Upstream traffic transmitter using injection-locked Fabry-Perot laser diode as modulator for WDM access networks

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An upstream-traffic transmitter based on a Fabry-Perot laser diode (FP-LD) as modulator is proposed and demonstrated for wavelength division multiplexed (WDM) access networks. By injection-locking the FP-LD with the downstream wavelength at the optical network unit (ONU), the original downstream data can be largely suppressed while the upstream data can be transmitted on the same injection-locked wavelength by simultaneously directly-modulating the FP-LD.

Introduction: The application of wavelength division multiplexing (WDM) in local access networks [1] is a promising approach to meeting increasing bandwidth demand from enterprises and households. For better wavelength management, network architectures with centralised light source at the central office (CO) and data remodulation of the downstream signal for the upstream traffic at the optical network unit (ONU) were proposed. The blank time slots from the downstream signal were modulated with upstream data at the ONU via either an optical modulator [2] or a semiconductor optical amplifier [3], thus eliminating any wavelength-registered source at the ONU. In [4], an amplified-spontaneous-emission (ASE) injected Fabry-Perot laser diode (FP-LD) was proposed as a WDM source at the remote ONU to transmit the upstream data traffic. However, it required completely unmodulated ASE wavelengths from the central office and thus could not support downstream traffic with the same set of wavelengths.

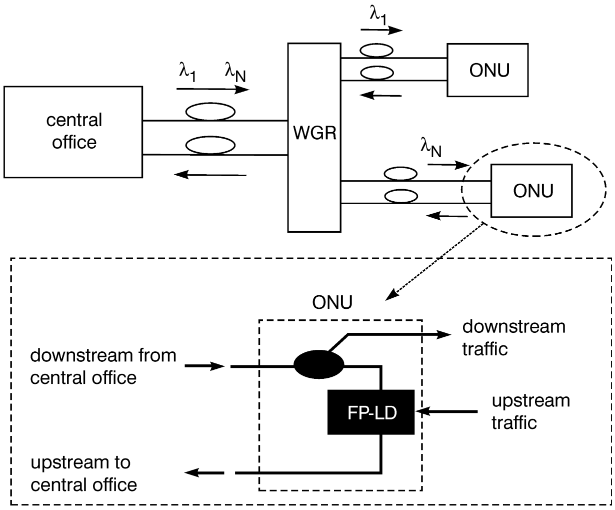

Fig. 1 *WDM access network with proposed upstream traffic transmitter at ONU*

ONU: optical network unit; WGR: wavelength grating router; FP-LD: Fabry-Perot laser diode

In this Letter, we propose and demonstrate a novel upstream traffic transmitter, based on injection-locking of an FP-LD with the downstream wavelength carrying high-speed downstream data. The proposed transmitter requires only an FP-LD at the ONU and thus is potentially low-cost. Experimental results showed that, under suitable operation conditions, the injection-locking of the FP-LD largely suppressed the original 10 Gbit/s downstream data stream, allowing reuse of optical power and simultaneous direct modulation of 1 Gbit/s upstream data. The injection-locked FP-LD offered singlemode operation and thus greatly reduced the fibre-dispersion-induced penalty. We have demonstrated that the upstream signal could be transmitted over a 50 km fibre span with error-free operation.

Upstream traffic transmitter with remodulation: Fig. 1 shows the architecture of a typical WDM local access network. A wavelength grating router (WGR) is employed to route different wavelength channels to different ONUs. Our proposed upstream traffic transmitter employs an FP-LD at the ONU (see inset of Fig. 1). At the ONU the downstream wavelength channel is partially tapped off for downstream data reception while the rest of the wavelength power is injected into the FP-LD for injection-locking. The injected-locked FP-LD exhibits a greatly improved sidemode suppression ratio (SMSR), which is necessary in a dense WDM environment. The improved SMSR also increases the tolerance to fibre chromatic dispersion and thus enhances the network transmission span. Under the condition that the power levels of both one and zero bits in the injected downstream signal are above a certain power threshold, the injection-locked FP-LD will emit the same wavelength as the downstream signal with the original data content largely suppressed, as shown in Fig. 2*a*. Thus, by directly-modulating the injected-locked FP-LD with the upstream data simultaneously (Fig. 2*b*) a potentially low-cost upstream data transmitter with improved signal quality can be realised.

Experimental demonstration: Fig. 3 shows the experimental setup to demonstrate our proposed upstream traffic transmitter, to perform data remodulation, for simplicity, on one particular downstream wavelength channel. At the central office, a DFB laser at 1546.2 nm was externally modulated with a 10 Gbit/s NRZ $2^{31}-1$ pseudorandom bit stream (PRBS) data to form the downstream signal, which was then transmitted over a fibre span of 50 km to the ONU. The extinction ratio of the downstream signal was adjusted to −2.9 dB so that the power of the one and the zero levels were well above the locking threshold (measured to be −15.2 dBm) before the FP-LD at the ONU. At the ONU, 50% of the downstream signal was tapped off for downstream data reception via a 10 Gbit/s optical receiver while the rest of the signal power (at −6.1 dBm) was injected into a FP-LD, which was simultaneously directly-modulated with a 1 Gbit/s NRZ $2^{31}-1$ PRBS upstream data. An optical circulator was used to separate the reflected and injection-locked upstream signal from the downstream signal. The injection-locking improved the SMSR of the FP-LD from 2 to 29.7 dB (see inset of Fig. 4) and the output signal was observed to have 1.7 dB power gain. The remodulated upstream signal was then transmitted over another 50 km fibre span and was received at the central office. Fig. 4 shows the BER performance of the 10 Gbit/s downstream signal and the 1 Gbit/s remodulated upstream signal, measured at ONU and CO, respectively. The eye diagrams for both signals are also shown in insets of Fig. 4. Both measurements showed error-free operation and proved the effectiveness of our proposed scheme.

