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Simultaneous Transmission of Point-to-Point Data and Selective Delivery of Video Services in a WDM-PON Using ASK/SCM Modulation Format

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Abstract: We propose and experimentally demonstrate simultaneous transmission of point-to-point data signals and selective delivery of point-to-multipoint video services based on extinction ratio control of ASK data and subsequent SCM modulation in a WDM-PON system.

OCIS codes: (060.2330) Fiber optics communications; (060.4252) Networks, broadcast.

1. Introduction

Wavelength-division-multiplexed passive optical network (WDM-PON) is a promising technology for future broadband access networks, since it can offer advantages including high capacity, large coverage range, upgradeability, and cost-effective configuration. Conventionally, WDM-PONs utilize arrayed waveguide gratings (AWGs) to provide virtual point-to-point connectivity. To support simultaneous delivery of point-to-point data signals and point-to-multipoint video services in WDM-PON systems, a number of studies have been carried out [1-5], where the video services are broadcast to all end users regardless of their service subscriptions. In practice, only a certain number of customers subscribe the video services. In addition, some customers may only subscribe the video services in a particular duration of time. Thus it is desirable to realize selective broadcasting of the video signals to customers according to their individual requests. Recently, there have been some experimental demonstrations of selective delivery of video signals in WDM-PON systems [6, 7].

In this paper, we propose a new scheme to simultaneously deliver the downlink point-to-point data and selectively broadcast the video services in a WDM-PON system. In our scheme, the downlink data signals are in amplitude shift-keying (ASK) format with adjustable extinction ratios (ERs). The wavelength channels are combined by an AWG followed by a modulator, which is driven by the broadcasting video signal in a sub-carrier multiplexing (SCM) format. By simply controlling the ER of the ASK data, the video signal can be enabled on a wavelength channel to achieve selective and dynamic broadcasting and thus realizing flexible network functions. The uplink signal re-modulation based on the downlink ASK format with a low ER is also demonstrated.

2. Principle

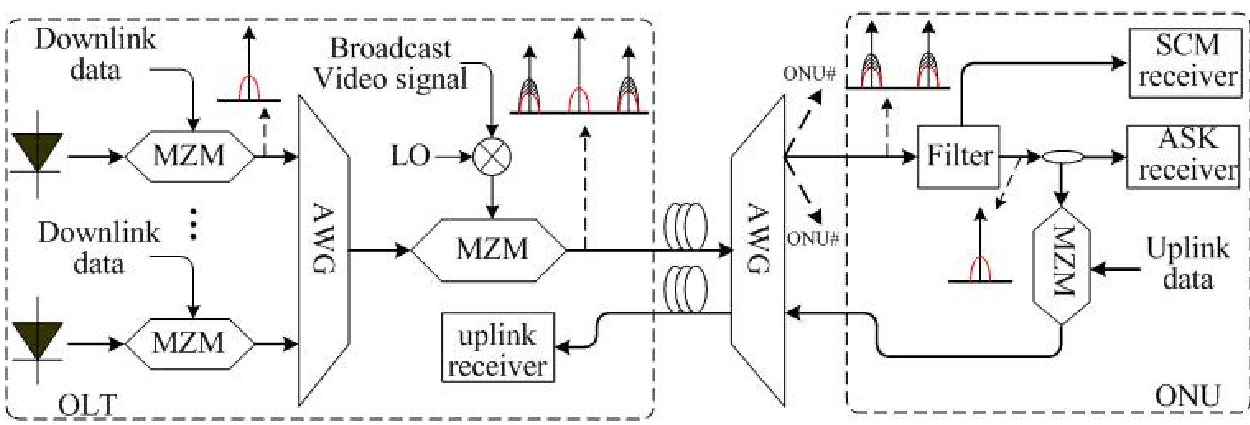

Fig. 1. Schematic diagram of the proposed WDM-PON system

Fig. 1 shows the schematic diagram of the proposed WDM-PON system. In the optical line terminal (OLT), a set of single drive Mach-Zehnder modulators (MZMs) are driven by downlink point-to-point data signals, the biases of the MZMs are set to the quadrature points to generate ASK format. The ER of the obtained ASK format can be adjusted by controlling the voltage-amplitude of the driver signal. The downlink data signals from different wavelength channels are combined by an AWG and then fed to a following single drive MZM as a video signal transmitter, which is also biased at the quadrature point and driven by the video signal in the SCM format to produce a double-sideband optical signal including an optical carrier and two sidebands. Thus, the SCM video signal is superimposed onto the ASK data in all wavelength channels. The optical carrier only carries the ASK modulated downlink data, while the optical SCM carries the hybrid SCM video-signal and the ASK downlink data.

