A Simple High-Speed WDM PON Utilizing a Centralized Supercontinuum Broadband Light Source for Colorless ONUs

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Abstract: We propose a simple high-speed WDM-PON, using a centralized supercontinuum broadband light source based on a nonlinear PCF for upstream optical carriers. "Colorless" ONU operation has been demonstrated in a 10Gb/s bidirectional transmission over 40 km distance.

OCIS codes: (060.2330) Fiber optics communications; (060.4250) Networks

1. Introduction

Much attention has been focused on the wavelength division multiplexed passive optical network (WDM-PON) for next-generation broadband access architecture, due to its large bandwidth, upgrade flexibility and security with dedicated connections. Spectral slicing is desirable for access network, since it eliminates the need for wavelength-specific transmitters at the customer site optical network units (ONU), thus relaxing the wavelength management on the customer side of the access network [1]. Previous works on spectral slicing have focused on the use of LED or superluminescent diode (SLD) as broadband source at each ONU [2, 3]. However, the upstream transmission capacity was limited due to the large spectral slicing loss and low output power of LED and SLD. In [4], a wavelength-locked Fabry-Perot laser diode (F-P LD) locked to an injected spectrum-sliced amplified spontaneous emission (ASE) light was proposed, while the bit rate was still confined at 155 Mb/s, which may not fulfill the expected growth of bandwidth demands.

On the other hand, supercontinuum (SC) is a promising technique to generate broadband light owing to its easy implementation, flexible design and large number of supporting channels, which has been investigated for use in dense wavelength division multiplexed (DWDM) transmission systems [5, 6]. In this paper, we propose and demonstrate a simple high-speed WDM-PON access architecture using centralized supercontinuum broadband light source for upstream optical carrier supply. The elimination of the light source at the ONU avoids its stabilization and provisioning and all ONUs are wavelength independent ("colorless"). Since a high nonlinearity photonic crystal fiber (PCF) is very efficient for supercontinuum generation [7], our SC broadband source is based on the use of a photonic crystal fiber. We bidirectionally transmit upstream and downstream data at 10 Gb/s over 40 km of single mode fibers (SMF).

2. Proposed access network and experiments

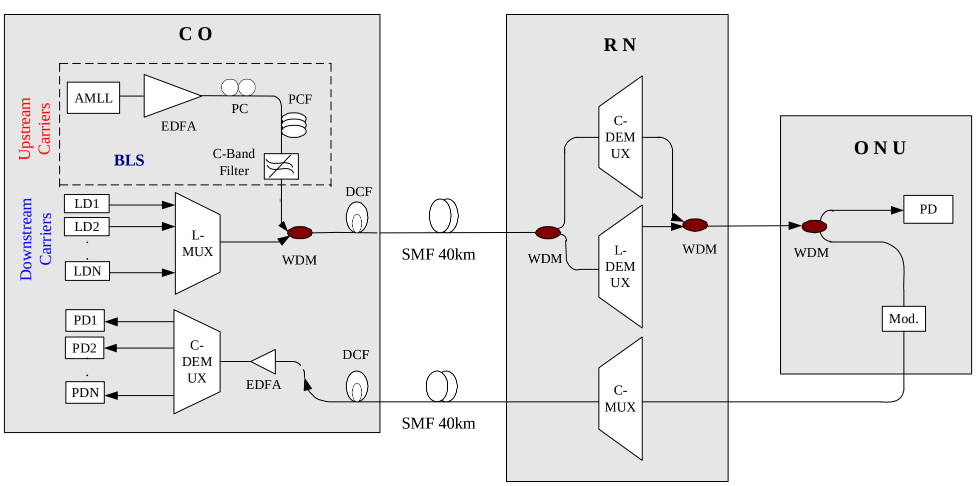

Fig. 1 Experimental setup for bidirectional WDM PON

The experimental setup to demonstrate the WDM-PON is shown in Fig. 1. We used conventional C band for upstream data transmission and L band for downstream data transmission. The central office (CO) consisted of a broadband light source (BLS), L band DFB laser transmitters, optical receivers, a L band multiplexer, a C band demultiplexer, a C/L band wavelength division multiplexer (WDM), an EDFA, and two dispersion compensation modules (DCM). The supercontinuum BLS consisted of an actively mode-locked laser (AMLL), an EDFA, a polarization controller (PC), a piece of nonlinear photonic crystal fiber and a C band bandpass filter.

