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Effective dispersion management in Chirp-Managed Directly Modulated Laser based Reach colorless DWDM-PONs with remodulation

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Abstract: Chirp Managed Laser (CML) based colorless 10 Gbps long reach dense wavelength division multiplexing passive optical network (LR-PON) system, having 50 GHz channel spacing with remodulation in upstream, was simulated. Two methods of chromatic dispersion management namely Fiber Bragg Gratings and Dispersion Compensating Fiber were employed. With the help of DCF, network reach was extended to 62 km both in downstream and upstream. In case of FBG, network was increased to 70 km in both directions. Comparatively FBG is better dispersion compensator and cost effective tool for LR-PONs.

Keywords: Chirp managed laser (CML), Wavelength division multiplexing passive optical network (WDM-PON); dispersion chromatic management (DCM); fiber Bragg grating (FBG); dispersion compensating fiber (DCF)

1. INTRODUCTION

Wide scale deployment of fiber to the home (FTTH) at an exponential rate is giving birth to a new type of passive optical network (PON) beyond 20 km, called long-reach (LR) PON (Chow *et al.,* 2012 and Wong *et al.,* 2012). This network is rapidly evolving in response to higher bandwidth demands in access part at the lowest price (Hong *et al.,* 2011).

In rural areas, customers are located at far-flung places from switching centers. Concurrently, they are situated from each other at long distances. Therefore task of providing higher bandwidth to these remotely placed subscribers can only be achieved with the help of LR-PON at an affordable expense.

A LR-PON structure in general, consists of an enhanced fiber that connects the central office (CO) and the local exchange, and optical splitter linking subscribers to the fiber. The main purpose of LR-PON is to increase the reach of the network and minimize the switching nodes. It results in simplified hierarchy of telecom networks and allows consolidation of access and metro networks (Kazovsky *et al.,* 2011, Song *et al.,* 2010) as illustrated in (**Fig.1)**. LR-PON reduces both network capital expenditure (CapEx) and operating cost (OpEx) (Cvijetic *et al.,* 2010). LR-PONs have usually larger split ratios and the cost of the equipment for each subscriber is shared by each customer. It results in maximum utilization of resources (Lin *et al.,* 2009). To increase the link reach and coverage of OLT, optical amplifiers are to be used in GPON (Cauvin *et al.,* 2006). Researchers in 1990s were also interested in the idea of extending the reach via intermediate optical amplifiers (Paiva, *et al.,* 2011).

However, link reach of Dense-Wavelength-Division-Multiplexed-Passive-Optical-Network DWDM -PON) is limited due to chromatic dispersion (CD) (Davey *et al.,* 2009). It can be mitigated by using several dispersion compensating measures such as applying optical single sideband with carrier (OSSB+C) modulation, an optical carrier suppression modulation, Chirped Fiber Bragg Gratings (FBG), and Dispersion Compensation Fiber (DCF). In recent years, Fiber Bragg Gratings (FBGs) and Dispersion Compensation Fiber (DCF) have been identified as effective remedies for minimizing the effects of chromatic dispersion and improving the bit error rates (BER) (Spolitis *et al.,* 2011).

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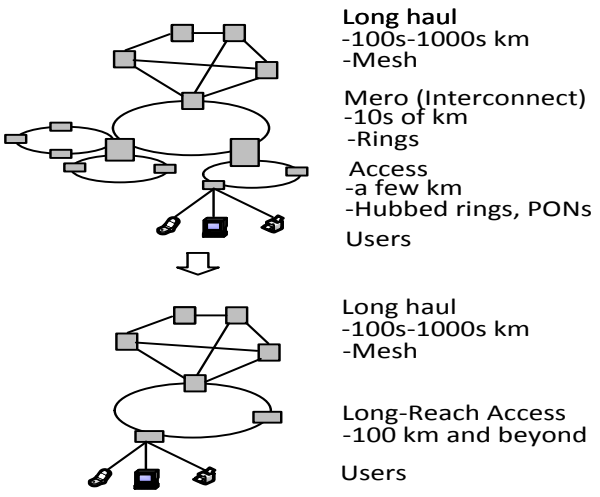


Fig. 1: Simplified Long-Reach PON

To further reduce the price in the cost-sensitive access network, chirp managed lasers (CMLs) can be used as efficient alternatives, compared to the transmitters with external modulators (ems), such as electro-absorption modulator (EAM) or Mach-Zehnder modulator (MZM) because external modulators are expensive and have larger size (> 45mm) and higher power consumption (requiring driving voltage 5V or more) (Latif et al 2012). Besides being inexpensive, CML transmitters are have tolerance to dispersion.

