Hybrid WDM-OFDMA-PON utilising tunable generation of flat optical comb

C. Chen, C.F. Zhang, W. Zhang, W. Jin and K. Qiu

Proposed is a wavelength-division multiplexed orthogonal frequency-division multiple access passive optical network (WDM-OFDMA-PON) for both wired and wireless OFDM signal access, by using a tunable generation scheme of a flat optical comb. 17 comb lines with 30 GHz space and no more than 0.5 dB flatness are obtained theoretically and experimentally. The obtained flat optical comb is used as the optical source for 17 WDM channels in the proposed WDM-OFDMA-PON. A 16-quadrature amplitude modulation OFDM signal achieving 10.85 Gbit/s traffic data is modulated onto each channel with double sideband modulation and the transmission for both wired and wireless access has been successfully demonstrated by experiment.

Introduction: Orthogonal frequency-division multiplexing (OFDM) has been considered as a promising candidate for next generation passive optical networks (NG-PONs), because it is not only a high-efficiency modulation format but also a flexible multiuser access technology [1, 2]. Recently, PON systems are expected to support both wired and wireless access due to the ever-increasing requirements of end users for high-speed and high-mobility services [3]. To increase system capacity further and connect more end users, wavelength-division multiplexing (WDM) reveals great potential for application in optical orthogonal frequency-division multiple access (OFDMA) based PON systems [4].

In a typical WDM-OFDMA-PON, multiple individual WDM lasers are used to provide as many WDM channels and these expensive WDM lasers greatly aggrandise the overall cost and inevitably reduce system scalability. An optical multicarrier or optical comb has been proposed to serve as the WDM source and thus reduce system cost [2, 5].

In this Letter, we propose and demonstrate a hybrid WDM-OFDMA-PON for both wired and wireless services access, utilising a flat and scalable optical comb generated by an advanced tunable comb generator (TCG). By cascading a single phase modulator (PM) with two identical intensity modulators (IMs), an optical comb with enhanced flatness and scalability can be obtained. Generation of 17 comb lines with 30 GHz space and no more than 0.5 dB flatness is investigated theoretically and experimentally. A 16-quadrature amplitude modulation (QAM) OFDM signal is modulated onto the obtained optical comb through double sideband (DSB) modulation in another IM and a net 10.85 Gbit/s traffic data per channel can be provided for both wired basedband access and wireless 10 GHz radio-frequency (RF) access in our experimental verification. The system performance of the proposed hybrid WDM-OFDMA-PON is also evaluated and discussed.

Experiment and results: Fig. 1 illustrates the experimental setup of the proposed hybrid WDM-OFDMA-PON for both wired and wireless access using the advanced TCG. Here, the TCG contains a continuous-wave (CW) distributed-feedback (DFB) laser at 1552.52 nm, a 30 GHz sinusoidal RF source, a $LiNbO_3$ PM and two single-arm chirp-free $LiNbO_3$ IMs. In this scheme, two IMs are choose of the same type to guarantee their identicality. The half-wave voltages of the PM and two IMs are 3.2 V and 4.6 V, respectively. A tunable electrical amplifier (TEA) is employed to control the input signal voltage of the PM so as to dynamically control the scalability of the advanced TCG [2] and a phase shifter (PS) is adopted to adjust the phase of the input electrical signal of the two IMs. The optical comb generated by the advanced TCG is then used as the WDM source for the proposed WDM-OFDMA-PON.

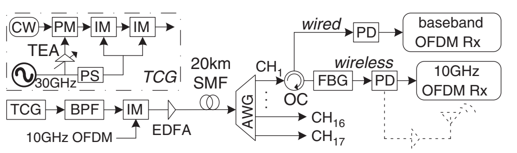


Fig. 1 *Experimental setup of proposed hybrid WDM-OFDMA-PON using advanced TCG*

To generate a flat optical comb, we assume that the CW laser is represented as

$$E_c(t) = E_c \exp(j\omega_c t) \tag{1}$$

where E_c and ω_c are the amplitude and the angular frequency of the CW laser, respectively. Therefore, the output comb of the advanced TCG can be expressed as

$$\begin{aligned} E(t) = \frac{E_c}{4} \sum_{n=-\infty}^{\infty} \{ & J_n(m_{PM}\pi) + 2\exp(j\beta) J_n[(m_{PM} + m_{IM})\pi] \\ & + \exp(j2\beta) J_n[(m_{PM} + 2m_{IM})\pi]\} j^n \exp[j(\omega_c + n\omega)t] \end{aligned} \tag{2}$$

where ω is the angular frequency of the sinusoidal RF source. m_{PM} is the PM electrical input voltage normalised by its half-wave voltage while m_{IM} and β are the IM electrical input voltages and the IM bias voltages normalised by their half-wave voltages, respectively. n is the comb line index and $J_n(x)$ is the first kind Bessel function of nth order.

