13 Gbit/s WDM-OFDM PON using RSOA-based colourless ONU with seeding light source in local exchange

C.W. Chow, C.H. Yeh, Y.F. Wu, H.Y. Chen, Y.H. Lin, J.Y. Sung, Y. Liu and C.-L. Pan

Optical-carrier-distribution using reflective-semiconductor-optical-amplifier (RSOA)-based colorless optical-networking-unit (ONU) is a promising candidate for the wavelength-division-multiplexed passive-optical-network (WDM-PON). However, commercial available RSOA has a typical modulation-bandwidth of ∼1 GHz, which is not enough for the future bandwidth demand. Here we demonstrate a WDM-PON using 1 GHz bandwidth RSOA-based ONU, which can be operated up to 13 Gbit/s. Experimental results show that 20 km singlemode-fibre transmission of the 13 Gbit/s orthogonal-frequency-division-multiplexed (OFDM) signal can be achieved with bit-error rate lower than the forward error correction threshold.

Introduction: The wavelength division multiplexed passive optical network (WDM-PON) is a promising candidate for the future fibre-to-the-home (FTTH). Optical carrier distribution with a colourless optical networking unit (ONU) is one of the cost-effective implementations of the WDM-PON [1]. The reflective semiconductor optical amplifier (RSOA)-based ONU is important for the WDM-PON owing to its compact size and low power consumption [2–5]. Recently, using optical orthogonal frequency division multiplexing (OFDM) modulation in PONs has attracted much attention [6]. As the OFDM quadrature amplitude modulation (QAM) signal is very spectrally efficient, the data rate of the PON can be increased while low bandwidth optical components optimised for the present PON can still be used [7]. By using OFDM access (OFDMA), one more degree of freedom can be obtained for bandwidth sharing and dynamic bandwidth allocation apart from time division multiple access (TDMA) and WDM access (WDMA).

Commercially available RSOA has a typical modulation bandwidth of ∼1 GHz. It is desirable to operate the RSOA-based ONU >10 Gbit/s for the future WDM-PON. Recently, there have been several demonstrations to increase the RSOA operation speed to 10 Gbit/s by using adaptively modulated optical OFDM (AMOOFDM) [2], offset optical filtering and electronic equalisation [3], special design structure [4], or adding a delay interferometer [5]. In this Letter, we demonstrate a WDM-PON using a commercially available 1.2 GHz bandwidth RSOA-based ONU, which can be operated up to 13 Gbit/s. In this demonstration, the optical seeding light source is located in the local exchange (LE) for providing relatively higher injection power to enhance the relaxation oscillation speed of the RSOA. The proposed scheme does not require complicated OFDM subcarrier-level power management and analysis when compared with the AMOOFDM. It also does not require the optical filtering or delay interferometer. 20 km singlemode-fibre (SMF) transmission of the 13 Gbit/s OFDM signal can be achieved with a bit-error rate (BER) lower than the forward error correction (FEC) threshold.

Experiment: Fig. 1 shows the experimental setup. A continuous-wave (CW) optical signal produced by a tunable laser at wavelength of 1550 nm with different injection powers was launched into the RSOA via an optical circulator. The RSOA (standard product by CIP) has a 3 dB bandwidth of 1.2 GHz when DC-biased at 80 mA, and has a small signal gain of 20 dB. The noise figure and the polarisation dependent gain are 7 and 1 dB, respectively. The RSOA was directly modulated by a baseband electrical OFDM upstream signal generated by an arbitrary waveform generator (AWG). The data was packed into 93 OFDM subcarriers; each was in a 128-QAM. The total data rate of 15.3 Gbit/s can be provided by these 93 OFDM subcarriers. By using inverse fast Fourier transform (IFFT), this signal was converted to a real-valued time-domain waveform. Then the digital-to-analogue converter (DAC) (AWG having the sampling rate of 4 Gsample/s) converted the digital data to an analogue signal for the RSOA. It has the resolution of 6-bit. The cyclic prefix (CP) was 1/64. The electrical signal was then applied to the RSOA via a bias-tee.

Then, the optical upstream signal was transmitted in 20 km SMF without dispersion compensation, and was directly received by a 2.5 GHz *pin* photodiode (PD) at the central office (CO) without using an optical preamplifier. As shown in Fig. 1, the received OFDM signal was captured by a real-time oscilloscope (RTO) with 12.5 GHz bandwidth. The RTO performed the analogue-to-digital conversion (ADC). For signal analysis, offline digital signal processing (DSP) was used. It consisted of synchronisation, FFT and QAM symbol decoding. Finally the BER was calculated using the measured signal-to-noise ratio (SNR).

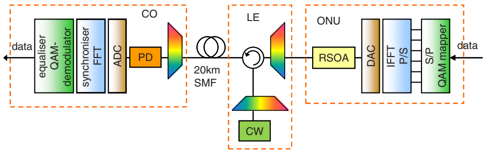

Fig. 1 *Experimental setup of WDM-PON with seeding light source at local exchange (LE)*

S/P: serial-to-parallel; P/S: parallel-to-serial; IFFT: inverse fast Fourier transform; FFT: fast Fourier transform; DAC: digital-to-analogue converter; ADC: analogue-to-digital converter

Results and discussion: Fig. 2 shows the measured SNR of each OFDM subcarrier from frequencies of 0.1 to 2.3 GHz under different injection powers. The RSOA was DC-biased at 80 mA in all cases. We can observe the frequency ripple problem of the RSOA under low optical injection powers. This produces relatively low SNR at some frequencies, such as at frequencies of 0.19 and 0.94 GHz. The frequency ripple can be improved under high optical injection powers, as can be seen in Fig. 2. Insets show the corresponding measured constellation diagrams of the 128-QAM OFDM signal including all the 93 OFDM subcarriers at different injection powers. We can clearly observe that the overall performance of the upstream signal can be improved by increasing the optical injection power.