A 1-ps pulse train centered at 1550 nm was generated by a semiconductor-laser-based actively mode-locked laser with a repetition rate of 10GHz, and then amplified by an erbium doped fiber amplifier (EDFA) delivering up to 23 dBm average power before input to 64m of a dispersion-flattened highly nonlinear PCF from Crystal Fiber A/S. The overall dispersion of this PCF is flat over a wide wavelength range (less than -3ps/km/nm over 1500-1600nm) with the nonlinear coefficient of the PCF was 11.2 $(W \cdot km)^{-1}$ [8]. The dispersion variation is less than l ps/km/nm in the 1550nm range. Due to the fiber birefringence, a PC is used before the PCF. The C band bandpass filter centered at 1550 nm (bandwidth: 13 nm) was used behind the PCF to limit the spectral width of the supercontinuum to be at the C band for upstream carrier use, which is separated from the L band downstream channels. The L band DFB lasers directly modulated at 10 Gb/s were combined with the C band upstream carrier, and then sent to the remote node (RN) through 40 km long single mode fiber. To suppress the effect of fiber dispersion, we used a dispersion compensation module at the CO. These combined signals were separated by a C/L band WDM filter, and demultiplexed at the RN respectively.

The ONU consisted of an optical modulator, an optical receiver, and a C/L band WDM filter. Since there is no light source, the “colorless” ONU can support any wavelength channel, which minimized the costs of system operation and maintenance, but at the expense of an external modulator at the ONU. The C band upstream carrier was first divided from downstream data by the C/L band WDM filter, then modulated at 10 Gb/s with a 2^{31}-1 pseudorandom bit sequence (PRBS) pattern at each ONU, and finally sent to the CO through 40 km SMF transmission line after being multiplexed at the RN. After passing through an optical amplifier, the upstream signals were demultiplexed, and received in individual optical receivers at the CO.

3. Experimental results and discussions

Since the downstream data was transmitted by single DFB laser diode separately, we only demonstrated 8 upstream channels supplied by the SC source with 100GHz channel spacing. 23 dBm optical power was generated from the supercontinuum broadband light source. The splicing loss was 15 dB (for the worst channel) at the DEMUX in RN, thus the total down link loss (caused by DCM, 40 km long SMF, WDM coupler, DEMUX) was 30 dB. At each ONU, the upstream carrier experienced 9 dB loss for modulation, and the uplink loss (caused by MUX, 40 km long SMF, DCM) was 18 dB. Since the receiver sensitivity with pre-amplifier was -38 dBm at 10Gb/s, there was still a 4 dB power margin for the worst channel.

Fig. 2 shows the generated supercontinuum spectrum before and after the C band bandpass filter. The spectrum was broadened to 25nm (-20 dB bandwidth) after SC generation and we filtered out 13nm in C band for use as upstream carriers. Because the spectrum was inherently not smooth, it resulted in optical power variation among different channels. After being demultiplexed, the maximum difference in received power between two channels was 3.6 dB. Fig. 3 shows the eye diagram of the upstream channel 2 (with maximum optical power) and channel 8 (with minimum optical power) after transmission. We observed clear eye diagrams as shown in Fig. 3 in spite of the power variation.

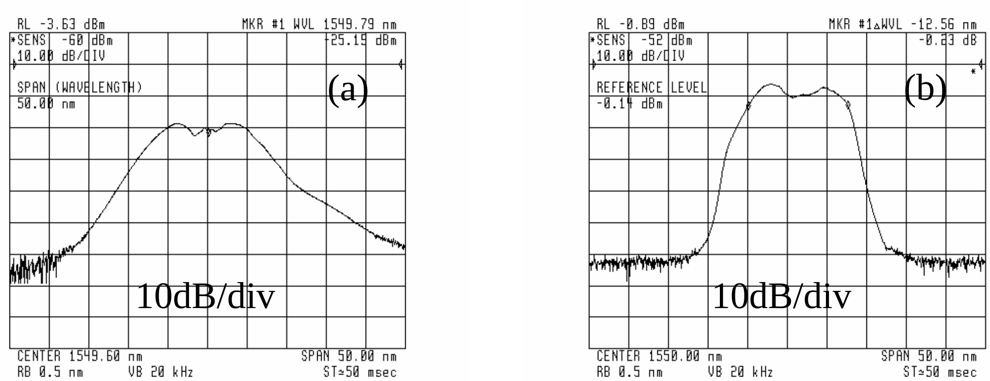

Fig. 2 Optical spectrum of SC generation (a) before and (b) after C band bandpass filter.