In this article, reach of a DWDM-PON access network has been extended to make it LR-PON. At OLT, chirp-managed directly managed laser (CML) is employed as transmitter and remodulation of the signal from the source located at OLT is performed at ONU to save the cost of extra source at last mile section. The resulting chromatic dispersion in the fiber has been controlled with the help of two ways: FBG and DCF and increase in the link reach of DWDM-PON network is analyzed in both cases.

The remainder of the article is structured as follows. A brief theoretical description of CML and Chromatic Dispersion Management (CDM) is given in section-II, and FBG and DCF are also concisely described. Simulation set up of both DCM methods is illustrated in section-III. In subsequent section, performance and results are discussed. Section-V concludes the work.

2. THEORETICAL BACKGROUND

2.1. Basic theory of CML

The greatest benefit of CML is that it has high tolerance towards dispersion produced in the fiber. CML consists of directly modulated laser (DML) and optical filter, also called optical spectrum reshaper (OSR). A wavelength locker is formed at the OSR using two photodiodes. The purpose of these diodes is to keep a close watch on power from the laser source and also reflections returning from optical filter respectively. Temperature of the signal from DFB is controlled by this locking circuit to control wavelength and thence achieving constant ratio of both photodiodes.

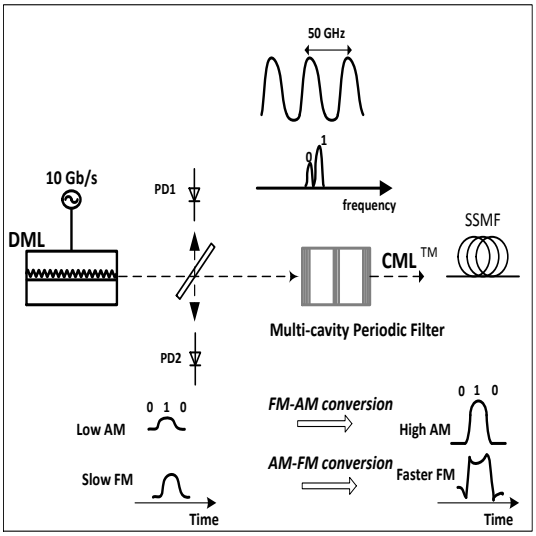


Fig. 2 CML working principle

Fig. 2 shows the working of CML. A DML is usually biased near threshold and modulated to get high extinction ratio (ER) ranging between 8 to 10 dB, it increases transient chirp. This type of chirp occurs, when there is transition of bits. This chirp spreads the optical pulse. To avoid this chirp, laser in CML is biased at ~ 5 times of threshold. Digital data is used to modulate it. By this way, a low extinction ratio (ER ~ 1-2 dB) is obtained. This operation results in frequency shift keying (FSK) modulation and "1" bits are faster (blue shifted) than "0" bits. (Yu *et al.,* 2009). It produces high output power with low jitter and transient chirp is adequately suppressed.

Laser wavelength and transmission edge of the OSR are aligned. Due to this alignment, blue shifted "1" bits are passed and "0" bits are attenuated (FM-AM conversion) and ER > 10 dB is achieved. Besides, OSR has a limited bandwidth. It filters out any residual high frequency components of transient chirp.

After that the role of OSR comes into play. Here, adiabatic chirp is utilized to improve the transmission characteristics. If adiabatic chirp of laser is set as half of the bit rate, i.e., 5 GHz chirp for 10 G bit/s and the pulse width at this rate is 100 ps, phase shift during "0" bit will be ($2\pi \times 5$ GHz $\times 100$ ps)= π.

