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Implementing a Long Reach Upstream and Downstream Data rate 40Gbps WDM-PON by using Directly Modulated RSOA

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Abstract- This paper presents Long Reach Wavelength Division Multiplexing Passive Optical Network (WDM-PON) system capable of delivering downstream 40 Gbit/s data and upstream 40 Gbit/s data on a single wavelength. The optical source for downstream data and upstream data is CW Laser at central office and reflective semiconductor optical amplifier (RSOA) at each optical network unit. We use four RSOAs at each optical network unit for the 40-Gb/s upstream transmission. The operating wavelengths of these RSOAs are separated by the free-spectral range of the optical demultiplexer at the central office and remote node (RN) for demultiplexing the WDM channels. We extend the maximum reach of this WDM PON to be 100 km by using Erbium-doped fiber amplifiers at the RN. Bit error rate, receiver sensitivity were measured to demonstrate the proposed scheme. In this paper Long reach and large data service aspects of a WDM-PON is presented. The results show that the error-free transmission can be achieved for all WDM channels with sufficient power margins.

Key words- 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).

I. INTRODUCTION

The increasing demands for higher speed and advanced services in access 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 trans- mission 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, are small, and require 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]. A hybrid WDM/TDM PON system that combines the TDM and WDM PON systems was recently developed [7]. The hybrid system com- bines the high bandwidth capacity of WDM-PON and the bandwidth efficiency of TDM-PON, thereby achieves the accommodation of great number of ONUs while the high bandwidth per ONU is maintained. On the other hand, there has recently been a strong demand for so called "triple play" broadband access services including internet protocol (IP) telephony and video broadcasting. A video overlay technique has been also proposed in a WDM-PON system using an MI-FPLD as a BLS for broadcasting and upstream transmission [8]. Unlike other video overlay techniques, this does not require the modification of either remote node (RN) at outdoor or the transmitters at CO to deliver the broadcast signals to ONU. These, ultimately, increase the system cost and make worse bandwidth utilization, which weaken the original purpose of developing a low-cost. Further K. Y. Cho et. al. [9], proposed WDM-PON with 10Gb/s upstream and down- stream transmission. In this the bandwidth of RSOA is 2.2 GHz, and investigated for distance 20km, the optical power incident on the RSOA was -12 dBm and the upstream signal power received by the PIN receiver at the CO was -10 dBm.

In this work, we propose and demonstrate a long-reach wavelength-division-multiplexed (WDM) PON capable of providing 40-Gb/s service to each subscriber. For the cost effectiveness (as well as the colorless operation of ONUs), we implement this network in loopback configuration by using directly modulated reflective semiconductor optical amplifiers (RSOAs) operating at 10 Gb/s. Thus, the 40-Gb/s upstream signal is obtained by combining the outputs of four RSOAs at each ONU using the coarse WDM (CWDM) technique.