The optical SCM signal can be described by the Bessel function [8]:

$$E(t) = 2E_{ASK}\exp(i\omega t + \frac{\pi}{2}i) \times \sum_{k=0}^{\infty}(-1)^k J_{2k+1}(\pi)\cos[(2k+1)\omega_s t]$$

where E_{ASK} repents the optical field of the modulated ASK format, ω and ω_s are the angular frequencies of the optical carrier and the electrical SCM signal, respectively. $J_x(\cdot)$ is the coefficient of the first kind of Bessel function. Therefore, when the ASK data have a sufficiently high ER, the absence of the optical power in bit "0" results in 'loss of signal' detection for the SCM video signal. On the other hand, if the ER of the ASK data is reduced such that the bit "0" contains certain power, the SCM video signal can then be recovered. The lower the ER of the ASK is, the higher quality of the recovered SCM video signal is. However, a trade-off is needed between the performances of the ASK data and the SCM video signal. When an optical network unit (ONU) on a wavelength makes a request for the video service, the ER of the ASK data from the corresponding transmitter in the OLT is adjusted to allow for simultaneous recovery of the downlink data and the SCM video signal. To disable the SCM video signal for an ONU user on a particular wavelength, the ER is increased significantly so that the SCM video signal cannot be recovered in the ONU,while the ASK data still can be correctly detected. Thus, the SCM video signal can be selectively and dynamically broadcast to destined users on arbitrary wavelength channels, by simply controlling the ER of the downlink ASK data in the OLT.

After transmission over fibre, an AWG is used to demultiplex the optical signals and route them to individual ONUs. At each ONU, an optical filter is employed to separate the ASK downlink data and the optical SCM signal. The separated signals are detected by a ASK receiver and a SCM receiver, respectively. For users who subscribe to the video service, the separated ASK data with the lower ER is split into two parts. One part is directly detected by the ASK receiver, while the other part is re-modulated by an uplink ASK data with optimized ER and sent back to the OLT. Thus interactive services, such as video-on-demand and online games, can be provided without the need of light source and wavelength management in the ONU.

3. Experimental Setup and Results

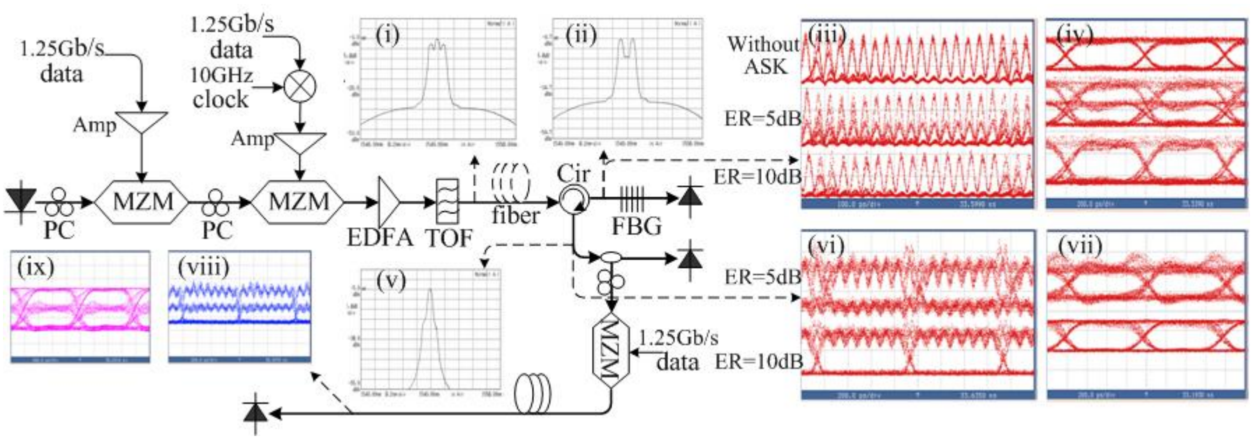

Fig. 2. Experimental setup of the proposed scheme. Optical spectra resolution: 0.07 nm. X-axis scale of spectra: 0.2 nm/div, Y-axis scale of spectra: 5 dB/div. Time scale of eye diagrams: 100 ps/div