Therefore second "1" bit will be π out of phase with first "1". This causes a change in frequency profile of OSR and "1" bits are flat–topped and nearly chirp free. It helps in keeping the eye open even in the presence of fiber dispersion for longer transmission (Matsui *et al.*, 2006).

2.2 Chromatic Dispersion

Dispersion can be defined as broadening of light pulse travelling along the optical fiber. This distortion of the pulse has a damaging effect on neighboring pulses and causes inter-symbol interference (ISI) in received signal, which makes it difficult to recover clock and data at high frequencies and results in higher BER. It puts limitations on the rate of data transmission and reach of network.

Chromatic dispersion has two components: waveguide dispersion and material dispersion. The waveguide dispersion occurs due to the structure of core and cladding of the optical fiber and different wavelengths travel with different velocities in it (Keiser 2003). Material dispersion forms major portion of CD, and it occurs due to the variance in refractive index ***n*** of optical fiber with wavelength λ.

2.3 Chromatic Dispersion Management

A dispersion management resolves the effect of chromatic dispersion along single mode fiber (SMF). The basic idea behind such a scheme can be understood by following equation (Agrawal 2011):

$$\frac{\partial A}{\partial z}+\frac{i}{2}\beta_2\frac{\partial^2 A}{\partial t^2}-\frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3}+\frac{\alpha}{2}A=i\gamma|A|^2A \quad (1)$$

Where A is the pulse – envelop amplitude, α is the fiber loss coefficient and γ is the non-linear parameter of the fiber. β_2 and β_3 are second and third order dispersion coefficients respectively. β_3 is ignored when $|\beta_2|$ is greater than 0.1 ps^2/km. Equation (1) can be solved by using Fourier Transform. For specific case of $\beta_3=0$, the solution becomes

$$A(z,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{A}(0,\omega)\exp\left(\frac{i}{2}\beta_2 z\omega^2-i\omega t\right)d\omega \quad (2)$$

Exp ($i\beta_2 z\omega^2/2$) is called phase factor. It causes dispersion in the optical signal. In order to reduce the dispersion, this phase factor must be eliminated. This can be done at any place in the network.

2.3.1 Dispersion Compensating Fiber (DCF)

The use of dispersion compensation fiber (DCF) can manage the Group Velocity Dispersion (GVD) in the fiber completely. Its working can be understood with the help of Eq. (1).

In this technique, a second fiber (DCF) with different parameters (effective core area, attenuation coefficient etc.) is used along with main fiber. Then eq. (2) becomes:

$$A(L,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{A}(0,\omega)\exp\left(\frac{i}{2}\omega^2\left(\beta_{21}L_{SMF}+\beta_{22}L_{DCF}\right)-i\omega t\right)d\omega \quad (3)$$

Where $L=L_{SMF}+L_{DCF}$ and β_{2j} is the GVD parameter for the fiber segment of length L_j (where j=1, 2). If ω^2 is vanished with the help of DCF, the dispersion will be completely eliminated, as shown in following equation:

$$\beta_{21}L_{SMF}+\beta_{22}L_{DCF}=0 \quad (4)$$

2.3.2 Fiber Bragg Gratings (FBG)

A Fiber Bragg Grating is a reflector that reflects a particular wavelength and passes all other wavelengths. The reflected wavelength is due to presence of a stop band. This is a frequency region blocking the wavelength. The Bragg wavelength (λ_B) is at the center of Stop band: $\lambda_B=2n_e\Lambda$, where Λ is the grating period and n_e is the effective index of the grating in the fiber core.

Chirped fiber gratings are used for reducing dispersion because they have larger stop band. The optical period $n_e\Lambda$ and Bragg wavelength both vary over the length of gratings. Therefore different frequencies are reflected at different points. The reflection occurs only when Bragg condition is met. In order to compensate the dispersion in the chirped fiber gratings:

$$D_{SMF}(\lambda_S)L+D_{FBG}(\lambda_S)=0 \quad (5)$$

Whereas $D_{SMF}(\lambda_S)$ is the dispersion coefficient of conventional Single Mode Fiber in the central wavelength (λ_S) and $D_{FBG}(\lambda_S)$ is the dispersion compensation amount of FBG. L is the length of SMF.