Fig. 2 shows the flatness contour plot with 17 comb lines generated by the advanced TCG. The electrical input voltage applied to the PM is set to $m_{PM} = 3$ and the X- and Y-axes show m_{IM} and β, respectively. By setting the parameters at the red cross point (0.43, 0.6) which is the optimised point to get a flat comb, the flatness of the obtained comb can be held within 0.1 dB for 17 comb lines.

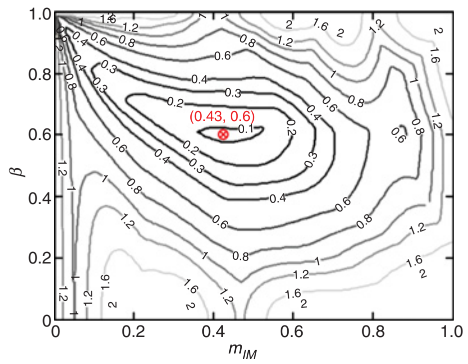


Fig. 2 *Flatness contour plot with comb lines generated by advanced TCG*

In our proof-of-concept experiment, the parameters of the advanced TCG are set to the optimised point calculated from Fig. 2. Figs. 3*a* and *b* display the output optical comb spectra generated by the advanced TCG in the calculation and the experiment, respectively. The flatness achieved by the experiment is 0.5 dB and it is 0.4 dB higher than the theoretical prediction. We believe this deterioration in flatness is mainly caused by the intrinsic difference of the two IMs where we assume two identical IMs are used in the theoretical analysis.

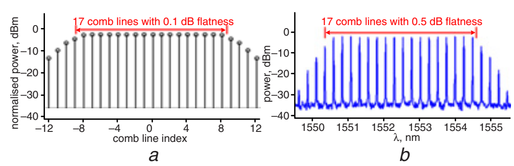
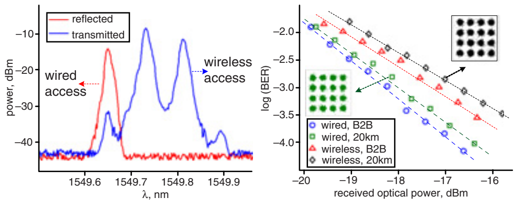


Fig. 3 *Output optical comb spectra generated by advanced TCG*
a Calculation
b Experiment

Then, the obtained comb with 17 comb lines held in 0.5 dB flatness passes an optical bandpass filter (BPF) which is used to remove the unwanted comb lines. A baseband 16-QAM OFDM signal achieving 10.85 Gbit/s traffic data is generated off-line with 128 subcarriers and a cyclic prefix (CP) of 1/32 and then it is upconverted to 10 GHz. The 10 GHz OFDM signal is modulated onto the optical comb in another IM where a DSB modulation is performed. After an erbium-doped fibre amplifier (EDFA) and 20 km standard singlemode fibre (SSMF), an arrayed waveguide grating (AWG) is used to divide the WDM-DSB signal into 17 separate channels. For the first channel (CH_1), the left sideband of the DSB signal is reflected by a fibre Bragg grating (FBG) and sent into a *pin* photodiode (PD) for wired baseband OFDM reception after an optical circulator (OC), while the transmitted signal is sent into another PD for wireless 10 GHz OFDM reception.

Figs. 4*a* and *b* show the received optical spectra of wired/wirelss access signals and the measured bit error rate (BER) performance for wired/wireless access of the proposed hybrid WDM-OFDMA-PON. The received sensitivities at the BER of 3×10^{-3} for wired baseband access and wireless 10 GHz access after 20 km SSMF are −18 and −16.7 dBm, respectively. The measured corresponding constellations for both wired and wirelss 16-QAM OFDM signals are also inserted in Fig. 4*b*.



a *b*

Fig. 4 *Experimental results of CH_1 transmission in proposed hybrid WDM-OFDMA-PON using advanced TCG*

a Received optical spectra of wired/wireless access signals
b Measured BER performance for wired/wireless access

Conclusion: We have demonstrated a tunable optical comb generation enabled hybrid WDM-OFDMA-PON by experiment. An optical comb with 17 comb lines held in 0.5 dB flatness is successfully obtained in the experiment which agrees well with the theoretical prediction. A net 10.85 Gbit/s traffic data employing 16-QAM OFDM format has been transmitted via the DSB modulated 17-channel WDM comb. Both wired basedband access and wireless 10 GHz access are simultaneously supported in the proposed hybrid WDM-OFDMA-PON.

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One or more of the Figures in this Letter are available in colour online.

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