II. OPERATIONAL PRINCIPLE

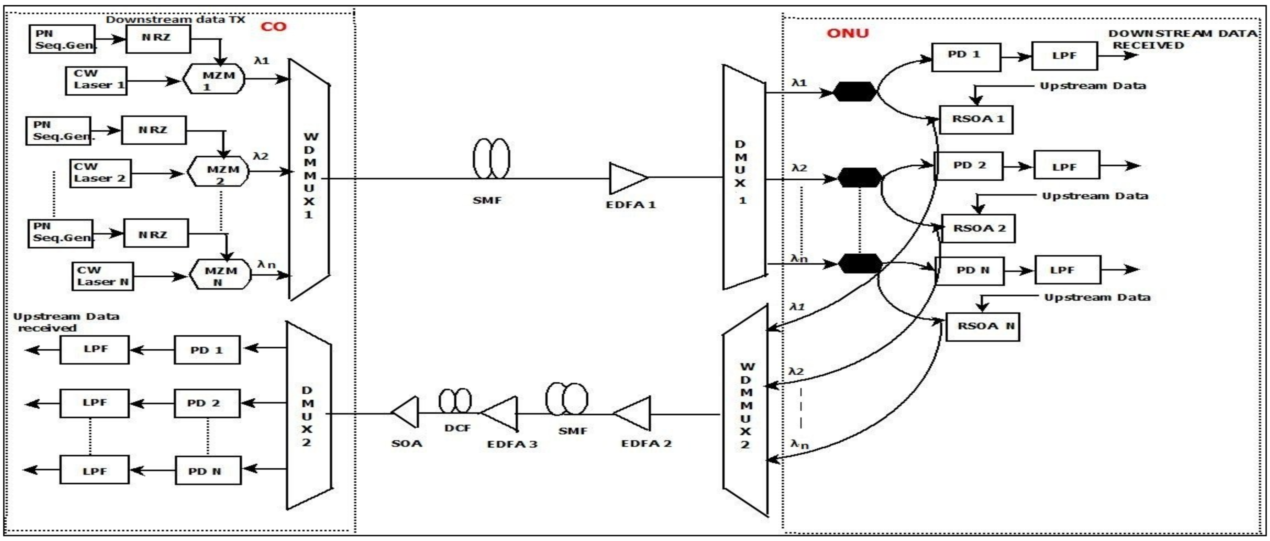


Fig. 1 The schematic diagram of the proposed WDM-PON

Fig.1 shows principle of the proposed WDM-PON. We are going to use Continuous wave (CW) laser as light source which generate light of difference wavelengths. At the central office, continuous wave (CW) optical signals at difference wavelength with specified peak power level are generated. In this paper, external modulation technique is used to improve the performance of communication system. In case of direct modulation technique, there is an unequal power distribution to each transmitted bits which affect largely on BER.

In this paper, to avoid above drawback external modulation technique is used. The downstream data is externally modulated over continuous wave optical signal using Mach- Zehnder modulator as external modulator .The downstream data are transmitted over continuous wave optical signals and given to wavelength division multiplexing 1 (WDM 1) which is used for multiplexing of downstream signal of difference wavelengths. All these downstream signals are transmitted via single mode fiber (SMF) which is practically used and EDFA1 .As shown in fig.1 EDFA 1 and DMUX 1 are used in Remote node. Downstream signals are transmitted via EDFA 1 to strengthen weaken signals ,to make it available for long distance and then after these are transmitted via DMUX 1 which is used for a purpose of demultiplexing of downstream signal and are transmitted to Optical Network Unit (ONU). The proposed network is implemented in loopback configuration. To generate the 40-Gb/s upstream signal, we use four butterfly-packaged RSOAs operating at 10 Gb/s at the ONU. Thus, we need to send a set of four seed light to each ONU from the central office (CO), we assume to use DMUX 1 and DMUX 2 at the CO and RN, and the operating wavelengths of the seed light are separated by the free-spectral range (FSR) of the DMUX. In ONU optical signal is splitted by splitter, half of optical signal is detected by APD photo-detector (PD) for reception of downstream data and output of APD photo-detector given to low pass Bessel filter. BER for downstream signals is observed and calculated at the output of Low pass Bessel filter. The other half of optical signal is injected by RSOA for remodulation of RSOA with the upstream baseband data. The RSOA is operating at the gain saturation region can squeeze out downstream baseband data, and enable the upstream data to be imposed directly upon downstream signal directly. Upstream data is directly modulated without an external modulator and amplified at the same time. A set of light can be sent to each ONU. At the ONU, this set of light is then directed to each RSOA which is modulated using the upstream data. The modulated outputs of these RSOAs are combined again by the WDM MUX 2 which are used for the purpose of multiplexing and sent back to the CO via EDFA 2, single mode fiber (SMF), EDFA3 DCF, and semiconductor optical amplifier (SOA), then demultiplexed by using DMUX 2.

The long-reach operation over 100-km long single-mode fiber (SMF) link is accomplished by using Erbium-doped fiber amplifiers (EDFAs) at the remote node (RN). We assume to use a pair of feeder fibers between the CO and RN to avoid the effects of Rayleigh backscattering. To secure the sufficient power budget needed for the long-reach application, we use EDFAs at the RN. The effect of chromatic dispersion (CD) is suppressed by designing the transmission link to have a slightly negative dispersion value by placing a dispersion compensation module (DCM) in front of the DEMUX 2 at the CO .At CO, upstream data signal is detected by APD photo-detector (PD) for reception of upstream data and output of photo-detector given to low pass filter.BER for upstream signals are observed and calculated at the output of Low pass filter.

III. EXPERIMENTAL SET – UP

We present 4 wavelength transmissions in this paper for sake of simplicity. Fig. 2 shows the experimental setup used to demonstrate the 40-Gb/s, long-reach WDM PON by using directly modulated RSOAs. At the CO, we combined a set of four seed light (operating at 1547.72 nm, 1548.51, 1549.32, and 1550 nm). For downstream transmission, an NRZ baseband signal running at 10-Gb/s [pseudorandom bit sequence (PRBS) length of 2^7 i.e. pattern length of 128 bits]. Input optical power equal to 0 dBm is given to all optical sources in CO. CW Laser was externally modulated at downstream data equal to 10 Gb/s using Mach- Zehnder modulator as external modulator. Mach- Zehnder modulator has extinction ratio equal to 30 dB. All those four downstream signals are multiplexed by using WDM MUX 1.After multiplexing; those entire four signals are transmitted via single mode optical fiber which is mostly used for practical application. The loss 3dB is considered in WDM MUX 1. These optical signals were amplified by the EDFA1 .Each provide gain of 30 dB. After travelling through SMF of length 100 km, optical signal is amplified by EDFA 1. A loss in SMF is 0.2 dB. The insertion loss of this SMF was compensated by using additional EDFAs at the RN. The DEMUX 1 was used with filter of type Trapezoidal which having filter BW equal to 2.50E+10 Hz and filter spacing equal to 1e+11 Hz. Further, all those two difference wavelengths signal are demultiplexed by DMUX 1 and which are given to 50:50 splitter .The insertion loss of DMUX 1 is equal to 3dB .The optical power received at the ONU was divided into 50% to the RSOA and 50% to the optical receiver by an optical splitter.

