Implementing Bidirectional Long Reach WDM-PON using Mode Locked Laser and RSOA

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ABSTRACT

This paper presents Long Reach Wavelength Division Multiplexing Passive Optical Network (WDM-PON) system capable of delivering downstream 20 Gbit/s data and upstream 10 Gbit/s data on a single wavelength. The optical source for downstream data and upstream data is Mode Locked Laser at central office and reflective semiconductor optical amplifier (RSOA) at each optical network unit. We use two RSOAs at each optical network unit for the 10-Gb/s upstream transmission. The operating wavelengths of these RSOAs are separated by the free-spectral range of the cyclic arrayed waveguide gratings used at the central office and remote node (RN) for (de)multiplexing the WDM channels. We extend the maximum reach of this WDM PON to be 45 km by using Erbium-doped fiber amplifiers at the RN. The hybrid amplifier is designed to enhance the signal power and compensated the fiber dispersion over a wide wavelength range. Optical Equalization technique is used before the receiver to improve modulation bandwidth of an RSOA based colorless ONU. Optical Equalization technique helps to improve downlink and uplink performance. Bit error rate measured to demonstrate the proposed scheme. In this paper Long reach and large data service aspects of a WDM-PON is presented.

Keywords

Wavelength division multiplexing passive optical network (WDM-PON), Reflective semiconductor optical amplifier (RSOA), Erbium doped fiber amplifier (EDFA), Single mode fiber (SMF), Photo detector (PD), arrayed waveguide grating (AWG).

1. INTRODUCTION

The increasing demands for higher speed and advanced services in accessing networks require a bandwidth of above 50 Mbit/s for next-generation services to end users [1]. The use of technologies based on optical fibers can easily achieve bandwidths higher than 100 Mbit/s and at the same time can reduce maintenance and repair costs [1, 2]. In terms of cost, a passive optical network (PON) is very attractive because there are no active components in the transmission line. A PON system typically consists of an optical line terminal (OLT) in a central office (CO), a remote node RN), and optical network units (ONUs).

There are limitations on the transmission capacity and number of users of time-division multiplexing (TDM) PONs with splitters, but they are easy to install and comparatively small as well as requires no electricity [3]. On the other hand, a wavelength division multiplexing (WDM) PON with arrayed waveguide gratings (AWGs) assigns a different wavelength channel to each end user, so the bandwidth can be high. In addition, it is far superior to TDM PONs in security [3, 4] and potentially cost effective [5]. The development of colorless ONUs is a key is- sue in WDM PON technologies to reduce the system cost dramatically. Among various solutions, the use of a reflective semiconductor optical amplifier (RSOA) in an ONU is a good candidate because this approach has the flexibility to assign a wavelength to the upstream signal, and the signal is directly modulated without an external modulator and amplified at the same time [6]. Wavelength division multiplexing (WDM) passive optical networks (PONs) have long been considered as a promising solution to meet the future bandwidth demands of next-generation broadband access networks, capable of providing more than 10-Gb/s data for each subscriber. The assignment of dedicated upstream and downstream wavelength channels to each optical network unit (ONU) not only guarantees large capacity and high security, but also facilitates graceful upgradability and network flexibility [7]–[9].

