Simulation models and Evaluation of Pre- and Post- Dispersion Compensation of DWDM Links Using a Bidirectional DCF with FBG Reflectors

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Abstract: - Dispersion compensation of ultra-high data rate optical transmission is a key function to increase optical signal integrity and link performance. It has been shown that the link performance profile is also used in link identification as well as source identification. Dispersion compensation is based on specialty fiber that has negative dispersion coefficient and it is many kilometers long. Typically such fiber is placed at the end or at the beginning of standard single mode fiber, termed pre-compensation and post-compensation, respectively. As such, few questions arise. How can the dispersion compensation fiber length be reduced? Which of the two methods performs better? What are the performance characteristics of each? In this paper, we model and simulate the pre- and post-compensation methods and we compare the results to establish which of the two exhibits better efficiency and performance in fiber optic links, each being eighty kilometers of standard single mode fiber. Dispersion compensation is accomplished with a novel cost-efficient method that uses half the required length of dispersion compensating fiber and also fiber Bragg gratings that act as reflectors. In our model we use 10 DWDM channels, each modulated at 10 Gbps. Simulation for multi-links of 600 km link path suggest that pre-compensation performs better than post-compensation.

Keywords: - DWDM networks, Dispersion Compensation, fiber Bragg gratings

1 Introduction

With the increasing demand of bandwidth over DWDM optical long haul communication links, link performance and data integrity is of paramount importance [1]. As the fiber link becomes longer, and as the data rate becomes higher, signal integrity and thus signal performance parameters degrade due to a number of photon-matter-photon effects [2]. Among the degrading phenomena is chromatic dispersion, the end result of which is manifested with increased intersymbol-interference (ISI), bit error rate (BER) and decreased signal-to-noise ratio (SNR) and [3]. To combat chromatic dispersion, specialty dispersion compensation fiber (DCF) is used in devices known as dispersion compensation modules (DCM); DCF creates chromatic dispersion opposite to the chromatic dispersion of standard single mode fiber (SMF) [4, 5]. However, the dispersion coefficient of DCF is about four to five times higher than that of SMF and thus the DCF length is about four to five times shorter than that of SMF. However, for about 60-80 km SMF, about 15-20 km of DCF is required. To reduce the physical length of DCF, a novel method has been developed that uses half the DCF length in a bidirectional mode using fiber Bragg gratings as reflectors (FBG) [6]. For simplicity of description, we call this method DCF:2+FBG.

The combination of SMF+DCF increases the total length of fiber and thus the attenuation and thus optical amplification is needed. Thus, two key components in a DCM is the DCF fiber and the optical amplifier, typically an Erbium doped fiber amplifier (EDFA). Typically, a DCM is placed at one of the two ends of a SMF fiber link; if at the beginning of the link, it is known as pre-dispersion compensation and if at the end post-dispersion compensation.

In this paper, we model and simulate the pre-dispersion compensation and the post-dispersion compensation methods for a multi-link design. The DCM in our model uses the novel DCF:2+FBG method. Simulation results for over 600 km multi-link path suggest that pre-compensation performs better than post-compensation.

2 Dispersion compensated multi-link model design

The multi-link design in our model consists of link lengths in increments of 80 km. Each link contains a DCM, and 10 DWDM optical channels with 100 Ghz spacing. Each channel is OOK NRZ modulated at 10 Gbps. Figure 1 shows the DWDM optical multi-link design using the pre-compensation dispersion scheme, and Figure 2 the post-compensation; in both models, the number of links is controlled with the "loop control" simulation tool. Table 1 tabulates the component parameters used in our model; to make our model as realistic as possible; we have selected parameters of components that are readily available.

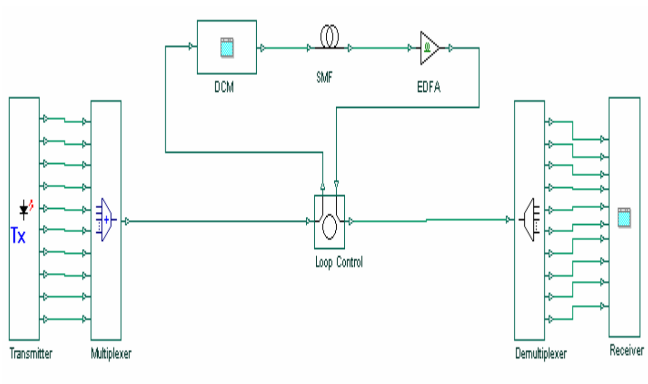

Figure 1. Link model design using pre-compensation scheme (Loop control is an artifice that defines the number of concatenated links)

In our model, we have ten optical sources ranging from 192.7Thz to 193.6Thz and with channel spacing of 100Ghz. Each source contains a pseudo random signal generators (PRS). The PRS is connected with a Mach-Zehnder modulator to produce a 10 Gbps on-off keying non return to zero (OOK NRZ) signal. The laser output power is set at 0dBm. Each link span consists of 80km SMF plus a DCM; the DCM contains 8km DCF fiber.