APD photo-detector (PD) is used for reception of downstream data signal and output of photo-detector given to low pass Bessel filter which having filter BW Equal to 10^{09} Hz and filter order equal to 4 to get better signal to noise ratio. The APD is having quantum efficiency and dark current is equal to 0.8 and $1e^{-06}$ A. The other half of optical signal is injected by RSOA for remodulation of RSOA with the upstream baseband data 10 Gbps. As shown in fig.2 the attenuator and optical power normalizers used to provide sufficient input power to the optical signals which are applied to RSOA so that RSOA is operating at the gain saturation region can squeeze out downstream baseband data, and enable the upstream data to be imposed directly upon downstream signal directly

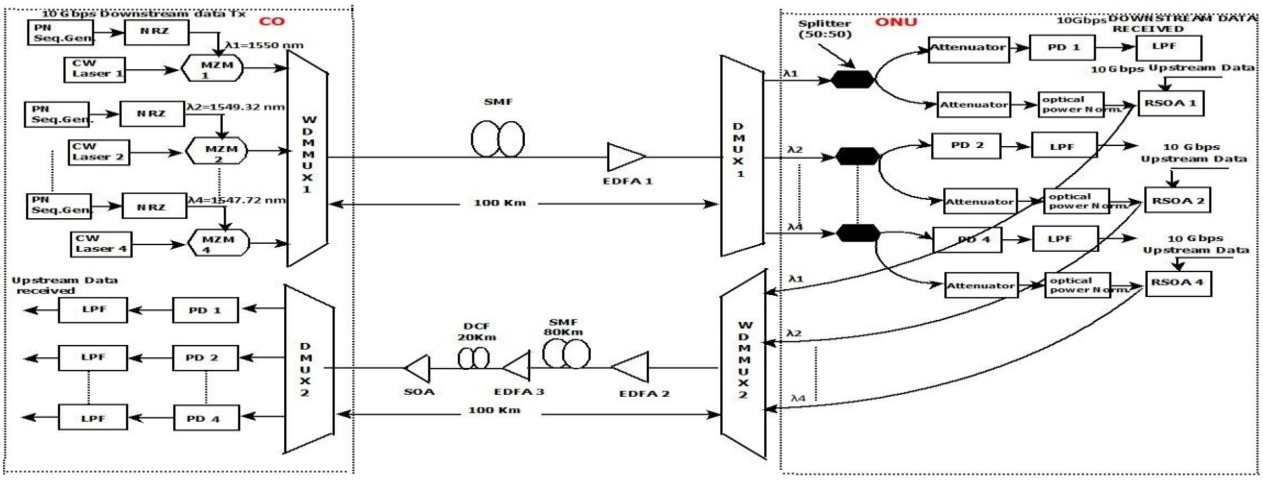


Fig. 2 Experimental set-up for proposed scheme

Further, all those four 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 four 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 10 Gbps, the modulated outputs of these four RSOAs are combined again by WDM MUX2. The multiplexed upstream data signals are passed via EDFA 2, SMF,EDFA3,DCF, and SOA. To secure the sufficient power budget needed for the long-reach application, we use EDFA 3 and SOA at the CO. After travelling through SMF of length 80 km and 20 km dispersion compensating fiber (DCF). The feeder fiber is compensated dispersion by a length of dispersion compensating fiber. Here, post compensation technique is used to reduce chromatic dispersion. At CO, The DEMUX 2 was used with filter of type Trapezoidal which having filter BW equal to 2.50E+10 Hz and filter spacing equal to 1e+11 Hz. The insertion loss of DMUX 1 is equal to 3dB.Further, all those four difference wavelengths upstream signal are demultiplexed by DEMUX 2 at CO. Upstream optical signal is detected by APD photo-detector (PD) for reception of upstream data signal and output of photo-detector given to low pass Bessel filter Finally BER performance of upstream data signal is measured.

