Optical WDM-PON Access System with Shared Light Source

Sandis Spolitis, **Lilita Gegere**, **Anita Alsevska**,
Ilja Trifonovs, **Jurgis Porins**, **and Vjaceslavs Bobrovs**
Institute of Telecommunications, Riga Technical University, Riga, Latvia

Abstract— The present paper investigates performance of next generation passive optical network (NG-PON) with effective chromatic dispersion (CD) compensation method in physical layer. We report on 16-channel spectrum sliced wavelength division multiplexed passive optical network (SS-WDM PON) with shared amplified spontaneous emission (ASE) light source as NG-PON solution, which is based on ITU-T G.694.1 DWDM frequency grid, and is capable to provide data transmission over 20 km fiber span with transmission speed at least 2.5 Gbit/s per channel. It is shown, that performance of this optical access system can be improved by using chromatic dispersion compensation module with fiber Bragg grating, in such a way providing data transmission over 20 km SMF fiber span with BER $< 10^{-10}$.

1. INTRODUCTION

The growing number of Internet users and bandwidth-driven applications, such as streaming video, online gaming, file sharing, video conferencing and others bring various challenges for network operators and force them to migrate toward new architectures and technologies [1]. Next generation passive optical networks (NG-PON) must provide higher data transmission speeds while keeping CAPEX and OPEX as low as possible [2]. There are two key factors which will influence telecommunication networks of the future. The first one is support of high bandwidth data transmission and the second one is usage of architectures which are both cost and energy efficient [3, 4]. Promising technology to fulfill the world-wide rising requirement for transmission capacity is spectrum sliced wavelength division multiplexed passive optical network named as SS-WDM PON. The strength of this technology is its ability to locate electronics and optical elements in one central office (CO) and simplify the NG-PON network architecture as well as use only one broadband light source (BLS) for all users [2, 5, 6]. SS-WDM PON optical system is energy efficient and cost effective in the way that single seed light is shared among multiple users instead of using individual light source for each of them [7].

SS-WDM PON systems benefit from the same advantages as traditional WDM-PON systems, while employing low cost incoherent light sources like amplified spontaneous emission (ASE) source or light-emitting diode (LED). The performance of the SS-WDM PON transmission systems is restricted by chromatic dispersion (CD) [6, 8]. Dispersion causes optical signal pulses to broaden and lose their shape as they travel along optical fiber. Eventually this limits the quality of transmitted signal, maximum achievable data transmission rate and transmission system reach [9, 10]. The optical bandwidth per channel of SS-WDM PON system is large compared to the bit rate and, therefore, CD significantly degrades the performance of this system more than it is observed in conventional laser-based systems like WDM-PON [7, 11]. Different CD compensation methods can be used in physical layer for NG-PON systems [8]. They can be dispersion compensation fiber (DCF) or fiber Bragg grating (FBG). In our previous researches [11] and [12] FBG provided better performance than DCF used for CD compensation, therefore FBG is used as effective CD compensation method in this research also. In this paper we investigate the performance of 16-channel SS-WDM PON system with typical access network link length of 20 km.

2. SPECTRUM SLICED WDM-PON ARCHITECTURE

Spectrum slicing technique is one of available techniques in WDM-PON systems in order to reduce cost of components and simplify the architecture of PON network [7]. This technique employs a single broadband light source (BLS) for transmission on a large number of wavelength channels. BLS like LED or ASE can be used in spectrum sliced systems for data transmission. As it is shown in Fig. 1, incoherent BLS (e.g., ASE) is sliced in equally spaced multi-wavelength channels [13]. BLS usually is sliced with arrayed-waveguide grating (AWG). Afterwards, optical slices are modulated by optical modulator, and multiplexed by second AWG for transmission over single mode (SMF) fiber span. Optical channels are demultiplexed by last AWG located after the SMF fiber span and received by direct detection optical receiver where PIN photodiode or avalanche photodiode (APD) is implemented. It should be taken into account that a larger slice width will increase not only the total channel power but also increase the influence of dispersion on transmitter optical signal and crosstalk between channels [14].

