Comparison of Chromatic Dispersion Compensation Techniques for WDM-PON solution

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Abstract — The upper transmission range of the wavelength division multiplexing passive optical network (WDM-PON) can be restricted by chromatic dispersion (CD). This paper contains the investigation of till 16-channel WDM-PON system with efficient CD pre-compensation and post-compensation methods. It is shown that CD offset has a marginal role for guaranteed optical link downstream performance and maximum length of high-speed WDM-PON system. The results show that employment of extra 7 km long dispersion compensating fiber (DCF) placed in central office (pre-compensation configuration) enhances the WDM-PON network link length by 19.3% (from 57 km up to 68 km), but if extra 2 km long DCF fiber is used in remote terminal (post-compensation configuration) link length can be extended up to 5.3% (from 57 km to 60 km). It was found that usage of fiber Bragg grating (FBG) in central office (pre-compensation configuration) improves network reach up to 26.3% (from 57 km up to 72 km), but using this FBG for CD post-compensation in remote terminal network reach can be improved by 15.8% or 9 km in length – from 57 km to 66 km. Basis on the results authors recommend to use FBG as the best solution for CD compensation in pre-compensation configuration (before SMF line) in future high speed long-reach DWDM-PON systems.

Keywords — chromatic dispersion (CD) wavelength division multiplexing (WDM); passive optical network (PON).

I. INTRODUCTION

Wavelength division multiplexed passive optical network is a fascinating solution to fulfill the worldwide rising requirement for transmission capacity in the next generation fiber optical access networks. The possible transmission distance of the Dense WDM-PON (DWDM-PON) transmission system can be restricted by chromatic dispersion (CD) [1, 2].

An effective solution for an optical access network is the absolutely passive long-reach optical access network. The strength of this optical technology is its ability to displace electronics and optical elements in one central office (CO) and simplify the DWDM-PON network architecture [3]. In traditional Time-Division Multiplexed Passive Optical Network (TDM-PON), the number of ONUs is restricted by optical splitter attenuation on single wavelength, but using WDM-PON technology we can provide 32, 64, 128 or even more wavelengths in optical access network [4, 5].

At the present moment WDM-PON become as an effective way to solve the bottleneck effect if we have great quantity of end users, hence in this condition any user receives its own wavelength. To enhance the performance of dense high-speed WDM-PON CD compensation is necessary, because it has a very important role on a quality of transmitted signal, quantity of provided users and passive optical network reach [6].

II. SIMULATION MODEL AND NUMERICAL ANALYSIS

Our accepted research method is a mathematical simulation using the OptSim 5.2 simulation software where using Split-Step algorithm the complex differential equation systems are solved. In order to study the nonlinear effects in optical fiber the nonlinear Schrödinger equation (NLS) is used. With the exception of certain solutions this equation cannot be solved analytically. Therefore, OptSim simulation software is used for simulation of fiber optical transmission systems where it solves complex differential equations using Time Domain Split-Step (TDSS) method [7].

The performance of simulated scheme was evaluated by the obtained Bit Error Ratio (BER) value of each WDM channel in the end of the fiber optical link. It must be declared that ITU recommended BER value for fiber optical transmission systems with bit rate 10 Gbit/s per channel is less than $10^{-9}$ [8]. As one can see, DWDM-PON simulation scheme consists of 16 channels (see Fig. 1). The frequency grid is anchored to 193.1 THz and channel spacing is chosen equal to 100 GHz frequency interval. Such an interval and frequency grid is defined in ITU-T recommendation G.694.1. Optical Line Terminals (OLT) are located at central office (CO). Each OLT consists of electrical data source, NRZ driver, continuous wavelength (CW) laser and external Mach-Zehnder modulator (MZM). Each OLT generates optical data stream with mean launched power +2dBm (this power level correspond with ITU-T 987.2 recommendation as N1 class) and data rate is equal to 10 Gbit/s.

Information from OLT is transmitted to an optical network terminal (ONT) or user over the fiber optical transmission link called optical distribution network (ODN). ODN includes the physical fiber and optical devices that distribute optical signals from CO to users in a passive optical network. Conventional optical signal intensity modulation direct-detection (IM-DD) format is selected. As layout scheme for electrical signal NRZ coding is chosen, hence it is one of the most lightly implemented and historically prevailed schemes in fiber optical transmission networks [8, 9].
Generated bit sequence from data source is sent to signal driver where NRZ pulses are formed. Afterwards formed electrical NRZ pulses are sent to Mach-Zehnder modulator. Finally the CW laser light beam is modulated via the Mach-Zehnder modulator and optical pulses are formed. These formed optical pulses are coupled by optical coupler (arrayed waveguide grating (AWG) multiplexer) from all WDM channels and sent into standard ITU-T G.652 single mode fiber (SSMF) [10, 11].

Our simulation scheme ODN consists of AWG multiplexer, optical erbium doped fiber amplifier (EDFA) with constant output power +12 dBm (equal to 15.85 mW), aforementioned single mode fiber (SMF) with changeable length and AWG demultiplexer.

For CD pre-compensation there is used PRE-DCM block, but for CD post-compensation there is used POST-DCM block in OptSim simulation model.

High-performance AWG multiplexers and demultiplexers are totally passive optical components with insertion loss up to 3dB and frequency spacing 100 GHz each. Initially the standard single mode optical fiber in length of 20 km was used in our investigation. Such a length span of fiber is defined in ITU-T recommendation G.984.2 as a possible upper limit of fiber distance between optical line terminal (OLT) and optical network terminal (ONT) in Gigabit Passive Optical Network (GPON). At the end of optical distribution network there is a 1x16 AWG demultiplexer where optical signal is split into 16 optical flows (wavelengths) and sent to receiver unit. In the end of fiber optical network each channel is analyzed separately after the optical filtering.

