Performance Improvement of Spectrum-sliced Passive Optical Network

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Abstract— Spectrum-sliced dense wavelength-division-multiplexed passive optical network (SS-DWDM PON) is an attractive and cost effective solution to satisfy the growing worldwide demand for transmission capacity in the next generation fiber optical access networks. The strength of SS-DWDM PON technology is use of one common broadband seed light source and its ability to place electronics and optical elements in one central office (CO), in that way simplifying the architecture of fiber optical network. The authors have successfully demonstrated the optical link reach improvement by implementation of chromatic dispersion compensation for cost effective SS-DWDM PON system.

1. INTRODUCTION

Traditional WDM systems have multiple transmitter lasers operating at different wavelengths, which need to be wavelength selected for each individual channel operated at a specific wavelength. It increases complexity of network architecture, cost and wavelength (channel) management. The strength and benefit of SS-DWDM PON optical systems from the same advantages as WDM, while employing low cost incoherent light sources like amplified spontaneous emission (ASE) source or light-emitting diode (LED). This spectral slicing method is a promising cost-efficient solution for a transmitter in an optical line terminal (OLT) of WDM-PON architecture. SS-WDM PON system is more energy efficient than traditional WDM PON because there is employed a single common broadband light source for transmission on a large number of wavelength channels, not a one source per user as it is in the traditional WDM-PON [1–3].

The optical bandwidth per channel of SS-WDM PON system is large compared to the bit rate. Therefore, dispersion considerably degrades the performance of this system more than it is observed in conventional laser-based systems. The influence of dispersion needs to be studied in order to understand the characteristic of a SS-WDM PON system employing a standard single mode optical fiber. In traditional time-division multiplexed passive optical network (TDM-PON), the number of ONTs (users) is limited by the attenuation of optical splitter in a single wavelength, but using WDM PON technology we can provide up to 64 or even more wavelengths in an optical access network [4]. Therefore WDM-PON becomes the strongest competitor because of its upgradeability and high capacity. In case of large number of end users the WDM-PON system can be assumed as an effective way to solve the bottleneck problem because each user receives its own wavelength [5].

It is very important to build a new type optical system based on widely used frequency grid, recommended by international standards because of such a system potentially is much more compatible with other already existing WDM-PON optical systems. The main benefit includes the reduction of network architecture complexity as well as cost per one user. It is possible by replacing the classic WDM-PON system (where one laser source is used for each user) with our proposed spectrum-sliced dense WDM PON system with CD compensation (where one seed broadband ASE source is spectrally sliced and used for multiple users) [6, 7].

2. SIMULATION MODEL AND NUMERICAL ANALYSIS

Our accepted research method is a mathematical simulation using newest OptSim 5.2 simulation software, where complex differential equation systems are solved using Split-Step algorithm. In order to study the nonlinear effects in optical fiber the nonlinear Schrödinger equation (NLS) is used. Except certain cases this equation cannot be solved analytically. Therefore, OptSim software is used for simulation of fiber optical transmission systems where it solves complex differential equations using Time Domain Split-Step (TDSS) method [3]. 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. Basis on ITU recommendation G.984.2 it should be noticed that BER value for fiber optical transmission systems with data rate 2.5 Gbit/s per channel is specified less than 10^{-10} [8].

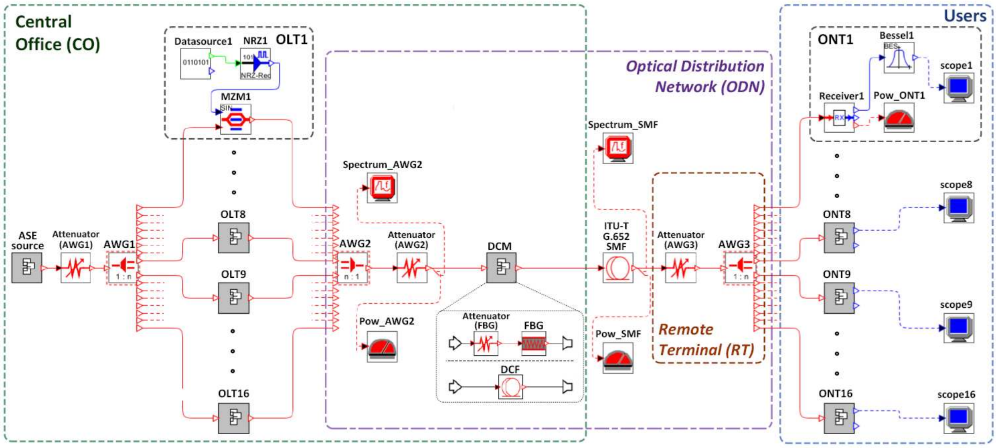


Figure 1: Experimental model of proposed high-speed 16-channel AWG filtered ASE seeded SS-DWDM PON system with DCM module.