In this paper, author describes wavelength division multiplexing passive optical network (WDM-PON) system delivering downstream data and upstream data on a single wavelength using pulse source is mode locked laser which is generating a single pulse of “sech” shape with specified power and width i.e. soliton pulse. To improve wavelength utilization of network, author adopts the transmission of downstream and upstream data on a single wavelength. This not only reduces the required number of optical sources and wavelength but also relieves complexity in WDM-PON. We also demonstrate the propagation of soliton pulse in optical fiber. The existence of solitons in optical fiber is the result of a balance between the chirps induced by fiber dispersion characterized by GVD (group velocity dispersion) coefficient β_2 and fiber nonlin- earity characterized by SPM (self phase modulation) coeffi- cient γ [10,11]. Today’s optical fiber system is limited by linear and non-linear effect. To avoid nonlinearity for achieving large number of PON subscribers’ author demonstrates the propagation of soliton pulse in optical fiber so that our scheme will be a practical solution to meet the data rate and cost-efficient. It will also be as compared to the optical links in tomorrow’s WDM-PON access networks. It presents a long-reach WDM–PON capable of providing downstream data 20 Gb/s & Upstream data 10Gb/s service to each subscriber. For the cost-effectiveness (as well as the colorless operation of ONUs), author implement this network in loopback configuration by using directly modulated reflective semiconductor optical amplifiers (RSOAs) operating at 5 Gb/s. Thus, the 10-Gb/s upstream signal is to be obtained by combining the outputs of two RSOAs at each ONU using AWG technique. In this paper, the technique of dispersion compensating Raman/EDFA hybrid amplifier with double-pump in feed-forward Raman amplifier cascade EDFA for secondary signal amplification is used. The hybrid amplifier is designed to enhance the signal power and to compensate the fiber dispersion over a wide wavelength range. To operate the RSOA at 5 Gb/s, Optical equalization technique is utilized before the receiver. There is an optical equalization technique which is utilized at the optical network unit (ONU) and central office (CO) before receiver to improve upstream and downstream performance respectively. The long-reach operation over 45-km long link is accomplished by using dispersion compensating Raman/EDFA hybrid amplifier. The upcoming results show that we can achieve the error-free transmission of the downstream data i.e. 20 Gb/s signals (obtained by combining two 10-Gb/s CWDM channels) & Upstream data 10-Gb/s signals (obtained by combining two 5-Gb/s CWDM channels) . To the best of our knowledge, this result represents the demonstration of the WDM PON capable of providing downstream data 20-Gb/s & upstream data 10-Gb/s service to each subscriber. We also investigate analysis of backscattered optical signal for upstream data and downstream data simultaneously.

2. EXPERIMENTAL SET – UP

Fig.1 shows Experimental set-up for proposed scheme. We present two wavelength 1550nm and 1551 nm transmission in this paper for sake of simplicity. At 10 Gbps initial pulse width is 14.18ps.The peak power necessary to launch a fundamental soliton pulse can be calculated by [12]

$$P_N = \frac{N^2|\beta_2|}{\gamma T_0^2} \qquad (1)$$

where

P_N peak power necessary to launch a fundamental soliton pulse

N Order of soliton pulse

β_2 group velocity dispersion coefficient i.e fiber dispersion parameter

T_0 initial pulse width

γ self phase modulation coefficent i.e nonlinear parameter

For given

N 1 for fundamental soliton

n_2 $2.6e^{-20}$ m^2/w,

A_{eff} core effective area= $60\mu m^2$

λ 1550nm & 1551 nm wavelength

α attenuation = 0.2 dB/km

β_2 -20 ps^2/km

T_0 14.18 ps

Nonlinear parameter calcualted as

$$\gamma = (2\pi n_2)/(\lambda A_{eff}) \qquad (2)$$

For above given value finally got for 1550 nm and 1551 nm

$\gamma=1.75e^{-3}$ 1/ m /w and P_N =7.56 dBm

Using above parameter soliton pulse was generated using mode locked laser, wavelength equal to 1550nm and 1551 nm. For downstream transmission, an NRZ baseband signal running at 10-Gb/s [pseudorandom bit sequence (PRBS) length of 2^{31} -1]. Soliton was directly modulated at downstream data 10 Gbps.