Table No. 1. Key parameters in RSOA simulation model

Parameters	
Input Facet Reflectivity	99.9999999 e^{-009}
Output Facet Reflectivity	0.3
Active Length	500e-6 m
Taper Length	0.0002 m
Width	1.2 e^{-006} m
Height	0.4 e^{-006} m
Optical Confinement Factor	0.15
Non Linear gain parameter	100 e^{-024} m^3

IV. RESULTS AND DISCUSSIONS

We estimated the BER from the recovered data. Fig. 3 shows the results for downstream data for four wavelength .The eye diagram is shown in fig 3 for wavelength 1550 nm when transmitted power was 0dBm.We have varied the input transmitted power from 0dBm to -1.5dBm and note the down the BER and received optical power for four wavelengths .It is shown in fig.3.The performance analysis for downstream data is done in fig.3.

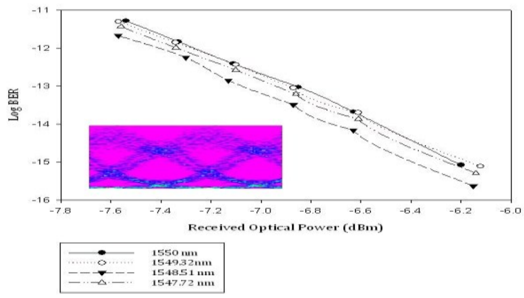


Fig. 3 Transmission performance of Downstream data

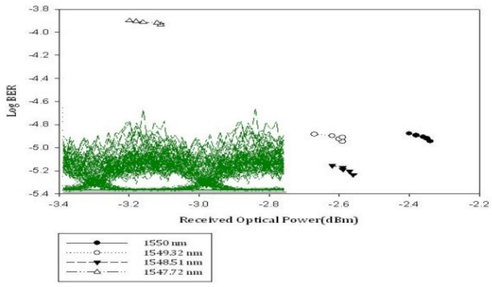
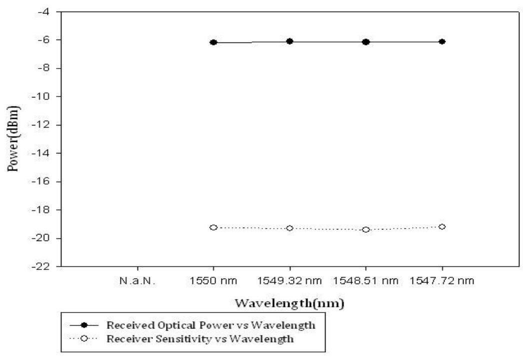


Fig. 4 Transmission performance of upstream data

We estimated the BER from the recovered data. Fig. 4 shows the results for upstream data for four wavelength .The eye diagram is shown in fig 4 for wavelength 1550 nm. Fig.5 shows the receiver sensitivities measured for downstream data at the threshold 1×10−09 for the 4 CWDM channels together with their received powers. The received 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 CWDM filter. However, the power margins were >12 dB for all 4 CWDM channels. Fig.6 shows the receiver sensitivities measured for upstream data at this FEC threshold for the 4 CWDM channels together with their received powers. However, the power margins were >13 dB for all 4 wavelength channels.



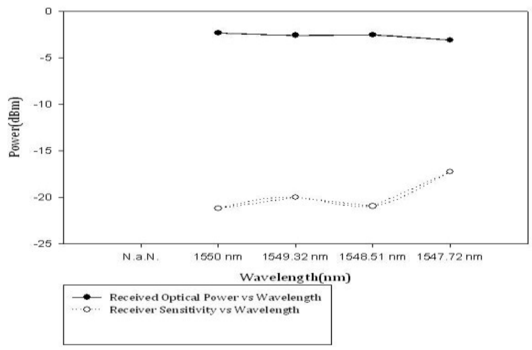


Fig. 5 Receiver sensitivities measured for Down Stream data at the FEC threshold of BER = 1×10−09 and the optical power incident on the receiver in the setup shown in Fig. 2.

Fig. 6 Receiver sensitivities measured for Up Stream data at the FEC threshold of BER = 1×10−4 and the optical power incident on the receiver in the setup shown in Fig. 2.

V. CONCLUSION

It is successfully demonstrated that wavelength division multiplexing passive optical network (WDM-PON) system can be successfully implemented for 100Km. It delivers downstream 40-Gbps data and upstream 40-Gbps data on a single wavelength. We have experimentally demonstrated the upstream link of 40-Gb/s, 100-km reach WDM PON implemented by using directly modulated RSOAs. For this experiment, we mounted the RSOA in a butterfly package to minimize the electrical parasitics. As a result, the modulation bandwidth of this RSOA was improved. The results show that the error-free transmission can be achieved for all WDM channels with sufficient power margins.

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