In order to investigate the performance of incoherent broadband ASE light source as seed light for usage in spectrum sliced WDM passive optical networks we created a simulation scheme of high-speed 16 channel SS-DWDM PON system in OptSim 5.2 software, see Fig. 1. The design of high performance broadband flat spectrum ASE source on the output of cascaded EDFAs in details is described in next chapter. This chapter describes the simulation model and parameters of proposed SS-DWDM PON system with flat ASE seed source. As one can see in Fig. 1, SS-WDM PON simulation scheme consists of 16 channels. The frequency grid is anchored to 193.1 THz and channel spacing is chosen equal to 100 GHz frequency interval. This frequency grid and interval is defined in ITU-T recommendation G.694.1.

Broadband ASE light source is spectrally sliced using 16-channel AWG filter (AWG1) with channel spacing equal to 100 GHz (0.8 nm in wavelength). Using this AWG unit we can obtain spectrally sliced optical channels (slices) with dense channel interval 100 GHz. Insertion losses of AWG units are simulated using attenuation blocks (attenuators).

Simulated athermal high-performance AWG multiplexers and demultiplexers are absolutely passive optical components (no need for thermal regulation and monitoring electronics) with insertion loss up to 3 dB each [1]. After spectrum slicing by AWG1 optical slices are transmitted to the optical line terminals (OLTs). OLTs are located at central office (CO). Each OLT consists of data source, NRZ driver, and external Mach-Zehnder modulator (MZM). Generated bit sequence from data source is sent to NRZ driver where electrical NRZ pulses are formed. Afterwards formed electrical NRZ pulses are sent to MZM modulator. MZM modulates the optical slices from AWG1 and forms optical pulses according to electrical drive signal. These formed optical pulses from all OLTs are coupled by AWG multiplexer (AWG2) and sent into standard optical single mode fiber (SMF) defined in ITU-T recommendation G.652. Information from OLT is transmitted to an optical network terminal (ONT) or user over the fiber optical transmission link called optical distribution network (ODN). In the end of fiber optical link optical channels are split using AWG demultiplexer (AWG3) located in remote terminal (RT). Receiver section includes ONT units. Each ONT consists of sensitivity receiver with PIN photodiode (sensitivity $S = -25\,\mathrm{dBm}$ at sensitivity reference error probability $\mathrm{BER} = 1 \cdot 10^{-10}$), Bessel electrical filter (3-dB electrical bandwidth $B_E = 1.6\,\mathrm{GHz}$), optical power meter and electrical probe to evaluate the quality of received optical data signal. Optical signal is converted to electrical signal using PIN photodiode and filtered by Bessel electrical filter to reduce noise [9]. In simulation setup we used real parameters of standard DCF fiber and tunable FBG.

3. RESULTS AND DISCUSSIONS

Flat-top type AWG units were chosen for spectral slicing of ASE light source in our optical system because of good filtering performance, excellent WDM channel separation and bandwidth allow passing sufficient high optical power [2]. To reduce the negative impact of intensity noise as well as cross phase modulation the correct choice of filter's shape and 3-dB pass bandwidth is very important [10, 11]. In Fig. 2, are compared two SS-DWDM PON channels (central frequencies

193.1 and 193.2 THz) which are filtered by Gaussian and flat-top type AWGs with identical 50 GHz 3-dB pass bandwidth.

It is shown that flat-top AWG has narrower spectral filter shape than Gaussian type AWG. Wider filter shape leads to larger slice width, higher resultant slice's power and optical signal dispersion [6]. In OptSim software we simulated flat-top type AWG filter shape using Raised Cosine optical filter's transfer function but using Super-Gaussian transfer function we approximate Gaussian AWG filter shape [10].

As one can see in Fig. 2, in the case of Gaussian filter the crosstalk between channels will be much higher than employing flat-top type filter. Based on this we can make a conclusion that AWG with flat-top filter spectral shape has higher optical signal to noise ratio (OSNR) than AWG with Gaussian type filter shape at identical bandwidth (3-dB bandwidth is 50 GHz). Based on above mentioned facts we chose flat-top AWGs for our investigated SS-DWDM PON simulation scheme. In Fig. 2, it is shown optical spectrum on the output of ASE source and spectra after each flat-top AWG unit.

We found that optimal 3-dB bandwidth value of flat-top type AWG unit for maximal system performance must be about 90 GHz. By slicing the spectrum of proposed ASE source with first AWG demultiplexer we obtain 16 separate WDM channels with channel output power variation less than 0.42 dB. As one can see in Fig. 3, the performance of investigated SS-DWDM PON system was completely sufficient to provide data transmission with BER $< 1 \cdot 10^{-10}$ over the fiber optical span of 12 km in length without CD compensation.

The first realized chromatic dispersion compensation method includes the implementation of DCF in central office. It was found that the optimal required DCF fiber length for maximum improvement of our SS-DWDM PON system's performance is 5.1 km. This length of DCF fiber can compensate about 410 ps/nm of accumulated CD. Using DCF fiber with such a length we can achieve the maximal 16-channel SS-DWDM PON system's link length of 24 km, see Fig. 3(a).

