Demonstration of an ONU for WDM Access Network with Downstream BPSK and Upstream Remodulated OOK Data Using Injection-Locked FP Laser

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Abstract: We propose an ONU for WDM access network with 2.5Gb/s passband BPSK downstream data and 1.25Gb/s OOK upstream data. The downstream wavelength is reused to injection-lock a FP laser diode at ONU to provide remodulation for the upstream data.

Introduction

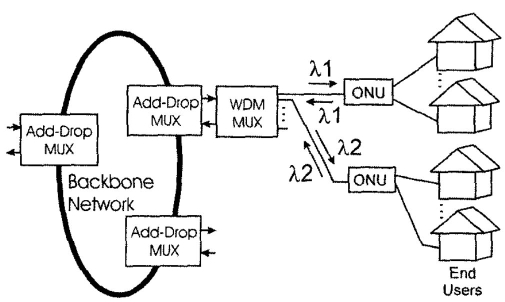

Figure 1: A generic optical network architecture showing the ONUs bridging subscribers access and the backbone network.

Researchers have proposed various schemes to implement low cost WDM transmitters at the optical network units (ONUs) for WDM access networks [1-4]. It benefits the network operator in terms of capital investment, no wavelength tracking at ONU, and components stocking. In [4], On-Off Keying (OOK) is used for both downstream and upstream data with data remodulation using an injection-locked Fabry-Perot laser diode (FP-LD) at the ONU. However, it sacrificed the extinction ratio and thus the performance of the downstream data. In this paper, we propose to carry downstream data in binary phase shift keying (BPSK) format at a passband carrier frequency while using the same downstream wavelength to injection-lock a FP-LD at ONU to provide data remodulation (in OOK format) for the upstream traffic. An ONU with 2.5Gb/s downstream data and 1.25Gb/s upstream remodulated data was experimentally demonstrated.

Principle of Operation

Fig. 1 illustrates a typical WDM access network architecture. We reuse the same wavelength in the upstream data traffic from the downstream light beam after light injection-locking at the ONU. Downstream data is carried in BPSK format at a passband carrier frequency. After the downstream wavelength reaches the ONU, we employ the light injection-locking scheme to remodulate a FP-LD at ONU with OOK format for carrying upstream data traffic. Thus the downstream light beam has two folds of usage: conveying downstream data and light injection-locking to the FP-LD. With injection-locking, the FP-LD exhibits a high SMSR which would not only reduce mode partition noise but also alleviate fiber dispersion problem.

Fig. 2 shows the experimental setup. The downstream data is modulated in BPSK format using a commercially available microwave mixer and a local oscillator to upconvert the data stream to a higher carrier frequency.

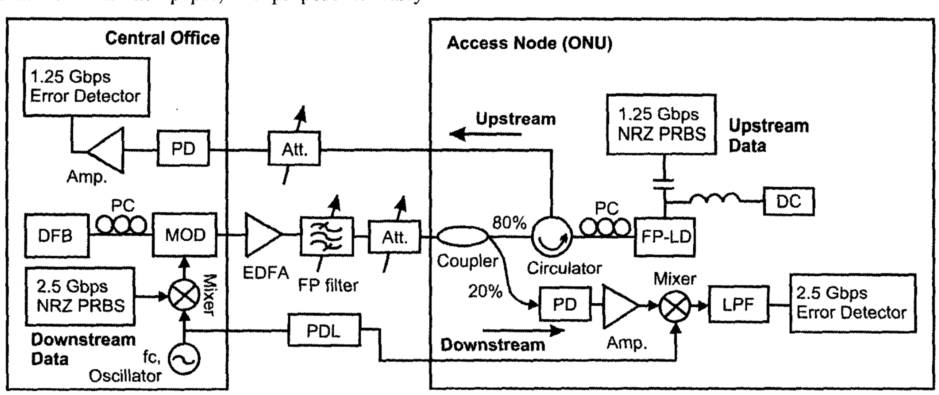

Figure 2: Experimental Setup: DFB – DFB laser, PC – Polarization Controller, MOD – Intensity Modulator, EDFA – Erbium-Doped Fiber Amplifier, Att. – Variable Optical Attenuator, FP-LD – Fabry-Perot Laser Diode, DC – DC Current Source, PD – Photodetector, Amp. – Electronic Amplifier, LPF – Low Pass Filter, FP filter – Fabry-Perot Bandpass Filter, and PDL – Programmable Delay Line.

