peaks of 28GBaud DP-QPSK signals in the sub-channel 1 and sub-channel 21 with wavelength 1546.4 nm and 1562.5 nm where the optimum orders are 0.118 and 0.131. At that point the aggregated CD can be ascertained through taking the optimum orders into equation 11 in the sub channel 1 and sub-channel 21. Similarly, all of accumulated CD with 21 sub-channels can be obtained. Next we get the $D_\lambda z - \lambda$ plots to fit the slope of the curve as indicated by equation 13. In figure 4, the fitted curve slope and the dispersion slope can be obtained; the measurement error is less than 2%. From the simulation results, the feasibility of our technique to appraise third-order dispersion can be checked.

When 5 channels with emission frequencies from 192 THz to 194 THz and channel spacing 500 GHz are utilized, it additionally can assess estimate dispersion slope with the worse estimation error than 21 channels as shown in figure 5(a) and 5(b). In any case, the estimation accuracy is sufficient to calculate dispersion slope. So simulations with 5 channels are used to evaluate the method’s tolerance for ASE and nonlinear noise. Firstly, to examine the tolerance for ASE noise, we calculated the absolute estimation error for 28GBaud DP-QPSK and 28GBaud DP-16QAM signals by setting different OSNR in case of 1000 km with the accumulated CD of 16,000ps/nm, keeping other simulation parameters constant. The results verify that our method can estimate dispersion slope precisely with OSNR from 10 to 30 dB for 28GBaud DP-QPSK signals in figure 5(a) and with OSNR from 14 to 30 dB for 28GBaud DP-16QAM signals in figure 5(b).

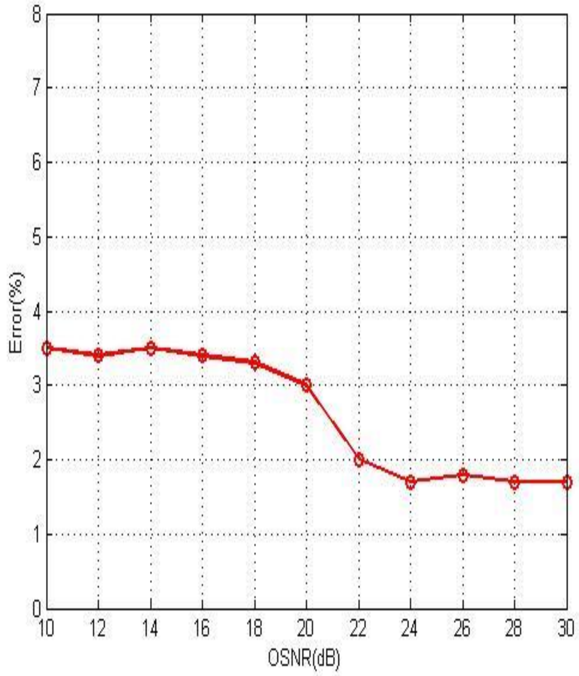

Figure 5 (a): Dispersion slope estimation error with different OSNR for DP-QPSK

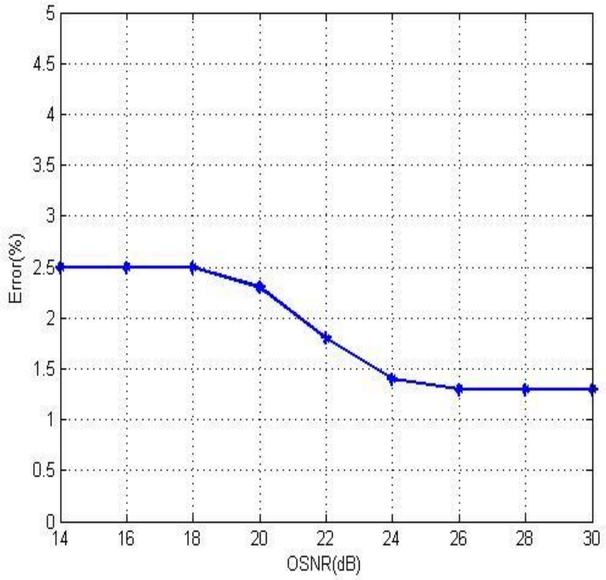

Figure 5 (b): Dispersion slope estimation error with different OSNR for DP-16QAM

The absolute estimation error for 28GBaud DP-QPSK and 28GBaud DP-16QAM signals are computed to look into the tolerance for nonlinear noise by setting different launch power per sub channel with 20 dB OSNR and keeping other simulation parameters constant. The result is appeared in figure 6.