3. SIMULATION SETUP

CML based WDM-PON was simulated in OptiSystem. **(Fig. 3)** shows the simulation set up for the proposed AWG based WDM-PON system with 04

channels in downlink (DL) direction and 04 channels in uplink direction (UL), each of 10 Gb/s, with FBG as DC compensator.

The same set up was used in fig. 4 with DCF. 04 signals having each 0 dBm power, were produced by 04 distributed feedback (DFB) lasers at wavelengths 1552.52nm (λ_1), 1552.12 nm (λ_2), 1551.72 nm (λ_3), and 1551.32 nm (λ_4) for four different channels respectively keeping 50 GHz channel spacing. Erbium Doped Fiber Amplifier (EDFA) with 10 dB gain was used immediately after multiplexing the four channels and before transmitting on SMF. For each channel, 10 Gb/s 2^7-1 PRBS data and 10 Gb/s clock signal were NANDED giving IRZ data to modulate CML. Bessel optical filters were used as OSRs. The output was then fed to the Mach-Zehnder modulator (MZM), driven by a 5-GHz clock pulse generating ~33% duty-cycle RZ pulses.

The four RZ-DPSK signals thus produced were then multiplexed by a 4x1 AWG MUX on 50 GHz channel grid and transmitted over a single mode feeder fiber. Values of parameters used here are given in (**Table 1).** The down link multiplexed signal was first de-multiplexed using a AWG DEMUX and then received by the ONUs. A 3 dB optical splitter taps half of the optical power. A Mach–Zehnder delay interferometric demodulator (MZDI) converted the phase-modulated to intensity-modulated signal. Then the signal was forwarded to PIN receiver. The other half of the signal power was sent to a Mach-Zehnder intensity modulator (IM) that modulates 10 Gbps upstream data with RZ-OOK.

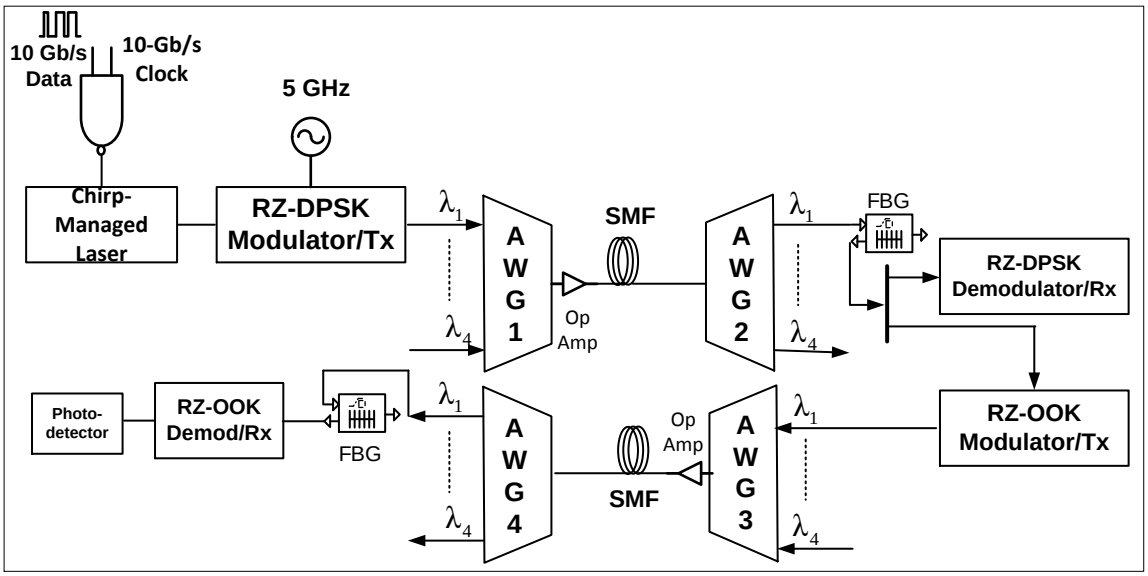


Fig. 3 Schematic diagram of RL-PON with FBG

Table 1 Simulation Parameters

Parameter	Value
Dispersion of SMF	16.75 ps/nm/km
Dispersion slope of SMF	0.075 ps/nm^2/km
Attenuation Coefficient of SMF	0.2 dB/km
Effective core area of SMF	80 um^2
Non Linear index-coefficient of SMF	2.6*10^-20
Responsivity of Photo detector	1 A/W
Dark current of photo detector	10 nA
Length of DCF	7 km
Dispersion of DCF	-80 ps/nm/km
Dispersion slope of DCF	0.19 ps/nm^2/km
Attenuation Coefficient of DCF	0.55 dB/km
Effective core area of DCF	20 um^2
Dispersion in FBG	-904 ps/nm

This signal was sent back to the Optical Line Terminal (OLT) along another fiber with 10 dB gain of EDFA and was received by an Avalanche Photodiode (APD). A 4th order Bessel low-pass electrical filter (LPF) with cut-off frequency of 7.5 GHz was used as RZ OOK decoder for 10 Gbps upstream data.

As same wavelengths were employed for DL and UL, two separate fibers were used between OLT and ONU for both directions to prevent Rayleigh backscattering reflections that degrade the signal. The proposed WDM-PON with four 10 Gb/s downlink channels and four 10 Gb/s uplink channels was evaluated for performance in both dispersion compensating methods.

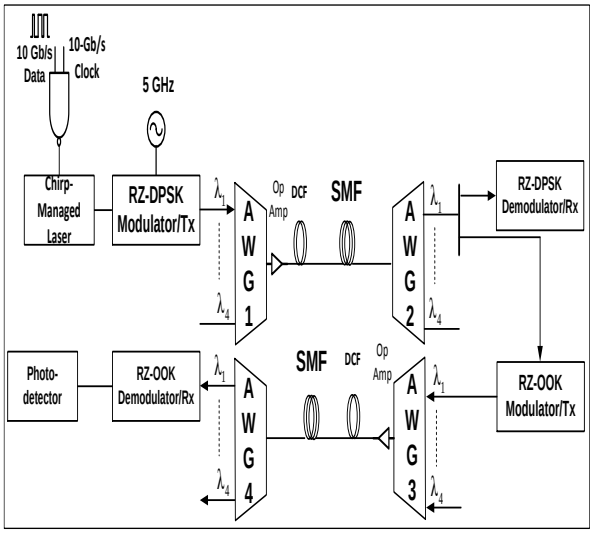


Fig. 4 Schematic diagram of RL-PON with DCF

4. RESULTS AND DISCUSSION

Both dispersion compensating methods: FBG and DCF were simulated in order to evaluate performance of each and measure the increase in the link reach. Instead of full dispersion management, about 54% dispersion cancellation was done. **(Fig. 5)** shows the BER diagram of four channels both in downlink and uplink directions, when FBG is used. The maximum length of fiber in both directions achieved is 70 km in the scenario of remodulation.

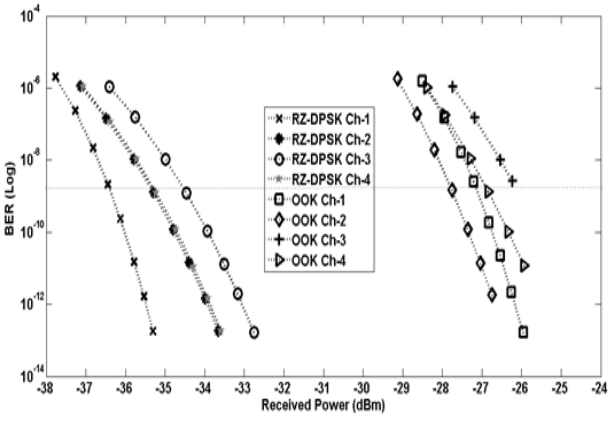


Fig. 5(a) BER Graph for four multiplex channels DPSK Down link & OOK Up link at 70 km with FBG

In the uplink direction, performance of channel 3 is lowest having bottommost power sensitivity. Nevertheless its eye is wide open reflecting a communication without errors. Eye diagram is given in **(Fig. 5(b).**