In our SS-WDM PON system setup we use previously [14] designed ASE source as BLS for spectral slicing operation due to its high optical output power compared by other mentioned BLS. This ASE source has a nearly flat spectrum in frequency range from 192.3 THz to 194.0 THz (C-band, wavelength range from 1545.32 nm to 1558.98 nm), which was designed by manipulating parameters of two cascaded EDFAs [14]. In this way, an ASE BLS source with nearly flat spectrum (variation from average value of power level in marked area is about 0.35 dB) and total output power of cascaded EDFA system +23 dBm (200 mW) can be constructed, see Fig. 2.

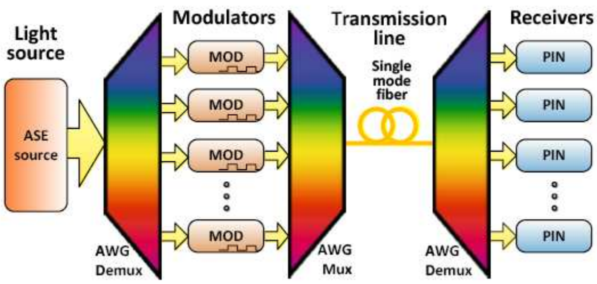

Figure 1: Operational principle of SS-WDM PON transmission system with N channels.

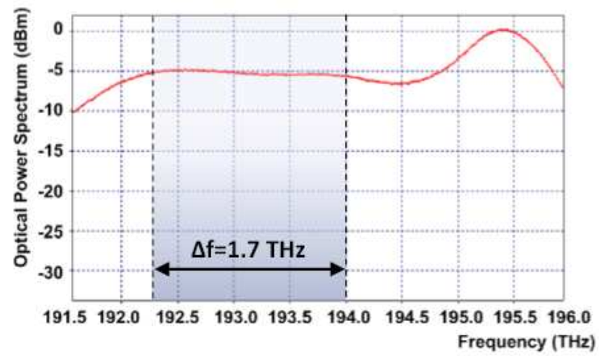

Figure 2: Output spectrum of realized noise-like ASE broadband light source.

3. EXPERIMENTAL SIMULATION MODEL OF 16 CHANNEL SS-WDM PON SYSTEM

This paper section shows realization of NG-PON 16-channel spectrum sliced WDM-PON access system in newest Synopsys RSoft simulation software which is reliable and widely used for design of high-performance optical communication systems [15]. In intensity modulated SS-WDM-PON system with NRZ line code and direct detection, transmission speed (2.5 Gbit/s) is limited due to the excess intensity noise which originates from non-coherent ASE source [11, 13]. 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 on each optical network terminal (ONT). BER threshold for this transmission system is set as BER $< 10^{-10}$. The SS-WDM PON system (see Fig. 3) has only one BLS light source (ASE) shared by all ONTs. Broadband ASE light source is spectrally sliced using 16-channel flattop AWG filter (AWG1) with channel spacing equal to 100 GHz. After the spectrum slicing operation, which is realized by first AWG (AWG1), optical slices are transmitted to optical