Receiver section includes ONTs. Each ONT consists of sensitivity receiver with optical filtering and PIN photodiode, Bessel electrical filter (5 poles, -3dB Bandwidth BwE = 7.5 GHz), optical power meter and electrical probe to evaluate the quality of received optical data signal [1, 7].

III. RESULTS AND DISCUSSIONS

There are two different chromatic dispersion (CD) compensation methods for reach improvement of DWDM-PON system described in this work. These CD compensation methods that can be implemented in DCM module are Fiber Bragg Grating (FBG) and Dispersion Compensation Fiber (DCF). We have investigated dispersion pre- and post-compensation schemes as well as compared these above mentioned CD compensation methods.

The goal of this section is to numerically estimate the performance of both methods and find the optimum suitable solution which allows enlarge the length of our investigated DWDM-PON simulation scheme.

As one can see, beside CD compensation (without any DCM) and utilize an optical EDFA amplifier (with constant output power +12 dBm) above the SMF of 20 km in length we received that BER value of optical signal from the worst channel was low enough (BER=1.40·10^-17) and it sense that our investigated DWDM-PON system’s performance is absolutely high (see Fig. 2).

We have received that the better BER value (lowermost performance) was formed by 8th channel of our investigated DWDM-PON system’s model and basis on this surveillance we show results only for this worst channel. As the BER for
It was fortuitous that in instance of 16 channel DWDM-PON system, the complete accumulated chromatic dispersion compensation is not necessary. The total stored CD amount of 68 km long SMF fiber span is about 1100 ps/nm, therefore using DCF fiber of 7 km in line length we can compensate CD amount of 560 ps/nm. Founded, that for optimal 16 channels DWDM-PON system performance it is sufficient to compensate a half (50%) of the total accumulated CD apropos of absolutely full CD compensation.

In case when DCF fiber is used for CD post-compensation in remote terminal (POST-DCM) we found that the optimal required DCF fiber length to reach optimal DWDM-PON system performance is 2 km (see Fig. 5).

Using DCF fiber of 2 km in length we increased the length of our long-reach passive optical network for an additional 3 km (extra 5.3 %) and achieved that the maximum DWDM-PON system’s link length is 60 km.

Figure 6. DWDM-PON system’s worst channel BER correlation diagram, output eye diagram of detected signal and BER value at maximum achievable link length with CD post-compensation module employing FBG.
The second realized CD compensation method for DWDM-PON system includes the implementation of FBG in central office (CO) and in remote terminal (RT). In CO there is used PRE-DCM module for pre-compensation, but in case of post-compensation there is used POST-DCM module in RT.

By realizing simulation model with FBG dispersion compensating scheme in CD pre-compensation configuration (PRE-DCM), we have found that BER value decreased and system performance improved. This enhancement was greater than if we use DCF for CD compensation, no reason in configuration of pre- or post-compensation (see Fig. 6). Was founded an optimal CD compensation quantity that should be compensated by FBG in pre-compensation configuration, it is 1100 ps/nm. This quantity is equivalent to the full CD compensation. Using FBG for CD pre-compensation the total reach of DWDM-PON system was extended by 15 km - from 57 km initially to 72 km now. The line length increase of 26.3% was obtained (see Fig.6).

By investigating the usage of FBG for CD post-compensation in remote terminal (POST-DCM) we found that optimal CD compensation amount that must be compensated by FBG in this configuration is -700 ps. In this solution it was needed to increase the common output power of EDFA (from 12 to 15 dBm) to cover FBG module insertion losses (3dB), because it was concluded that with the existing power budget significant reach improvement can't be achieved and system's performance is below required threshold.

Using FBG for CD post-compensation the total reach of DWDM-PON system was extended by 9 km - from 57 km initially to 66 km now, and the line length increase of 15.8% was obtained (see Fig.7).

IV. CONCLUSIONS

In this work we have implemented an experimental high-speed DWDM-PON system solution where different types (DCF and FBG) of accumulated CD compensation configuration are used for pre-compensation or post-compensation. The maximum achievable reach improvement of DWDM-PON system using proposed CD compensation methods and two different DCM unit positions (before and after SMF fiber span) have been investigated. The possible transmission length of realized DWDM-PON system without CD compensation was 57 km, but it has been shown that using appropriated CD compensation methods (DCF and FBG) system maximum transmission reach can be improved.

By implementation of DCF fiber in DCM unit the 16 channel DWDM-PON system’s maximal link length between OLT and ONT in pre-compensation configuration improved by 19.3% or 11 km in length – from 57 km to 68 km, but in post-compensation configuration by 5.3% or 3 km in length – from 57 km to 60 km.

The best results were obtained by using FBG for CD pre-compensation as well as for post-compensation. Employing the fiber Bragg grating pre-compensation solution in dispersion compensation module DWDM passive optical network transmission line can be improved by 26.3% or additional 15 km in length – from 57 km till 72 km, but using fiber Bragg grating in post-compensation solution transmission line can be improved by 15.8% or additional 9 km in length – started from 57 km till 66 km. Basis on the results we recommend to use FBG in DCM unit for CD compensation in pre-compensation configuration (before SMF fiber span) in future high speed long-reach DWDM-PON systems.

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