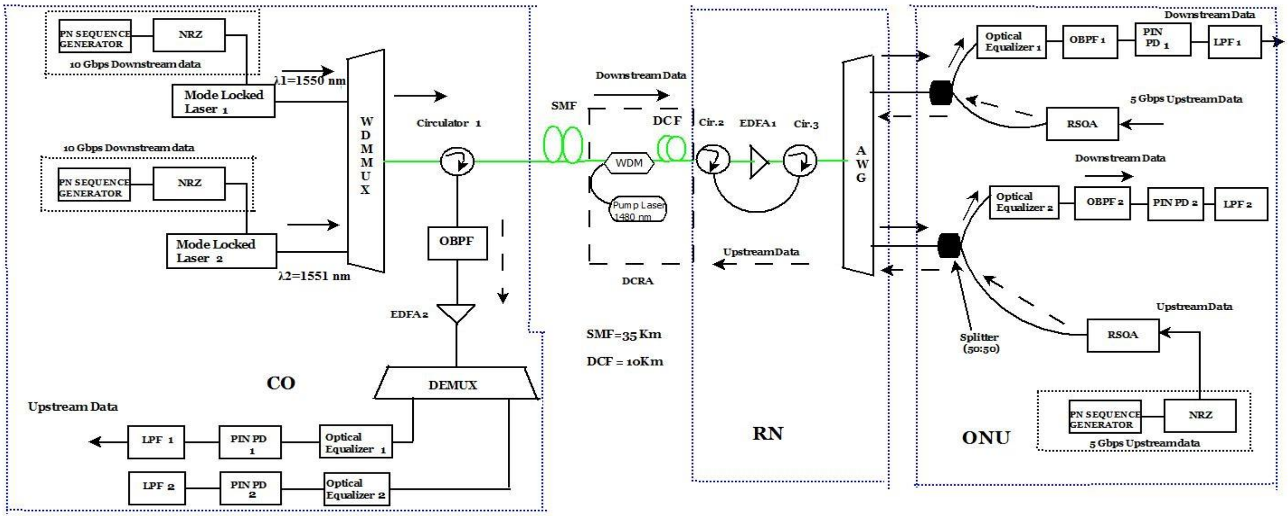

Fig.1.Experimental set-up for proposed scheme

TABLE 1 Key parameters in RSOA simulation model

Parameters	
Input Facet Reflectivity	99.9999999 e^{-009}
Output Facet Reflectivity	0.3
Active Length	0.00050556 m
Taper Length	0.0002 m
Width	1.2 e^{-006} m
Height	0.4 e^{-006} m
Optical Confinement Factor	0.4
Non Linear gain parameter	100 e^{-024} m^3

