A novel wavelength modulated transmitter and its application in WDM passive optical networks

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Abstract: We propose a novel wavelength modulated transmitter based on an optical phase modulator and demonstrate its application in a WDM-PON to facilitate upstream data re-modulation. The feasibility and performance of the system are experimentally investigated.

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1. Introduction

The application of wavelength division multiplexing (WDM) in optical access networks is a promising approach to provide sufficient bandwidth for broadband commercial and residential access. Recently, WDM passive optical network (PON) with centralized light sources (CLS) [1,2] emerges as an attractive solution to eliminate the need for wavelength management at each optical network unit (ONU). With CLS architecture, the upstream data transmitter is realized by re-modulating part of the received downstream optical power thus no wavelength-registered light source is incorporated at the ONU. Several schemes [2,3] were previously proposed to directly reuse the intensity modulated (IM) downstream optical signal as the upstream data carrier in such WDM-PON. However, they sacrificed the downstream modulation depth and required an additional step of erasing the downstream data at the ONU. In [4], we proposed and demonstrated the use of constant-intensity optical differential phase shift keying (DPSK) modulated downstream carrier for low-crosstalk upstream IM re-modulation without the need of downstream data erasure.

Recently, wavelength modulation (WM) [5], which was also regarded as optical frequency shift keying (OFSK), was proposed to realize constant-intensity modulation. Two light beams with close wavelength spacing are intensity complementarily modulated and combined to produce a constant-intensity composite signal. When compared with optical DPSK, WM signal demodulation is easier and more economical for ONU as only an optical filter is needed whereas DPSK requires an actively controlled delay demodulator. Previous implementation of WM transmitter employed a custom-made dual-input intensity modulator, which would be expensive and impractical if employed in WDM-PON to facilitate upstream re-modulation. In this paper, we propose a novel WM transmitter based on a single, relatively low-cost LiNbO$_3$ optical phase modulator. With this transmitter configuration, we demonstrated 10-Gb/s WM downstream transmission and simultaneous intensity re-modulation and transmission of 2.5-Gb/s upstream data.

2. Proposed WM transmitter and Re-modulation scheme in WDM-PON

Fig. 1 illustrates the operation principle of the proposed WM transmitter. Two CW light beams with small wavelength spacing are combined and fed into a LiNbO$_3$ phase modulator where both of them are phase modulated with the differentially pre-coded data signal at $B$ bps. The output then passes through a delay interferometer (DI) with a relative time delay $\Delta T$, which corresponds to the bit-period of the data signal. The wavelengths of the two optical carriers are chosen in such a way that they satisfy the conditions

$$\lambda = \frac{v}{mB}, \text{ and } \lambda' = \frac{v}{(m'+1/2)B},$$

where $v$ is the speed of light in the transmission media, $m$ and $m'$ are positive integers. Thus the DI essentially converts the phase-modulated optical signals into intensity-modulated ones. In addition, the output produced by
these two wavelengths would be complementary to each other. As a result, the combined output exhibits constant optical intensity as illustrated in Fig. 1. Such WM signal can be easily demodulated by means of optical filtering.

The CLS WDM-PON architecture using the proposed WM downstream transmitters is shown in Fig. 2. Each transceiver in the central office (CO) is composed of an upstream IM receiver and the proposed downstream WM transmitter, which includes a pair of CW sources and an optical phase modulator driven by the respective differentially pre-coded downstream data. In addition to satisfying the condition stated previously, the spacing of each wavelength pair is also chosen to fit into the passband of one array-waveguide grating (AWG) channel. The multiplexed signal from all the transmitters is then fed into a common DI to generate the downstream WM signal to be transmitted to the ONUs. With proper dispersion compensation, the constant intensity of the downstream WM signal can be preserved at the ONUs. In the ONUs, part of the received power is tapped out for downstream data demodulation and reception through optical filtering. The rest of the downstream power is then intensity modulated with the upstream data and sent back to the CO via the transmission link and the AWG.