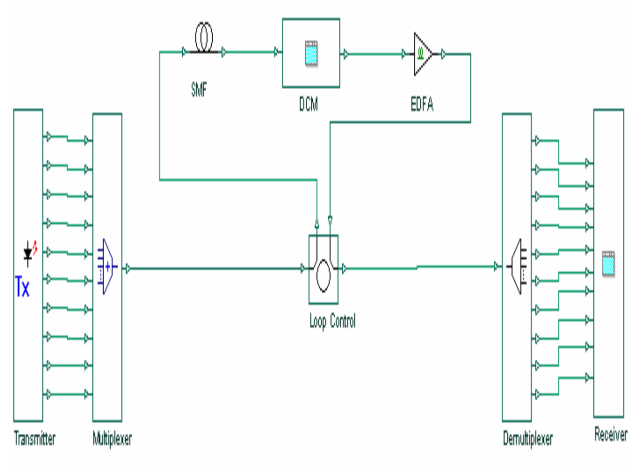

Figure 2. Link model design using post-compensation scheme (Loop control is an artifice that defines the number of concatenated links)

Figure 3 shows the dispersion compensation module (DCM). The DCM consists of 8km DCF, ten FBGs each at one of the ten center wavelengths (see Table 1), and each reflecting the corresponding signal. Thus, when a wavelength passes through the DCF, it is reflected by its corresponding FBG and it propagates in the opposite direction in the DCF (thus requiring half the DCF length). The reflectivity of each FBG is 0.99 or 99%. In a typical design, at the other end of the DCF optical rotators couple the compensated signals onto the next link, isolators do not let optical power to flow toward the source and an EDFA amplifier compensates for the power loss in both the SMF and DCF. In our simulation model we did not have a bidirectional DCF tool. To overcome the limitation of the simulation tools we used two separate DCF halves and an optical multiplexer and then amplified the optical DWDM signal.

For each scheme, we simulated different link lengths. The overall length of the multi-link was controlled by selecting the number of loops of the "loop control" simulation tool. In our simulation, the SMF model had chromatic dispersion, self phase modulation, and cross phase modulation nonlinear effects enabled. Modeling and simulation has been repeated for both pre-compensation (Figure 1a) and post-compensation (Figure 1b) schemes. Simulation results were obtained using the OptiSystem3.0 simulation tool of Optiwave Corporation.

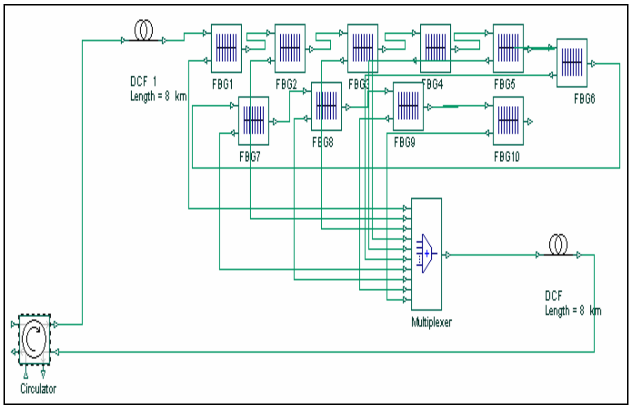

Figure 3. Model of the dispersion compensation module (DCM)

Table 1. Parameters of the simulation model

transmitter	10 channels, 100GHz spacing, 10Gbps, OOK NRZ, 0dBm output power, operating frequency from 192.7—193.6THz.
multiplexer	10 channels
SMF	Length=80km each link; attenuation=0.2 dB/km; group delay=4.9µs/nm; dispersion slope=0.075ps/nm^2-km; effective area=70 µm^2
EDFA	Gain=19dB ; Noise figure=4dB
DCM – DCF	Length=8km; Attenuation=0.3dB/km; Group delay=4.9µs/nm; Dispersion Slope=- 0.3ps/nm^2/km; Effective area=22µm^2
DCM – FBG	Number=10; Bandwidth=100GHz; Center frequencies: 192.7Thz, 192.8Thz, 192.9Thz, 193.0Thz, 193.1T,193.2Thz, 193.3Thz, 193.4Thz, 193.5Thz, 193.6Thz
Demultiplexer	Number of Output Ports=10; Bandwidth=20Ghz; Insertion loss=0dB.
Receiver PIN	Responsivity=1A/W; Dark current=10nA

3 Analysis of Simulation Results

The simulation results of the pre-compensation and post-compensation models are shown in Figure 4 and Figure 5. The performance of each model is evaluated based on bit error rate versus link length. Each link consists of 80km SMF, and 8km DCF and an optical amplifier.