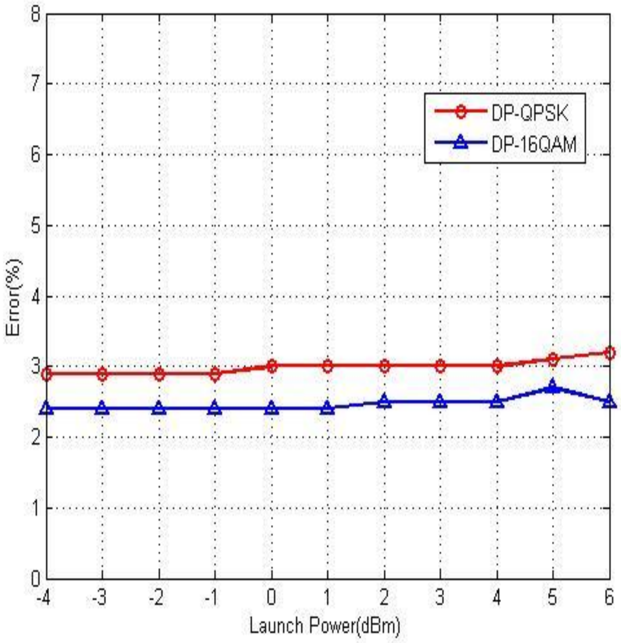

Figure 6: Dispersion slope estimation error with different launch power for DP-QPSK and DP-16QAM

The figure 6 is proves that, for 28GBaud DP-QPSK and 28GBaud DP-16QAM modulation formats, the dispersion slope estimation method based on FrFT is accurate until the launched power approaches 6 dBm per channel. Then the LMS adaptive equalization is additionally examined for CD compensation and the compensation graph is given in figure 7,

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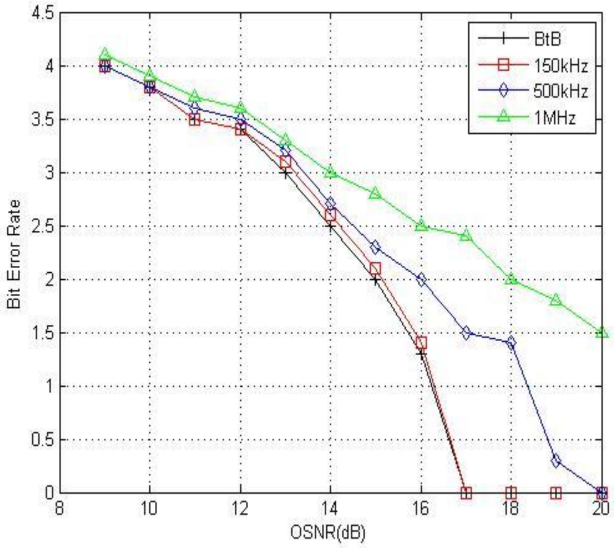

Figure 7: Performance of 28-Gbaud DP-QPSK transmission system using LMS dispersion compensation with different fiber lengths

The figure 7 demonstrates the BER performance of the 28-Gbaud DP-QPSK transmission framework using LMS equalization for dispersion compensation. The performance of a 20 km fiber transmission system with different wavelengths is in figure 7. This proves that the LMS algorithm can perform to some extent to compensate the dispersion as well.

V. CONCLUSION

We have presented an effective dispersion estimation and compensation utilizing FrFT and LMS adaptive strategies for coherent optic fibre communication. This technique has not connection with modulation formats, and the results for QPSK and 16QAM signals show that the measurement error is less than 2%. In addition, the proposed third-order dispersion estimation method is appeared to be robust against nonlinear and amplified spontaneous emission (ASE) noise. In this way, the method in view of FrFT can be utilized to monitor the third-order dispersion in optical fiber system. Further the LMS adaptive method compensates the dispersion as well.

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