We have kept channel spacing 1 nm to reduce effect of non linear and linear effect like FWM and chromatic dispersion. All those two wavelengths signals are multiplexed by using WDM MUX .After multiplexing; those entire two signals are transmitted via single mode optical fiber which is mostly used for practical application. After travelling through SMF of length 35 km, 10 km dispersion compensating fiber (DCF). The feeder fiber is compensated dispersion by a length of dispersion compensating fiber. The dispersion parameters for SMF at 1550nm are 16.75 ps/nm/km and 0.075ps/nm^2/km,respectively, while those for DCF at 1550nm are -95ps/nm/km and -0.62ps/nm^2/km. In the hybrid amplifier, the DCF is not only used to compensate fiber dispersion, but also used as part of Raman amplifier. Here, the dispersion compensating Raman amplifier (DCRA) is made of a Raman amplifier with 160mw pump power at 1480-nm and 10-km DCF. In order to boost up the signal power before the ONUs, the optical signal transmitted through feeder fiber with the help of hybrid amplifier. The analysis of backscattered signal for downstream data signal is done at circulator 1 by calculating optical power of backscattered signal. Bidirectional circulator which has insertion loss equal to 3dB. Further, all those two difference wavelengths signal are demultiplexed by AWG and which are given to 50:50 splitter. The optical power received at the ONU was divided into 50% to the RSOA and 50% to the optical equalizer by an optical splitter. Optical splitter has insertion loss equal to 0.5dB.In figure 3 structure of optical equalizer is shown .At ONU, cascaded optical equalizer is used for 1551 nm. Structure of cascaded optical equalizer is shown in fig.2 b. Structure of optical equalizer for 1551 nm is having initial delay equal to 10 ns,final delay equal to 20 ns and phase shift 0^0. Single optical equalizer is used for 1550 nm. Structure of single optical equalizer is shown in fig.2 a. Structure of optical equalizer for 1550 nm is having initial delay equal to 20 ns and phase shift 0^0.Optical equalizer which is used at ONU help to improve performance downstream data. At the end of link optical band pass Bessel filter is used which having bandwidth equal to 4*bit rate for downstream signal and insertion loss equal to 1dB. photo-detector (PD) is for reception of downstream data signal and output of photo-detector given to low pass Bessel filter which having cut of frequency 0.75*bit rate to get better signal to noise ratio. The other half of optical signal is injected by RSOA for remodulation of RSOA with the upstream baseband data 5 Gbps. Further, all those two difference wavelengths signals are applied to respective RSOA. Among various solutions, the use of a reflective semiconductor optical amplifier (RSOA) in an ONU is a good candidate because this approach has the flexibility to assign a wavelength to the upstream signal, and the signal is directly modulated without an external modulator and amplified at the same time. These entire two difference wavelength signals which are given to respective RSOA are directly modulated without an external modulator and amplified at the same time and assigned a wavelength to the upstream signal by respective RSOA. In table 1 design parameters and their values for RSOA are shown. These parameters belong to input facet, output facet, and active region of RSOA model. These parameters are selected to give desired result. After modulation of RSOA with the upstream baseband data 5 Gbps, the modulated outputs of these two RSOAs are combined again by AWG. The multiplexed upstream data signals are passed via bidirectional Circulator 3, Circulator 2,DCRA, SMF , Circulator 1,OBPF and EDFA 2. To secure the sufficient power budget needed for the long-reach application, we use EDFA 2 at the CO. The analysis of backscattered signal for upstream data signal is done at circulator 1 by calculating optical power of backscattered signal.

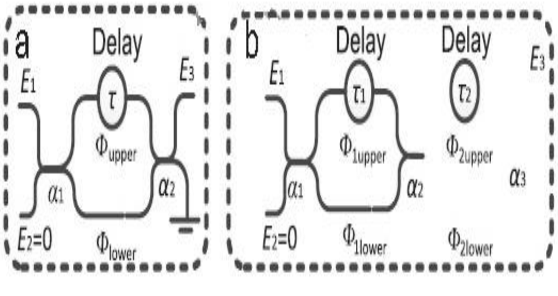

Fig.2 Structure of optical equalizer a) structure of single optical equalizer b) Structure of cascaded optical equalizer

At the CO, optical band pass Bessel filter (OBPF) is used that has the bandwidth equal to 4*bit rate for upstream signal and insertion loss equal to 1 dB. EDFA 1 and EDFA 2 are having Noise Figure (NF) equal to 4dB and gain equal to 40 dB. Further, all those two difference wavelengths upstream signal are demultiplexed by DEMUX at CO. Demultiplxed signals are given to optical equalizer. At CO, cascaded optical equalizer is used for 1551 nm and 1550 nm. Structure of cascaded optical equalizer is shown in fig.3 b. Structure of optical equalizer for 1551 nm is having initial delay equal to 1 ns,final delay equal to 20 ns and phase shift 0^0. Structure of optical equalizer for 1550 nm has initial delay and final delay equal to 20 ns and phase shift equal to 0^0.Optical equalizers which are used at CO help to improve performance upstream data and modulation bandwidth of RSOA. Upstream optical signal is detected by photo-detector (PD) for reception of upstream data signal and output of photo-detector given to low pass Bessel filter which having the cut of frequency 0.75*bit rate for upstream data to get better signal to noise ratio. Finally BER performance of upstream data signal is measured.