By using FBG we achieve better results than using DCF for accumulated CD compensation. Implementation of FBG for CD compensation extends the total reach of SS-DWDM PON system

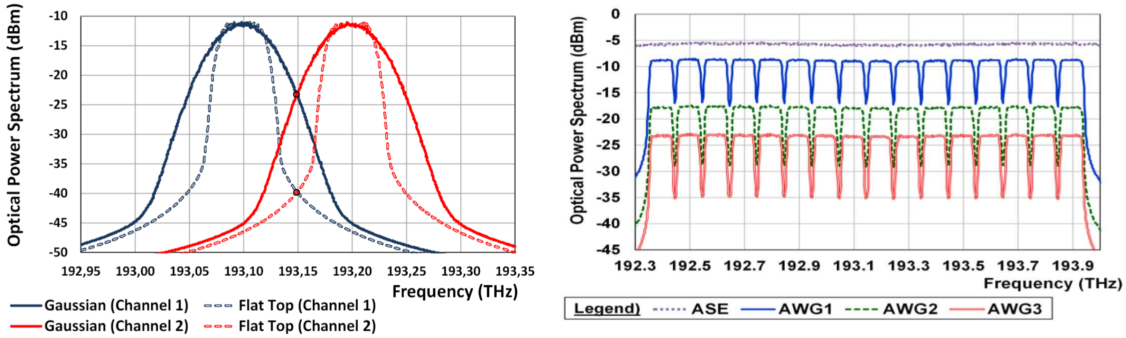
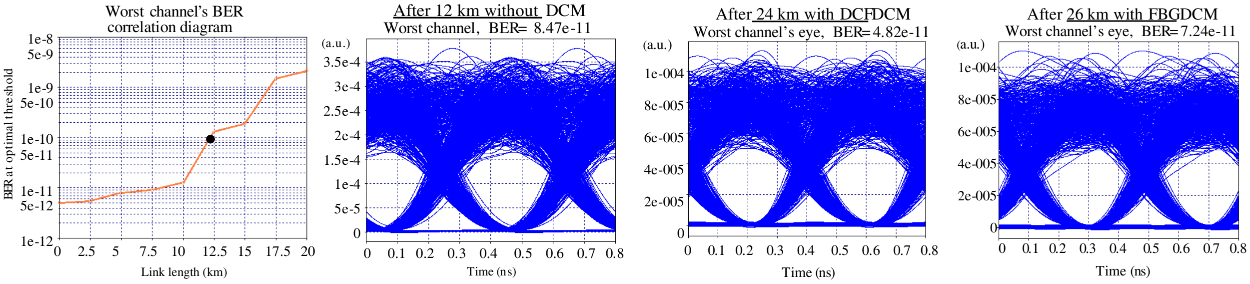


Figure 2: Optical output power spectrum of ASE source and 16-channel SS-DWDM PON system after each stage of flat-top type AWG unit. Comparison of Gaussian and flat-top type AWGs with 50 GHz 3-dB bandwidth in case of two adjacent WDM.



(a) (b)

Figure 3: BER correlation diagram and output eye diagram of worst spectrally sliced dense WDM PON system's channel after 12 km SMF link length without CD compensation module. SS-DWDM PON system's eye diagrams and BER values of the received signal from worst channels employing. (a) DCF fiber and (b) FBG for accumulated CD compensation in DCM unit.

up to 26 km, see Fig. 3(b). This result can be explained by the fact that FBG has relatively small insertion loss (< 4 dB) and instead of DCF fiber it can be used at higher optical powers without inducing nonlinear optical effects, which can reduce the system's performance. Optimal CD compensation amount that must be compensated by FBG is -420 ps/nm and this amount is equivalent to full CD compensation.

4. CONCLUSIONS

In this work, using we have realized and investigated an experimental high-speed SS-DWDM PON system where DCF and FBG are used for accumulated chromatic dispersion (CD) compensation to improve the maximal link reach from OLT to ONT at the same time providing high system performance with BER $< 1 \cdot 10^{-10}$. It is shown design of broadband ASE source with +23 dBm output power and flat spectrum in system's operating wavelength range (C-band) using two EDFAs connected in cascade mode. We demonstrate that using DCF for CD compensation SS-DWDM PON reach can be improved by 100% or extra 12 km in length — from 12 km to 24 km. But using FBG unit network reach can be improved by 117% or extra 14 km — from 12 km to 26 km. Basis on these results authors recommend to use FBG DCM units for CD compensation in future high-speed 16-channel dense SS-WDM PON systems for maximal system's performance and network reach.

ACKNOWLEDGMENT

The travel costs and participation fee to conference was supported by the European Regional Development Fund project "Development of international cooperation projects and capacity in science and technology Riga Technical University", Nr. 2DP/2.1.1.2.0/10/APIA/VIAA/003.

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