The simulation results suggest that performance degrades as the link length of both schemes increases; this is an expected result as residual dispersion and amplifier noise is cumulative. However, as we compare the performance of the pre- and post-compensation schemes, then simulation results indicate that the performance of pre-compensation is better than post-compensation for selected channels. For example, for seven concatenated links each of 80km SMF and a DCM, for the pre-compensating case the BER for channel 1 is about 1E-9, for channel 5 is about 1E-43, and for channel 10 is about 1E-12. For the post-compensating case and for the same link length, the BER for channel 1 is about 1E-6.5, for channel 5 is about 1E-20, and for channel 10 is about 1E-13.

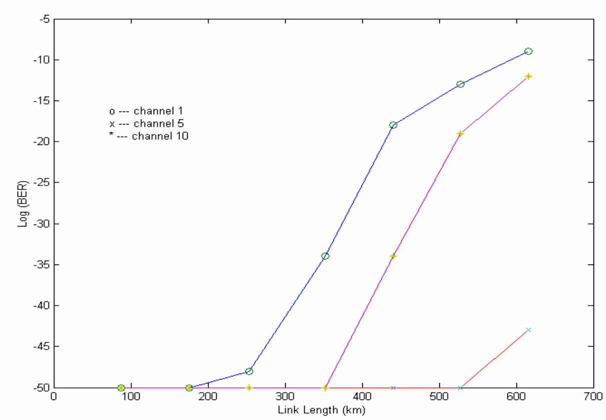

Figure 4. Channel performance with the pre-compensation scheme

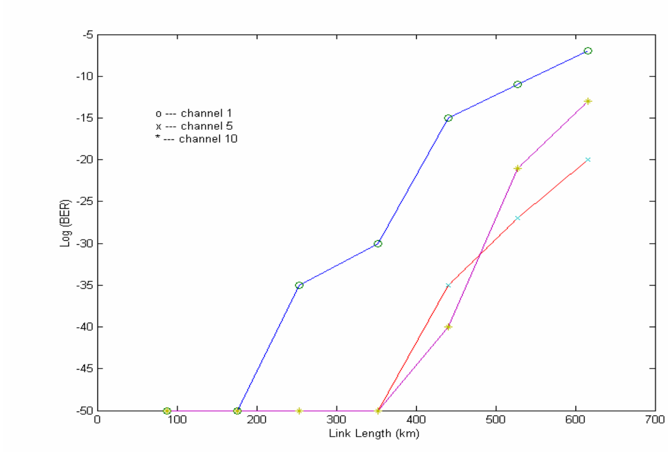

Figure 5. Channel performance with the post-compensation scheme

From the above simulation results, despite the performance improvement for selected channels with pre-compensation, BER at low levels may not be acceptable. However, one should also consider that the next generation optical network included protocols with forward error correction (FEC) [7], which by correcting errors greatly improves the link performance so that the actual link length can exceed 1000km.

4 Conclusions

We have used models and simulation tools to evaluate the performance of pre-compensation and post-compensation in optical multi-links at a total length exceeding 600km. In our models, we used 10 DWDM optical channels, each modulated at 10 Gbps. Each 80km link includes a bidirectional DCM that consists of an 8km DCF and 10 FBG that act as channel reflectors. Doing so, half the typical DCF length is required thus reducing the physical size of the compensating module and overall cost. We compared the performance of the pre and post dispersion compensation schemes. Simulation results suggest that pre-compensation performs better than post-compensation. Our research continues in order to identify an optimum pre- and post-compensation configuration over both the C and L spectral bands.

References:

[1] S.V. Kartalopoulos, "*DWDM : Networks, Devices and Technology*", IEEE Press/John Wiley & Sons, 2003.

[2] S.V.Kartalopoulos, "*Fault Detectability in DWDM*", IEEE Press, 2001.

[3] S.V. Kartalopoulos, "*Optical Bit Error Rate*", IEEE Press/John Wiley & Sons, 2004.

[4] B.Zhu, L.E. Nelson, B. Edvold, L. Gruner-Nielsen, S. Radic, J. Centanni, and A.Gnauck, "1.6 Tbit/s (40 x 42.7 Gbit/s) WDM transmission over 2400-km of fiber with 100km dispersion-managed spans", *Electronics Letters*, vol. 38, no. 13, 2002, pp. 1153-1155.

[5] A. Royset and D. R. Hjelme, "Combating Nonlinear Distortion in Optical Fiber Transmission Systems by Optimum Dispersion Compensation and Modulation Format", *Journal of Nonlinear Optical Physics and Materials*, vol. 9, no. 2, 2000, pp. 227-234.

[6] M. Bouhiyate and S.V. Kartalopoulos, "Performance of Optimized Chromatic Dispersion Compensated 10 Gbps DWDM links", *Proceedings of NFOEC-2003 Conference*, Orlando, FLA, Sept. 6-10, 2003, pp. 1162-1167.

[7] S.V. Kartalopoulos, "*Next Generation SONET/SDH*", IEEE Press/John Wiley & Sons, 2004.