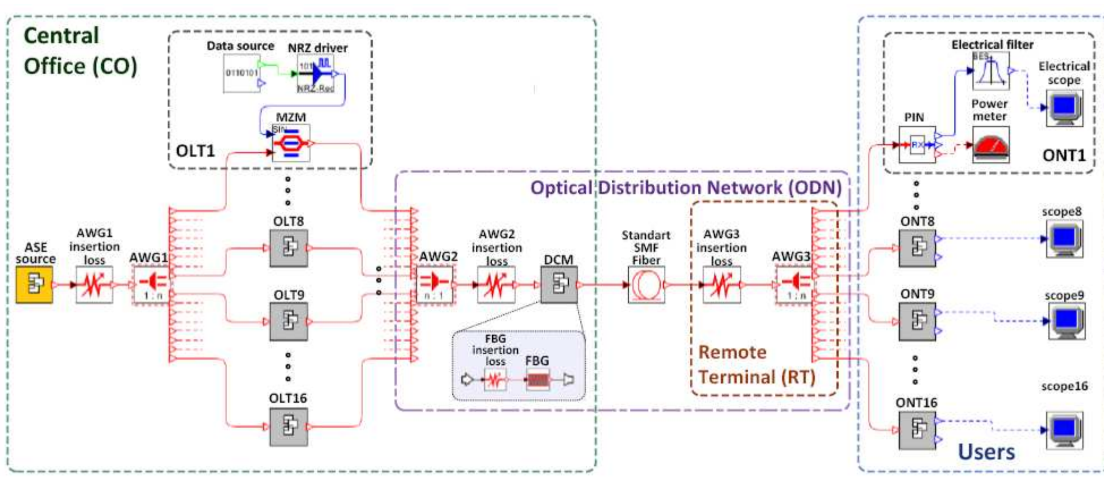

Figure 3: Simulation model of high-speed 16-channel AWG filtered and ASE seeded SS-WDM PON system with DCM module.

line terminal (OLT) transmitters located at central office (CO).

Each OLT consists of electrical data source, NRZ driver and external Mach-Zehnder modulator (MZM). Generated bit sequence from data source is sent to electrical signal driver where NRZ pulses are formed. Afterwards formed electrical NRZ pulses are send to Mach-Zehnder modulator. Each MZM has 5 dB insertion losses, 20 dB extinction ratio, modulation voltage of 5 V and maximum transmissivity offset voltage 2.5 V. Optical signals from all OLTs transmitters are coupled by optical multiplexer (AWG2) and send into standard ITU-T G.652 single mode fiber (SMF) located in optical distribution network (ODN). Insertion losses of AWG units are simulated using additional attenuation blocks. ODN includes the physical fiber and optical devices that distribute optical signals from central office (CO) to users in PON network. For CD compensation DCM with fiber Bragg grating (FBG) is used in ODN. Additional attenuator is used for simulation of FBG's insertion loss. Each ONT consists of PIN photodiode (sensitivity −25 dBm at BER = 10^{-10}), Bessel electrical lowpass filter (3-dB electrical bandwidth $B_E = 1.6$ GHz), optical power meter and electrical probe to evaluate the quality of received optical data signal (e.g., show eye diagram) [15]. Performance of transmission system is evaluated after 20 km transmission, because such an optical fiber span length is defined in ITU-T recommendation G.984.2 as upper limit of fiber distance between optical line terminal (OLT) and optical network terminal (ONT) in Gigabit passive optical networks (GPON) [12, 13].

4. RESULTS AND DISCUSSION

Performance results of proposed 16-channel SS-WDM PON system are shown in this section. In Fig. 4 it is shown spectrum of SS-WDM PON optical signals on the output of all OLT transmitters (OLT T × 1 to T × 16) and spectrum in the input of ONTs (ONT R × 1 to R × 16). We found that optimal 3-dB bandwidth value of AWG units for maximal quality of received signal and minimal crosstalk between channels is 90 GHz for spectrum sliced optical access system [13, 15]. The larger is width of spectral slice the higher performance we can obtain until a certain point, when arising crosstalk between channels must be taken into account [7]. Accordingly, there is a tradeoff between optical filter bandwidth and crosstalk between spectrum sliced channels, which can result in performance drop of optical access system. For spectrum sliced WDM-PON system we can see signal distortion in eye diagrams, see Fig. 5(a) and Fig. 5(b). It is seen in Fig. 5(b) that after 20 km transmission without CD compensation the performance of SS-WDM PON system is poor and data transmission with BER < 10^{-10} is not possible. Therefore, for CD compensation and performance improvement of proposed 16-channel SS-WDM PON system, fiber Bragg grating dispersion compensation module was used. We found that optimal CD amount, which must be compensated by FBG DCM for 20 km SMF fiber span is 310 ps/nm at 1550 nm wavelength.

