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A novel WDM passive optical network architecture supporting two independent multicast data streams

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ABSTRACT

We propose a novel scheme to perform optical multicast overlay of two independent multicast data streams on a wavelength-division-multiplexed (WDM) passive optical network. By controlling a sinusoidal clock signal and shifting the wavelength at the optical line terminal (OLT), the delivery of the two multicast data, being carried by the generated optical tones, can be independently and flexibly controlled. Simultaneous transmission of 10-Gb/s unicast downstream and upstream data as well as two independent 10-Gb/s multicast data was successfully demonstrated.

1. Introduction

The wavelength-division-multiplexed passive optical network is a promising approach to provide subscribers high speed services. In order to enable more flexible data delivery, a robust network architecture which can support simultaneous unicast data as well as multicast data transmissions is highly desirable. Several interesting schemes [1–4] have been proposed to overlay the multicast data onto a WDM-PON. The multicast data in either differential phase-shift keying (DPSK) format [1], inverse-return-to-zero (IRZ) format [2], or sub-carrier multiplexed (SCM) form [3], were modulated onto all of the downstream unicast data are modulated in non-return-to-zero (NRZ) and amplitude-shift keying (ASK) data format. In order to enable or disable the superimposed multicast, the extinction ratio [1,3] of the unicast data has to be adjusted, or its format has to be switched between IRZ and NRZ [2]. However, the unicast NRZ data might suffer from system penalty due to its reduced extinction ratio. In [4], multicast data are superimposed onto different sub-carriers generated by the optical carrier suppression (OCS) technique, which avoids the power penalty from reduced extinction ratio of the unicast data and improves the system performance. However, none of these schemes can support two independent multicast data simultaneously.

In this paper, we propose and demonstrate a novel WDM-PON architecture which can simultaneously support two independent multicast data streams as well as unicast and upstream transmissions. The two multicast data as well as the downstream unicast data are modulated onto the different carriers generated from a single continuous wave (CW) light source resided in each transmitter at the OLT. The downstream unicast data is modulated in DPSK format, which will be re-modulated with the upstream ASK data at the respective optical network unit (ONU). The control of the multicast transmission is achieved by controlling the clock signal and shifting the downstream laser wavelength, which is used to control the optical sub-carrier generation.

2. Proposed WDM-PON architecture with multicast overlay

Fig. 1 depicts the proposed WDM-PON multicast overlay architecture with N ONUs. At the OLT, the CW light from each transmitter is first modulated by a clock signal at f Hz, via a Mach-Zehnder intensity modulator (IM), biased at quadrature point to generate three carriers. The generated carriers are then fed into a fiber Bragg grating (FBG), where one of the generated carriers is reflected and then combined with other carriers via a WDM multiplexer, before being fed into a common IM for multicast ASK data 1 modulation. The multicast composite signal is then delivered over the fiber feeder (F2) and demultiplexed at the remote node (RN) before being detected at their respective destined ONUs. On the other hand, the carriers at the transmission output ports of the FBGs are phase modulated by the downstream unicast data and combined before being separated into two groups by an optical interleaver (IL). One group is modulated via an IM by the multicast ASK data 2 and then combined with the other group before delivered to the RN via fiber feeder (F1). After being demultiplexed at the RN, carriers for unicast and two multicast data are delivered to the

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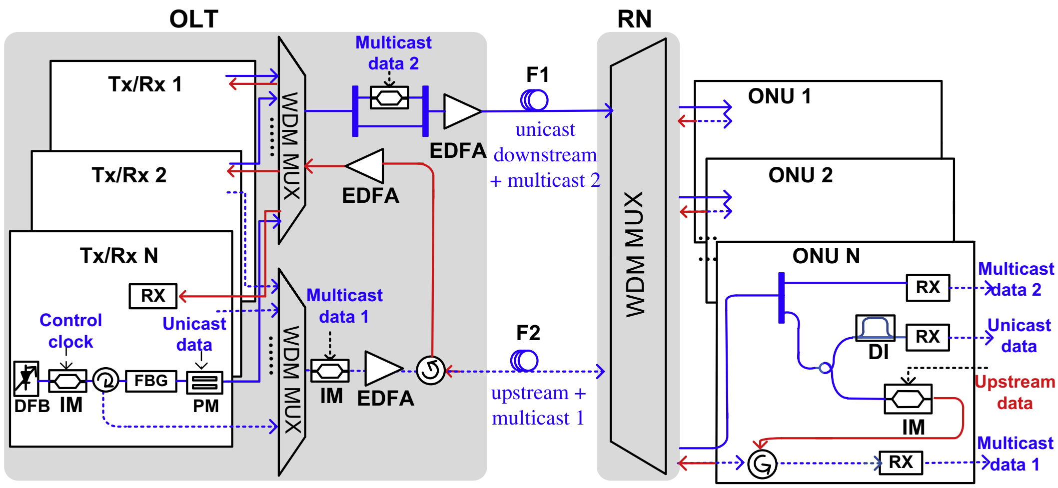

Fig. 1. A WDM-PON with proposed multicast overlay scheme. DFB: distributed feedback laser; EDFA: erbium-doped fiber amplifier; PM: phase modulator.

destined ONU, where the carrier for multicast data 2 is separated from unicast carrier and detected, while part of the unicast DPSK data is demodulated, via an optical delay interferometer (DI), before direct detection and the remaining power is then fed into an IM for upstream ASK data modulation. The upstream signal is then transmitted, via the fiber feeder (F2), back to the respective receiver unit at the OLT. As the downstream unicast signal and the upstream signal are carried on different fiber feeders, while the upstream signal and the multicast signals are carried on different carriers, though on the same fiber feeder, the possible Rayleigh backscattering effect is much alleviated.

The control of multicast transmissions for individual downstream channel is illustrated in Fig. 2. When the control clock is at f Hz, biased at quadrature point of the IM and with no wavelength shift of the downstream laser wavelength, as shown in Fig 2a, sub-carriers for the two multicast data and the unicast data are generated. Hence the simultaneous delivery of the two multicast data streams is realized. When the control clock frequency is changed to $f/2$ Hz, biased at null point of the IM and with a wavelength-shift of $f/2$ Hz of the downstream laser wavelength, via controlling the temperature of the light source, either right-shift or left-shift, as shown in Fig. 2b and c, the central carrier is suppressed through OCS and two sub-carriers with the wavelength spacing of f Hz are generated. One of the two generated subcarriers is used for unicast transmission while the other one for multicast transmission either for multicast data 1 or multicast data 2. When the control clock is in off-state and with no wavelength shift as in Fig. 2d, both multicast data streams are disabled without any affect to unicast transmission. The insets of Fig. 2 shown an example of the multicast control scheme when $f = 50$ GHz and wavelength shift = 0.2 nm (or 25 GHz) as used in our experiment.

3. Experiment and results

Fig. 3 shows the experimental setup for the proposed scheme. A CW light at 1547.29 nm was first fed into a 40-Gb/s optical IM, driven by a 50-GHz clock to create three combs (carriers), λ_{sub1} at 1546.89 nm, λ_{sub2} at 1547.29 nm and λ_{sub3} at 1547.69 nm as shown in Fig. 3 inset (i). The generated combs were then fed into FBG1 with a reflection full-width-at-half-maximum (FWHM) passband of 0.2 nm and a reflectivity of 99%, so as to separate out the carrier λ_{sub3} , as shown in Fig. 3 inset (iii), which was then reflected into an IM, where it was intensity modulated by the 10 Gbit/s $2^{31}-1$ pseudorandom binary sequence (PRBS) multicast non-return-to-zero (NRZ) data 1 before being amplified to about 3 dBm and delivered on a piece of 20 km fiber feeder (DSF2). Dispersion-shifted fiber (DSF) was employed to emulate dispersion compensated links for the fiber feeders. At the transmission output port of FBG1, λ_{sub1} and λ_{sub2}, as shown in Fig. 3 inset (ii), were modulated by the 10 Gbit/s $2^{31}-1$ PRBS unicast data via the optical PM and separated by the FBG2 with a reflection FWHM passband of 0.2 nm and a reflectivity of 99%. The carrier λ_{sub1} shown in Fig. 3 inset (v) was intensity modulated by the 10 Gbit/s $2^{31}-1$ PRBS multicast NRZ data 2 and then combined with λ_{sub2}, shown in Fig. 3 inset (iv), before amplified to about 5 dBm and delivered to the ONU, via another piece of 20 km fiber feeder (DSF1). At the ONU, multicast data 2 on λ_{sub3} was directly detected, while the multicast data 1 on λ_{sub1} were separated from λ_{sub2} and detected. The unicast DPSK data on λ_{sub2} was 3 dB split, half for reception and half for upstream remodulation by 10 Gb/s $2^{31}-1$ PRBS upstream data via another IM. The upstream ASK signal was then sent back to the OLT, via DSF2, before it was separated from the downstream signal and detected.

Fig. 4a shows the measured BER performances when the two multicasts were enabled by turning on the control clock signal to generate the carriers for the multicast modulations. Less than 0.5 dB penalty was observed for the unicast, the multicast and the upstream data after transmission, showing receiver sensitivity improvements by about 7 dB and 3.5 dB for unicast and multicast transmissions respectively, as compared with [1]. Fig. 4b and c shows the BER performances when only one multicast was enabled. Similar performances were observed for unicast and multicast data transmission as well as the upstream transmission for Fig. 4c but about 0.5 dB improvement for Fig. 4b after 20 km transmission compared with that in Fig. 4a for both unicast and upstream data. This may be mainly due to the Rayleigh backscattering eliminating in F2 when we disable the multicast transmission for data 1, implying that our proposed scheme suffers negligible Rayleigh backscattering. Fig. 4d shows the measured BER performances when the two multicasts were disabled by turning off the control clock signal and with no wavelength shift. Less than 0.4 dB penalty were observed for the unicast and the upstream data after transmission, guaranteeing good system performances, which mainly resulted from large wavelength spacing and eliminated Rayleigh backscattering. The performances of both downstream and upstream transmissions in Fig. 4d have been improved by about 1 dB, respectively, as compared with those in Fig. 4a–c. Table 1 has shown the receiver sensitivity at 10^{-9} both for downstream and upstream transmissions during different conditions.