To verify the feasibility of the proposed scheme, we perform an experiment as shown in Fig.2. In the OLT, a continues wave (CW) light from a tunable laser at 1549.89 nm is fed into a single drive MZM, the MZM is biased at the quadrature point and driven by a 1.25-Gb/s data with a 2^{31}-1 word length to generate a ASK format. An electrical drive amplifier can be adjusted to control the voltage amplitude of the data signal and thus its ER. In our experiment, the ER of the ASK data is set to 5 dB (SCM can be recovered) and 10 dB (SCM cannot be recovered), respectively. A following MZM is also biased at the quadrature point and driven by an electrical SCM signal, which is generated by mixing a 10-GHz clock signal with a 1.25-Gb/s data having a 2^{31}-1 word length. The SCM video signal is then superimposed onto the ASK data to form a hybrid ASK/SCM format. It should be noted that the relative delay between the downlink data and the electrical SCM signal needs to be properly adjusted to ensure synchronization, which can be controlled by an electrical phase shifter. The output from the second MZM is amplified by an erbium-doped fiber amplifier (EDFA) before transmission. A tunable optical filter (TOF) is used to suppress amplified spontaneous emission (ASE) noise. The optical spectrum is shown in inset (i) of Fig.2.

After transmission over 25-km single mode fibre (SMF), in the ONU, an optical circulator is connected to a fiber Bragg grating (FBG) with a 3-dB bandwidth of 0.1 nm and a reflection ratio of 90%. The FBG is used to reflect the ASK data and pass the optical SCM signal. The optical spectrum and the optical eye diagram of the passing optical SCM signal are indicated in Fig.2 as insets (ii) and (iii), respectively. The optical SCM signal is converted to the electrical signal using a 2.5-GHz PIN receiver, the detected electrical eye diagrams with different ERs are provided in inset (iv) of Fig.2. The optical and electrical eye diagrams of the SCM video signal without any superimposed ASK modulation show the best opening. In the case of ER = 5 dB for the ASK data, the eye opening of the SCM signal is affected by the superimposed ASK data but the SCM video signal still can be correctly detected. When the ER of the ASK data is improved to 10 dB, the eye of the SCM video signal is closed. The optical spectrum and the optical eye diagrams of the reflected ASK data with different ERs are shown in insets (v) and (vi) of Fig.2, respectively, while the corresponding electrical eye diagrams after PD detection are provided in inset (vii) of Fig. 2. In the case of ER = 5 dB, the reflected ASK data is split into two parts. One part is directly detected by a PIN receiver, and the other part is re-modulated by an uplink 1.25-Gb/s data with a 2^{31}-1 word length. The optical and electrical eye diagrams of the re-modulated ASK signal are shown in inset (viii) and inset (ix) of Fig. 2, respectively.

The BER measurement results are provided in Fig.3. After the transmission over the 25-km SMF, for the downlink ASK data of 5-dB and 10-dB ER, the power penalties are ~0.8 dB and ~0.5 dB, respectively. For the SCM video signal, the power penalty is ~0.8 dB with the 5-dB ER of the ASK data, while for the re-modulated uplink signal, the power penalty is ~1 dB.

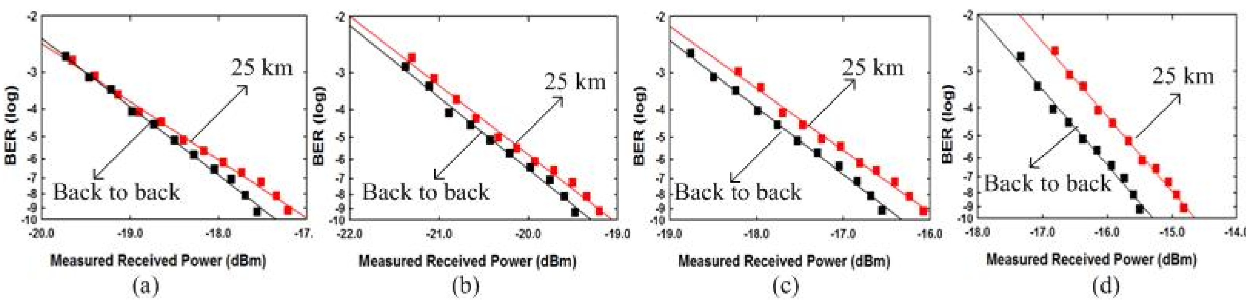

Fig. 3. BER curves: (a) Downlink data of 5-dB ER ; (b) Downlink data of 10-dB ER; (c) Video signal when ER = 5 dB for the ASK data; (d) Re-modulated uplink signal.

4. Conclusion

We proposed a novel scheme to simultaneously deliver downlink ASK data and selectively broadcast SCM video signal based on the ER control technique of the ASK format. The feasibility of the technique was experimentally demonstrated with the power penalties less than 1 dB.

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