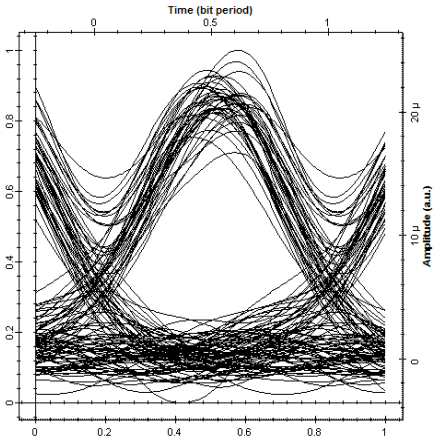


Fig. 5(b) Eye diagram of Channel 3 in UL

In case of DCF, 7 km at OLT side was used and the maximum DWDM-PON system's link length of 62 km was achieved in both downlink and uplink directions in the setup of colorless operation. Same parameters were used here as in the earlier simulation done for FBG. BER diagram vs receiver power sensitivity is given in the **(Fig. 6 (a).**

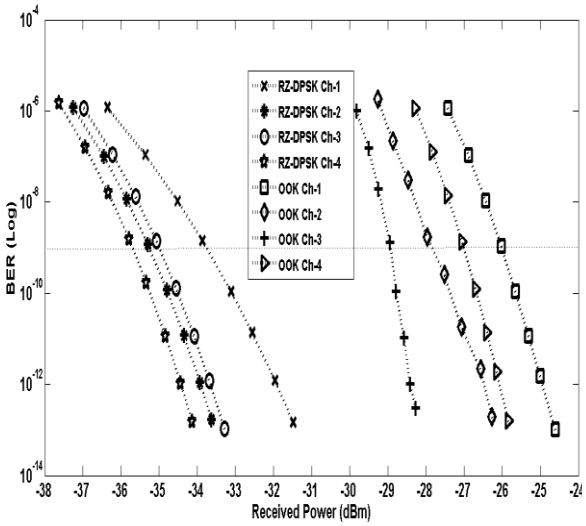


Fig. 6(a) BER Graph for four multiplex channels DPSK Down link & OOK Up link at 62 km with DCF

The eye diagram of channel 2 in UL direction is shown in **(Fig. 6(b).** Eye is wide open indicating a fault free communication. .

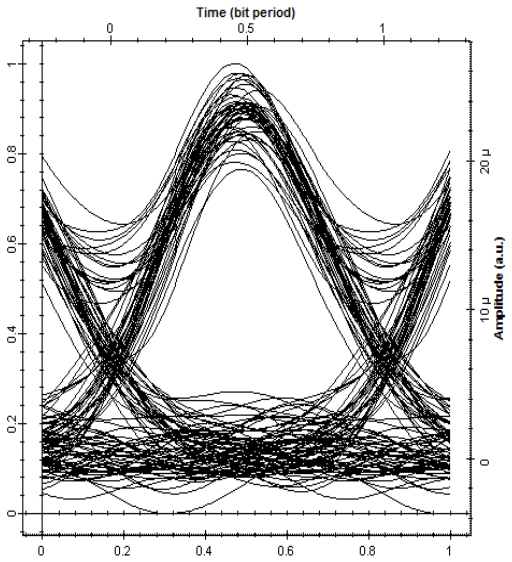


Fig. 6(b) Eye diagram of Channel 1 in UL

BER diagrams show that in all 8 channels (4 in DL and 4 in UL) a fault free communication is achieved in LR-PON with CML as transmitter.

Both DCM techniques successfully increase the reach of a conventional DWDM-PON and can be employed for LR-PONs. However, FBG performs better than DCF and is more effective in extending transmission length upto 70 km.

FBG has low insertion loss of 3 dB and it may be used in environment having greater optical powers in order to avoid non-linear effects, because losses can degrade the performance of the system.

5. CONCLUSION

From the simulation results, it can be concluded that FBG proves to be a better dispersion compensator in in long range dense wavelength division multiplexing optical networks because link reach in case of FBG is increased to 70 km whereas in case of DCF, maximum reach achieved is 62 km. We used CML here as transmitter in 10 Gbps LR-PON system with 50 GHz channel spacing in our simulation because of its dispersion tolerance. Simulated results justify its application in LR-PON.

. ACKNOWLEDGEMENT

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