3. Experiments and Results

Fig. 3 shows the experimental setup to demonstrate our proposed scheme. The outputs from the two DFB lasers (LD1 & LD2) were combined with a 50/50 fiber coupler. The combined signal was then phase-modulated by a 9.953-Gb/s NRZ 2^{11}-1 pseudo random binary sequence (PRBS) via the optical phase modulator (PM). The signal was then amplified by an EDFA to about 5 dBm and filtered by an optical bandpass filter (OBPF1) with 3-dB bandwidth of 0.8 nm. This optical filter was used to emulate a channel of a 100-GHz AWG and also to suppress the excessive amplified spontaneous emission (ASE). A fiber-based DI with a relative delay of 94.3 ps was placed after the optical filter to generate the desired downstream WM signal, as shown in the inset of Fig. 3. The wavelength of LD1 (1552.95 nm) was exactly aligned at the maximum transmittance point of the DI while that of LD2 (0.65 nm apart from LD1) was aligned at the minimum transmittance point. From the inset waveform of Fig. 3, the WM signal experienced nearly no walk-off and still kept constant-intensity after transmission over a span of 20-km dispersion shifted fiber (DSF), operated in non-zero dispersion region. Similar or better performance could be achieved with standard single mode fiber (SMF) with full dispersion compensation.

At the ONU side, the received downstream signal was split by a 40/60 fiber coupler. One branch of the output was filtered by an optical grating filter (OBPF2) with a 3-dB bandwidth of 0.2 nm and was then detected by a 10-Gb/s PIN receiver. As shown in the upper inset of Fig. 5, the filter suppressed one of the wavelengths by about 40 dB, effectively converting the wavelength modulation into intensity modulation as could be observed from the eye-diagram shown in Fig. 5. The BER curves shown in Fig. 5 reveal a power penalty of only 0.1 dB when compared...
with the back-to-back case. The other part of downstream optical power was fed into an optical intensity modulator, driven by a 2.488-Gb/s NRZ 2^31-1 PRBS upstream data. The re-modulated upstream IM signal was then coupled into another span of 20-km DSF. The received upstream data at CO was detected by a 2.5-Gb/s APD receiver. The BER curve shown in Fig. 6 indicates a sensitivity of -33.2 dBm and a power penalty of less than 0.1 dB when compared with the back-to-back case. These results demonstrate the effectiveness of this WM transmitter and the re-modulation scheme in WDM-PON.

To further investigate the performance of WM signal transmission, we varied the wavelength spacing of the two carriers and measured the power penalty for both the upstream and downstream data with respect to the case of 0.65-nm wavelength spacing. The wavelength spacing was discretely tuned from ~0.16 nm to 0.98 nm by adjusting the temperature controllers of the two DFB lasers. Note that with a fixed DI, there are only a finite number of wavelength pairs within OBPF1 passband that satisfy the WM condition given in the previous section. Fig. 7 shows the measured results. For the wavelength spacing ranging between 0.32 nm and 0.65 nm, negligible power penalty was achieved. However, when the wavelength spacing was tuned to be less than 0.23 nm, severe interference between the two wavelengths was observed. It resulted in large amplitude fluctuations in the downstream WM signal. This inevitably deteriorated the downstream signal quality, which in turn, adversely affected the re-modulated upstream IM signal. Besides, such narrow wavelength spacing also hindered the demodulation of downstream signal with optical filtering. On the other hand, when the wavelength spacing was set beyond 0.65 nm, both the upstream and the downstream signals were increasing degraded. This could be attributed to the increased amplitude fluctuation in the WM signal due to larger walk-off between the two wavelengths and the signal distortion caused by band-edge filtering at OBPF1. Moreover, excessive wavelength spacing would increase the signal leakage into the adjacent channels and induced channel crosstalk. Thus, the optimal wavelength spacing for the WM signal was found to be within the range from 0.23 nm to 0.65 nm.

4. Summary

We have proposed and experimentally demonstrated a novel wavelength modulated transmitter, which comprises a single optical phase modulator and a DI. Its application in upstream re-modulation in a WDM-PON has also been investigated. The constant intensity of the downstream WM signal can be re-modulated at the ONU to carry upstream data. Thus a simple ONU structure can be realized and good upstream/downstream data isolation can be achieved. The transmission performance of the 10-Gb/s downstream WM signal and the 2.5-Gb/s re-modulated upstream IM signal was evaluated. The dependence of system performance on the wavelength spacing of the downstream WM signal was also studied. This work was partially supported by a research grant from Research Grants Council of Hong Kong SAR (CUHK 4191/01E).

References: