Optical Dispersion Management for 10Gbps Upstream Directly-modulated Signals Covering Ranges from 0 to 100km with Maximal 51-dB Loss Budget

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Abstract: An ODC with fixed dispersion value is used in OLT to manage the dispersion of 10Gbps upstream directly-modulated signals, achieving 51-dB loss budget within 100km transmission distance thanks to the positive chirp of directly-modulated signals.
OCIS codes: (320.1590) Chirping; (260.2030) Dispersion

1. Introduction

Time and wavelength division multiplexed-passive optical network (TWDM-PON) has been selected as a primary solution for NG-PON2 by FSAN. With the increasing upstream bandwidth requirement, symmetric 40Gbps TWDM-PON becomes an inevitable trend, which requires a 10Gbps upstream transmitter. Compared with external modulation schemes, thermally tuned directly-modulated laser (DML) with a small wavelength tuning range is a cost-effective and practical solution for optical network unit (ONU) in TWDM-PON. However 10Gbps DML suffers from strong frequency chirp and dispersion causing signal distortion, which can only support tens of kilometer fiber transmission. Various methods have been proposed to solve the problem to enable long-reach applications, for example, chirp-managed laser (CML) could be used to enable more than 100km transmission [1], while the spectral-reshaping filter after the DML increases the cost a lot, which is not suitable in ONU. Spectral efficient formats including duo-binary and PAM-4 have been used to drive the DML, realizing 20-km fiber transmission but after 40-km transmission, the penalty became unacceptable [2]. By using burst-mode electronic dispersion compensation (EDC) at the receiver side in optical line terminal (OLT), 40-km transmission is realized with only 1.9-dB penalty comparing to the back to back (BtB) case [3]. But there is no demonstration of 100-km transmission using the burst-mode EDC yet and it is unclear if the burst-mode EDC can compensate the accumulated dispersion for bursts from different distance with very short guard band. We have proposed to use dispersion-supported transmission (DST) effect combining with a delay-interferometer (DI) in OLT to mitigate the dispersion effect for all upstream channels, which can achieve similar performances for all the users distributed within 100 km range [4]. But the main issue of this technique is that the central wavelengths of the DI and the DMLs are difficult to be well aligned due to temperature drift, which will affect the practical applications.

In this paper, we make full use of the positive chirp of the directly-modulated signals and propose to use an optical dispersion compensator (ODC) with fixed negative dispersion value in OLT to manage the dispersion for all upstream users within 100-km transmission distance. By optimizing the operating conditions of the DML and the negative dispersion value of the ODC, a maximal loss budget (LB) of 51 dB for 100-km distance has been achieved, which is equivalent to the coherent PON [5]. Experimental results also demonstrate that the ODC with fixed dispersion value can be used for compensating the dispersion of bursts from users with different transmission distances, which provides a cost-effective and practical solution for the long-reach TWDM-PON.

2. System architecture

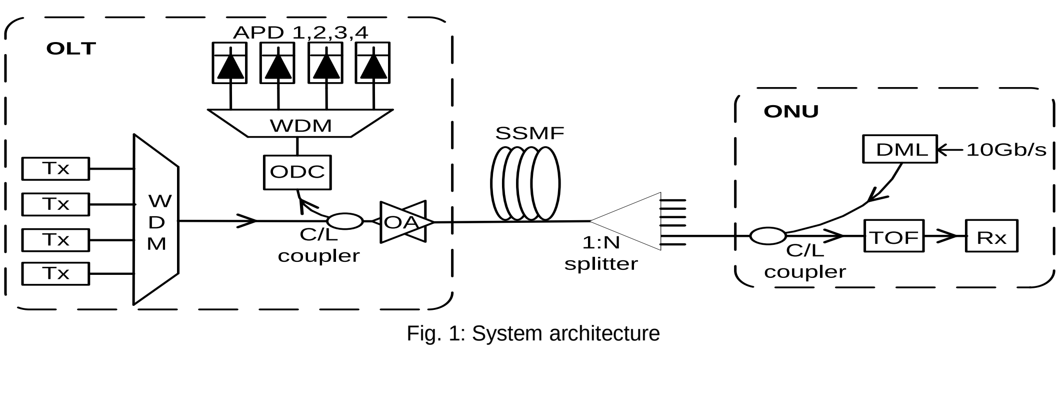

Fig. 1: System architecture

Fig.1 shows the proposed system architecture. For the upstream direction, the DML is modulated by 10Gbps pseudo random binary sequence (PRBS) data with a 2^31-1 word length. The upstream data from all users are combined by a 1: N optical splitter and then transmit through the standard single-mode fiber (SSMF). An Erbium-doped fiber amplifier (EDFA) with maximal 35-dB gain and ~5dB noise figure (NF) is used as a preamplifier to improve the receiver sensitivity. A tunable dispersion compensator (TDC, II-VI network solutions PS3400) with maximal tuning range from -2200 ps/nm to +2200 ps/nm is used to optimize the dispersion value in the experiment, and once the optimal value is defined, an ODC with fixed dispersion value can be used. After being divided by a wavelength division multiplexer (WDM) component, the upstream signals are detected by 4 avalanche photo diodes (APDs). For the downstream direction, since the 4 transmitters are shared by all users, the cost is not very sensitive, so CML can be used to support long-reach access, which is not in the scope of this research.

The directly modulated signal shows a high tolerance to negative dispersion due to its inherent positive chirp, but the signal sensitivity varies with different dispersion compensation values. Considering that the fiber losses for short-distance cases are lower, a degraded performance is acceptable. And the best receiver sensitivity is required for the longest transmission distance. In order to serve all users within the 100-km distribution range, the value of the TDC and operating conditions of the DML should be optimized.

3. Experimental results and discussions

To prove the feasibility of the method, we firstly set dispersion at -2200 ps/nm, which is the maximal negative dispersion compensation value of the TDC, and the eye diagrams at different distances are shown in Fig.2. The BtB eye diagram is the worst since -2200 ps/nm dispersion is over compensated for the positive chirp of the 10-Gb/s directly-modulated signal. But compared with the zero-chirped external modulated signal experiencing -2200 ps/nm dispersion, the eye diagram would be much better. With the increasing of the transmission distance, the eye diagram becomes better, which exactly meets our expectation.

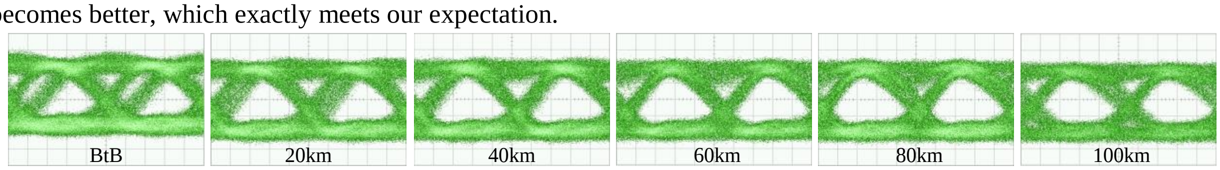

Fig. 2: Eye diagrams of 10-Gb/s upstream signals with different transmission distances for ODC at -2200 ps/nm.

To achieve a high LB, we need to optimize the launch power as well as the receiver sensitivity (considering the FEC limit of bit-error-rate at 3.8×10^{-3}). As we know, the launch power and the chirp value of the DML are decided by the bias current and the driving voltage. We firstly fix the dispersion value at -2200 ps/nm and bias current at 80 mA corresponding to an output power of 8.3 dBm, then we adjust the driving voltage on DML and measure the signal sensitivities in different transmission distance cases, as shown in Fig.3 (a). We can see that a higher driving voltage offers a better result, especially after 100-km transmission, since higher driving voltage results in higher extinction ratio (ER) and larger frequency chirp. We also investigate the relationship between sensitivity and bias current with the driving voltage fixed at 2 V, the measured sensitivities are shown in Fig.3 (b). By operating the DML at different bias currents, the output power and the frequency chirp vary. For low bias current of 60 mA, the DML output power of 6.2 dBm does not benefit the high LB and the BtB sensitivity is also very bad due to too strong frequency chirp. For high bias current of 100 mA corresponding to 10-dBm output power, the DML is operating at its saturation region and the ER becomes smaller, therefore the receiver sensitivity degrades. The middle bias current corresponding to 8.3-dBm output power results in the best receiver sensitivity. In the following tests, the bias current and the driving voltage are set at 80 mA and 2 V respectively.

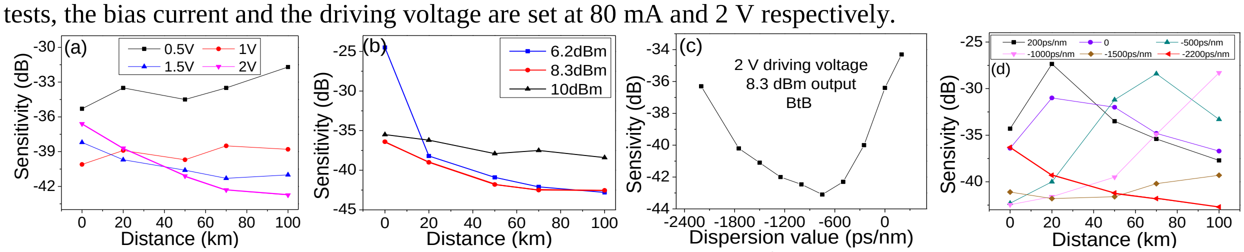

Fig. 3: The sensitivity variations with driving voltage, bias current of the DML and the dispersion value

In order to find the optimal dispersion value of the ODC, we need to know the corresponding dispersion value of the chirped directly modulated signal. By varying the dispersion compensation value and measuring the signal sensitivities, we obtained the BtB sensitivity curve as shown in Fig. 3(c). We get the highest sensitivity when the dispersion value is -750 ps/nm, and the performance degrades with either higher or lower values. In order to achieve the highest sensitivity at 100-km distance, it is better to set the TDC at -2450 ps/nm, which can fully compensate the 1700-ps/nm accumulated dispersion after 100-km SSMF transmission and the frequency chirp of the DML. To find the optimal dispersion compensation value of the TDC, we tune the dispersion value from 200 ps/nm to the maximal negative value of -2200 ps/nm and evaluate the sensitivity variation with the transmission distance. The results are shown in Fig.3 (d). The receiver sensitivity of -42.7 dBm at 100-km distance is the best in the case of -2200 ps/nm dispersion compensation and it linearly degrades with the decrease of the transmission distance. In the BtB case, the sensitivity of -36.2 dBm is almost same with the case without any dispersion compensation. From the variation trend, we can assume if the dispersion value is -2450 ps/nm, the receiver sensitivity at 100 km will be improved while the sensitivity at BtB will be degraded.

We evaluate the upstream loss budget of the proposed TWDM-PON by fixing the ODC at -2200 ps/nm. The LB is 44.5 dB for the BtB case and linearly increases to 51 dB for 100-km transmission case. Considering the transmission loss of the SSMF of 0.25 dB/km and the insertion loss of 24 dB for a 1: 256 splitter, the system margin for the BtB case is as high as 20.5 dB and reduces to 2 dB for 100-km distance. Therefore it is possible to use an ODC with higher negative dispersion value to balance the system margin.

Finally, to prove the proposed fixed ODC suitable for burst mode operation, we evaluate the performance of the bursts from different transmission distances with and without the ODC. The data packet used to modulate the DML is shown in Fig.5 (a). We divide the modulated signal into two branches with 12.5-km and 1-m SSMF respectively, and then couple them together to emulate the data packets from users with different transmission distances. After that, the combined data packets are transmitted through another 40-km SSMF. As shown in Fig.4 (b), the dispersion induced penalties for different data packets are also different, which is difficult to be compensated by the traditional EDC. While adding the -2200 ps/nm optical dispersion compensation before the receiver, the data packets can be clearly recovered as shown in Fig.5 (c) and (d). Actually from the principle of optical dispersion compensation, we can also conclude that this method is transparent to the bursts types.

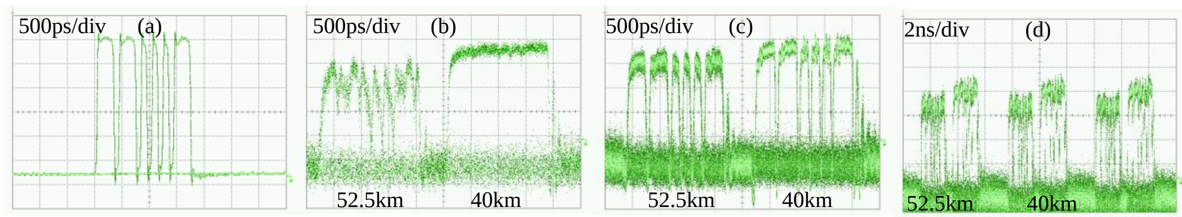

Fig. 4: The burst mode operation verification

4. Conclusions

In this paper, we demonstrate the feasibility of using a fixed-value ODC at OLT to manage the fiber dispersion with different transmission distances and the frequency chirp of DMLs. By optimizing the operating conditions of the DML and the dispersion value of ODC, maximal 51-dB LB can be achieved for 100-km transmission distance, providing a cost-effective and practical solution for long-reach TWDM-PON.

5. Acknowledgements

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6. References

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