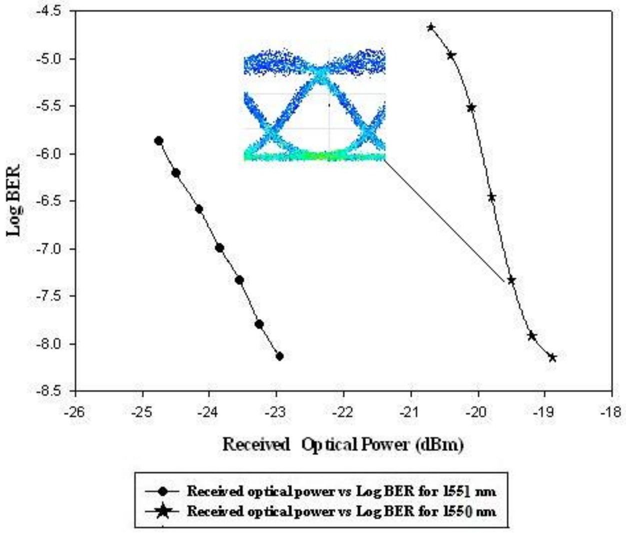

Fig. 3. Transmission performance of downstream data

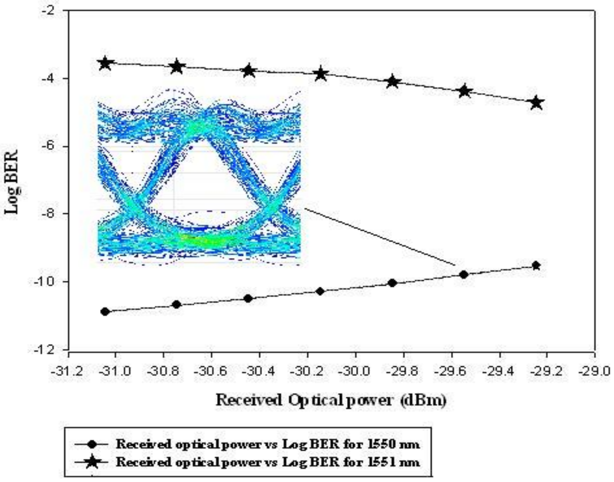

Fig. 4. Transmission performance of upstream data

3. RESULTS AND DISCUSSIONS

We estimated the BER from the recovered data. Fig. 3 and fig.4 show Measured BER curves of downstream and upstream channels after the transmission over 45 km-long fiber the results. The eye diagrams are shown after equalizer for downstream and upstream performance. The power penalties were larger for the channels operating at shorter wavelengths due to the increased chirp of the RSOA. In this paper, receiver sensitivity of −30dBm at bit error rate (BER) of $1.0\mathrm{x}10^{-3}$ is the threshold of error free operation. The received optical power was slightly different from channel to channel due to the wavelength dependence of the EDFA's gain, RSOA's gain, and loss of the filter. Obviously, the downstream and upstream performance increases with increase in received optical power. In case of downstream data performance, received optical power and BER were high and low respectively for 1550 nm than 1551 nm channel. But in case of upstream data performance ,received optical power was equal for 1550 nm and 1551 nm .BER for 1550 nm channel was low compare to 1551 nm channel. If optical power for 1551 nm is increased, BER decreases. But BER increases for 1550 nm. It is observed that for 1550 nm channel BER get better when the receiver optical power is decreased.

This happen due to response of optical equalizer for 1550 nm.

4. CONCLUSION

It is successfully demonstrated that wavelength division multiplexing passive optical network (WDM-PON) system can be successfully implemented for 45Km. It delivers downstream 20-Gbps data and upstream 10-Gbps data on a single wavelength. To perform this function it uses pulse source-mode locked laser that generates a single pulse of "sech" shape with specified power and width i.e. soliton pulse. The transmission distance of the proposed WDM-PON system can be expanded while the performance is maintained.

5. REFERENCES

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