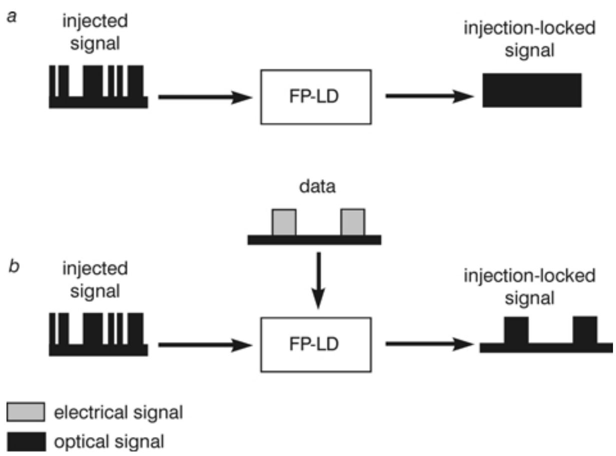

Fig. 2 *Operation principle of proposed upstream traffic transmitter by injection-locking of FP-LD*

a Downstream data suppression
b Upstream data modulation

Conclusion: We have proposed and demonstrated a novel upstream traffic transmitter for a WDM access network (10 Gbit/s downstream signal and 1 Gbit/s upstream signal) with a centralised light-source approach. The FP-LD replaces the local laser source and optical modulator in a conventional ONU, thus resolving the problem of wavelength mismatch between the downstream and upstream wavelengths in a low-cost regime. The ‘re-writing’ of the downstream signal by injection-locking of the FP-LD is promising in an access network since it works for both symmetric and asymmetric two-way traffic, thus eliminating the complicated synchronisation process. In addition, better bandwidth utilisation is achieved as no blank time slots in the downstream signal are reserved for the upstream signal. The injection-locking method enables the FP-LD to achieve much better tolerance to the fibre chromatic dispersion, thus enhancing the network transmission span.

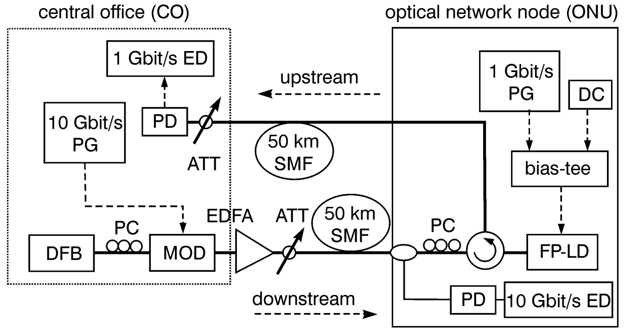

Fig. 3 *Experimental setup*

DFB: distributed feedback laser; PD: photodiode; MOD: external modulator; SMF: standard singlemode fibre; EDFA: erbium-doped fibre amplifier; ATT: variable optical attenuator; PG: pattern generator; ED: error detector; DC: DC bias current to FP-LD; PC: polarisation controller

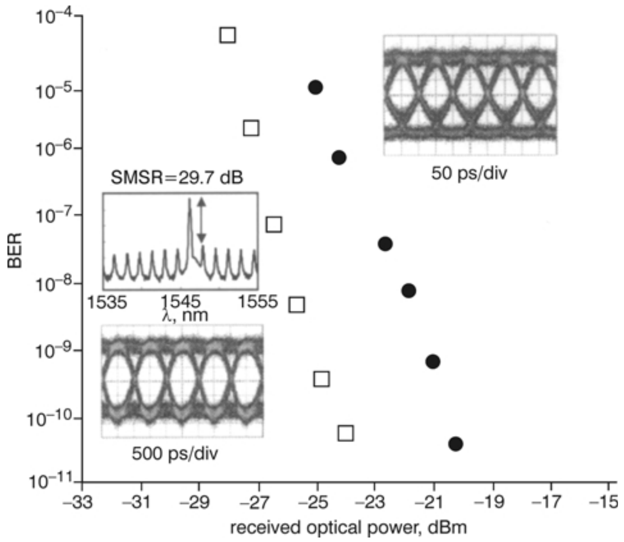

Fig. 4 *BER measurements for 10 Gbit/s downstream signal at ONU and 1 Gbit/s remodulated upstream signal at CO each transmitted over 50 km fibre span*

● downstream signal
□ remodulated upstream signal
Insets: respective detected eye diagrams and optical spectrum of injected-locked FP-LD with SMSR of 29.7 dB

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