Fig. 4 shows the BER performances of all 8 upstream optical channels. Fig. 5 shows Q factor measured by the threshold-variation method after transmission for all 8 channels. It can be seen from both Fig.4 and Fig. 5 that all channels were transmitted error-free (bit-error rate < 10^{9}) albeit with variation in channel performance.

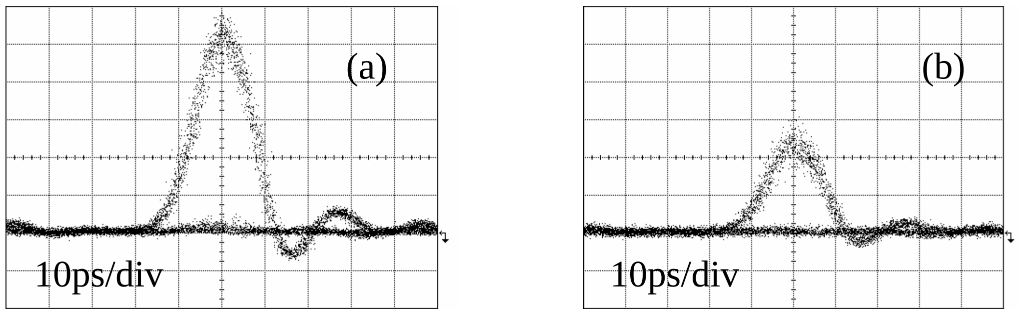

Fig. 3 Eye diagram of different upstream channels
(a) Channel 2 centered at 1547.7 nm(with the highest power); (b) Channel 8 centered at 1557.36 nm(with the lowest power).

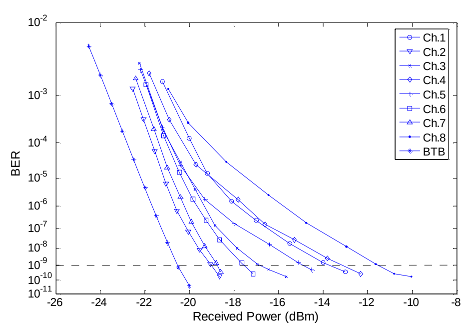

Fig. 4 BER performances of 10 Gb/s upstream channels

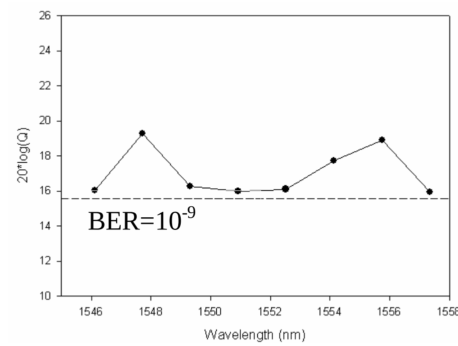

Fig. 5 Measured Q factor
Dashed line show the Q factor needed for error floor of 10^{-9}.

In our experiment, due to the limit of EDFA, the maximum power input to the PCF was 23 dBm, which limited the bandwidth of the SC spectrum. The SC spectrum can extend over 60 nm with an average pump power of 30 dBm [7], which cover the C and L bands used for optical communication. In that case, the supported channel number can be readily extended to 16 or 32. To achieve the colorless ONU operation, external modulators are needed in each ONU for the upstream signal, and here we assume that such modulators would be low cost in high volumes.

4. Conclusion

We have proposed and demonstrated a simple high-speed passive optical network architecture using centralized nonlinear PCF-based supercontinuum broadband light source for upstream optical carriers in colorless ONUs. 8 channel bidirectional transmissions at 10Gb/s over 40 km distance were demonstrated. All 8 channels achieved error-free transmission albeit with variation in channel performance. In future work, we can upgrade the proposed WDN-PON using higher power EDFA, providing more upstream optical carriers for a larger number of ONUs.

5. References

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