The BPSK signal is then used to modulate the output of a DFB laser through an intensity modulator. The downstream light channel is split into two at the ONU, one for injection-locking the FP-LD of the upstream data, and the other for data reception through the coherent BPSK demodulation. In the experiment, instead of using a phase-locked loop circuit for coherent detection at the receiver, we use a programmable delay line to synchronize the BPSK carrier.

Experimental Results

The FP-LD of our experiment shown in Fig. 2 was biased at 1.4 I_{th} (threshold current) which achieved the lowest power penalty. The upstream and downstream data traffics are generated from two bit-error-rate testers (BERT) using $2^{31}-1$ pseudorandom bit-stream in Non-Return-to-Zero (NRZ) format. The data rates for downstream and upstream were 2.5 Gb/s and 1.25 Gb/s, respectively. At ONU, an optical circulator was used to divert the injection-locked upstream signal from the downstream signal. The side-mode suppression ratio (SMSR) of the FP-LD was improved from 2.6 dB to 25 dB with an injection power of –9 dBm. The improvement in SMSR alleviated the dispersion-induced power penalty on the upstream transmission.

First, we investigated the effect of BPSK carrier frequency on the system. Error-free transmission for BPSK downstream data was achieved with carrier frequencies ranging from 6 to 11 GHz for received power > –19.0 dBm. An optical receiver with responsivity equal to 305 V/W was used for the downstream data detection. The variation of bit-error-rate (BER) measurement of the downstream BPSK data for different carrier frequencies was very small, within 1 dB.

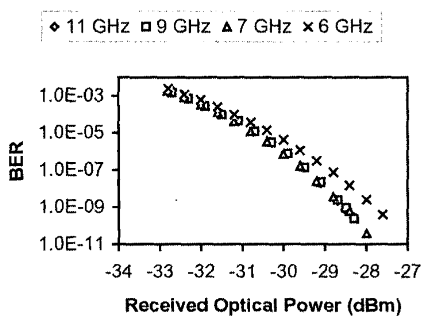

Figure 3: BER performance of 1.25 Gb/s upstream data after light injection-locking from a BPSK downstream data at different carrier frequencies.

The BER for the upstream after injection-locking under different BPSK carrier frequencies is shown in Fig. 3 for back-to-back measurement without fiber. The variation in the sensitivities at 10^{-9} BER is less than 1-dB. It is shown that better receiver sensitivity could be achieved if higher carrier frequency is employed. This can be attributed to a better injection-locking of the FP-LD, as higher BPSK carrier gives shorter duration of small incident power period that leads to the unlocking of the FP-LD. We further investigated the upstream BER performance of the FP-LD with CW light injection and with injected light carrying 2.5Gb/s BPSK data at 6-GHz carrier frequency. The average incident power was about -5 dBm in both cases. The BER performance in both cases was depicted in Fig. 4. It was shown that the power penalty of the remodulated upstream data using injected BPSK signal is about 1 dB, as compared to the case using CW injected light. This proved the feasibility of our proposed scheme for both downstream and upstream data transmission in a WDM access network. Note that if free-running FP-LD is used to carry the upstream data to travel over a certain length of fiber, the upstream traffic will definitely suffer a large power penalty due to the fiber dispersion. Moreover, using BPSK downstream modulation can eliminate the detrimental effect of possible lost locking at the FP-LD due to long zeros as in the case of OOK downstream data.

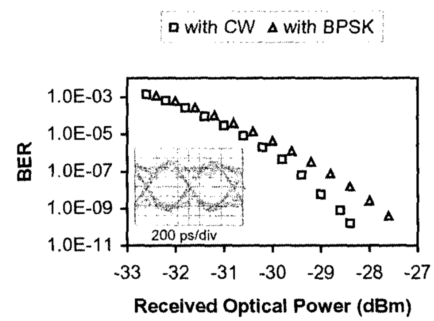

Figure 4: BER performance of 1.25 Gb/s upstream data after light injection-locking from the downstream with BPSK data and without data (CW). The inset show demodulated eye diagrams of the upstream data.

Summary

We propose and demonstrate a WDM access network which employs injection-locking of an FP-LD at the ONU with 2.5-Gb/s downstream passband BPSK modulation and upstream 1.25-Gb/s OOK modulation. With our proposed data remodulation scheme for upstream traffic using low-cost injection-locked FP-LD, no wavelength registration is needed at ONU and thus eases the network maintenance.

References

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