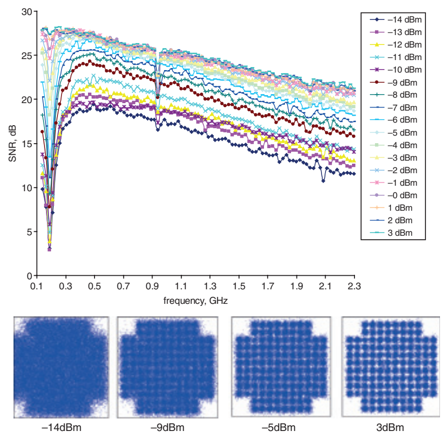

Fig. 2 *Measured SNR of each OFDM subcarrier under different CW injection powers*

Insets: constellation diagrams of 128-QAM OFDM signal including all 93 OFDM subcarriers at different injection powers

We then analysed and compared the BER performance based on the measured SNR using the equations as described in [7]. We can observe from Fig. 3*a* that the BER of the upstream signal cannot achieve the forward error correction (FEC) threshold (BER = 3.8×10^{-3}) [8] if all the 93 OFDM subcarriers are included. Hence, at the CO, some of the low SNR OFDM subcarriers are neglected to obtain an improved upstream signal performance. By including 80 OFDM subcarriers (subcarrier 1 to subcarrier 79), a BER lower than the FEC threshold can be achieved, providing a total upstream data rate of 13.1 Gbit/s when the injection power to the RSOA is larger than −1 dBm. Neglecting the low SNR OFDM subcarriers at the CO is much simpler than the AMOOFDM case since the ONU using the AMOOFDM requires feedback information for the CO to control the power levels of different OFDM subcarriers. Higher performance signals can be achieved by neglecting the relatively low SNR OFDM subcarriers; however, the data rate is sacrificed. For example, if only 12 OFDM subcarriers are included (total data rate is 2 Gbit/s), BER $< 1 \times 10^{-4}$ can be achieved with improved dynamic range of the optical injection power (injection power >−4 dBm). As mentioned before, OFDMA can provide one more degree of freedom for bandwidth sharing and dynamic bandwidth allocation. Here, we also analysed the bit rate per user for the proposed OFDM-WDM PON. We can observe from Fig. 3*b* that, when 80 OFDM subcarriers are used, the bit rate per user can be 410 and 205 Mbit/s when the OFDM split-ratios are 32 and 64, respectively.

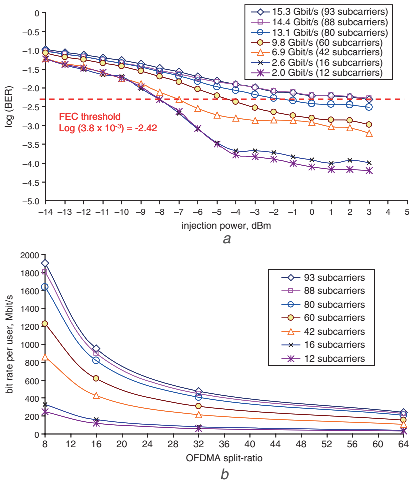

Fig. 3 *BER measurements of upstream signal with different effective data rates and under different CW injection power; and bit rate per user against OFDMA split-ratios when different numbers of OFDM subcarriers are used*

a BER measurements of upstream signal
b Bit rate per user against OFDMA split-ratios

Conclusions: The commercially available RSOA has a typical modulation bandwidth of ~1 GHz. Recently, there have been several demonstrations to increase the RSOA operation speed to 10 Gbit/s, but they require complicated AMOOFDM, special design structure or addition of optical components. We have demonstrated a WDM-PON using a commercially available 1.2 GHz bandwidth RSOA-based ONU, which can be operated up to 13 Gbit/s. In this demonstration, the optical seeding light source is located in the LE for providing relatively higher injection power for the RSOA to enhance the relaxation oscillation speed of the RSOA. 20 km SMF transmission of the 13 Gbit/s OFDM signal can be achieved with BER lower than the FEC threshold.

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C.W. Chow, Y.F. Wu, Y.H. Lin and J.Y. Sung (*Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Rm 216A, Tin Ka Ping Building, Hsinchu 30010, Taiwan*)

E-mail: cwchow@faculty.nctu.edu.tw

C.H. Yeh and H.Y. Chen (*Information and Communications Research Laboratories, Industrial Technology Research Institute (ITRI), Hsinchu 31040, Taiwan*)

Y. Liu (*Hong Kong Productivity Council (HKPC), Hong Kong*)

C.-L. Pan (*Department of Physics and Institute of Photonics Technologies, National Tsing-Hua University, Hsinchu, Taiwan*)

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