Minimal received power to obtain BER < 10^{-10} must be more than −17.9 dBm for B2B configuration (without transmission line) and −16 dBm for 20 km SMF transmission line with CD compensation. Without CD compensation data transmission over 20 km fiber span with BER < 10^{-10} is not possible. As one can see in Fig. 6 power penalty to receive optical signal for 16-channel SSWDM PON system with BER < 10^{-10} after 20 km transmission and CD compensation with

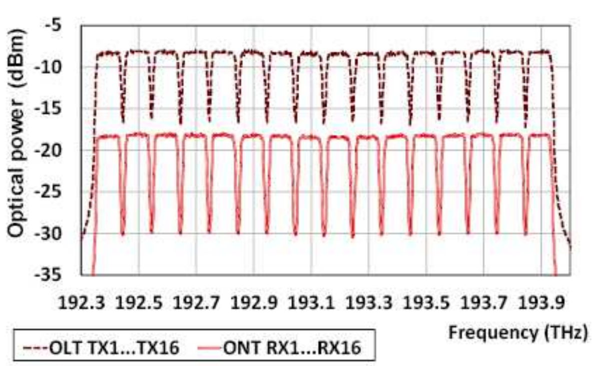

Figure 4: Optical power spectra of transmitted signals on the output of OLT transmitters and on the input of ONT receivers after 20 km transmission.

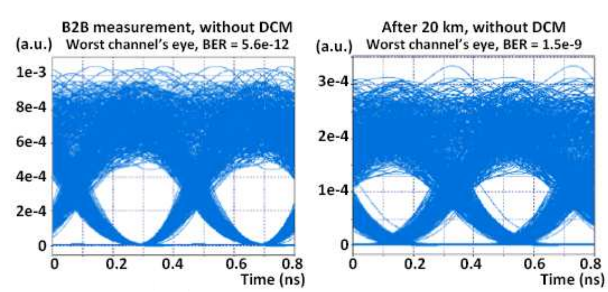

Figure 5: Eye diagrams and BER values of received signal of 16-channel SS-WDM-PON scheme without DCM module for measured, (a) B2B signal and (b) signal after 20 km transmission.

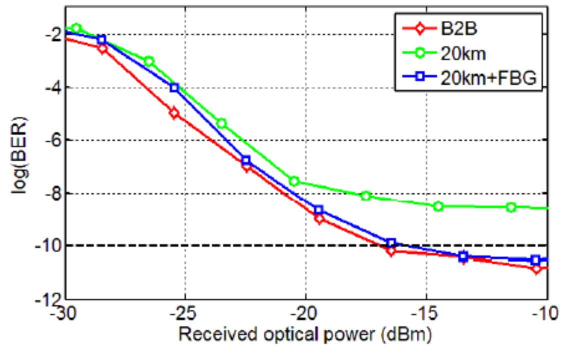

Figure 6: Measured BER versus the received average optical power for 16 channel SS-WDM PON system.

FBG DCM is 1.9 dB. This penalty is introduced by the crosstalk effects, dispersion and due to the noise-like nature of broadband ASE light source.

5. CONCLUSIONS

In this work we have realized and investigated the performance of SS-WDM PON system which is NG-PON suitable technological solution. Evaluated system is based on ITU-T DWDM frequency grid, defined in recommendation G.694.1, has 16 channels and is capable to provide data transmission over 20 km fiber span with transmission speed at least 2.5 Gbit/s. In evaluated system the fiber Bragg grating was used for accumulated chromatic dispersion compensation in DCM module to provide high system performance with BER $< 1 \cdot 10^{-10}$. It is shown that spectrum-sliced WDM PON is a good candidate for NG-PON systems, because it utilizes only one broadband light source which is shared among all users. In this research it is shown, that system performance of SS-WDM PON system can be improved by using additional CD compensation with FBG DCM. We believe that SS-WDM system architecture is potential solution for next generation passive optical networks to support high bandwidth data transmission from OLT to ONTs.

ACKNOWLEDGMENT

This work is supported by the Latvian National research program SOPHIS under grant agreement Nr. 10-4/VPP-4/11.

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