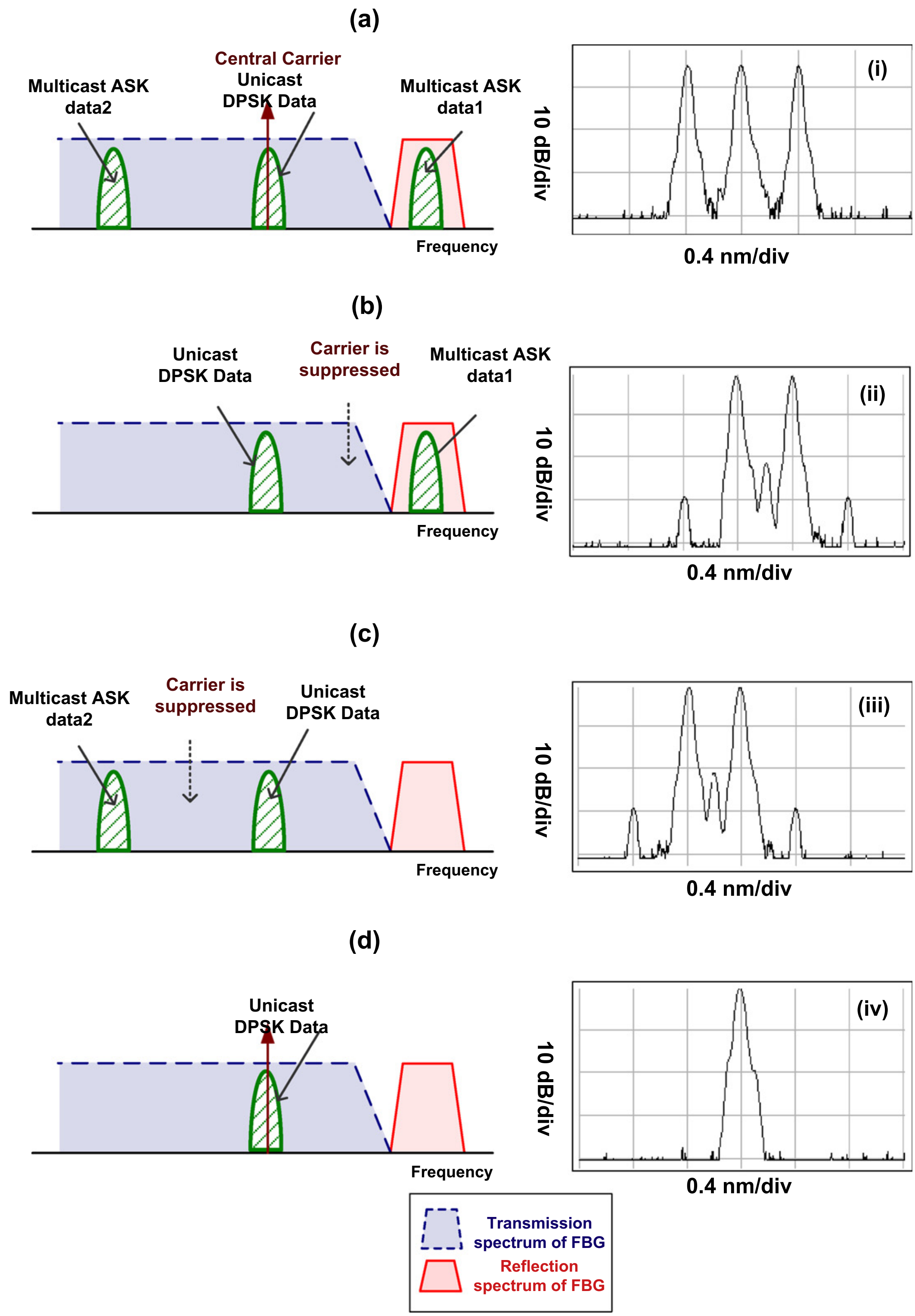

Fig. 2. Principle of multicast overlay fiber control. (a) Two Multicast Enabled: With Control Clock f and no wavelength shift. (b) One Multicast Enabled: With Control Clock $f/2$ for OCS and wavelength right-shift $f/2$. (C) One Multicast Enabled: With Control Clock $f/2$ for OCS and wavelength left-shift $f/2$(d) Multicast Disabled: With no Control Clock and no wavelength shift.

In the proposed architecture, the power fed into transmission link was about 3 dBm, 5 dBm and 5 dBm for multicast data 1, unicast and multicast data 2 respectively. The losses caused by transmission (20 km DSF), AWG, optical circulator, IL and DI were around 5 dB, 5 dB, 2 dB, 1 dB and 5 dB respectively. Thus the power for unicast data detection after DI was around −14 dBm providing more than 4.6 dB system margin, and the power for multicast data 1 detection is around −7 dBm implying around 11.8 dB system margin, while the power for multicast data 2 detection is around −6 dBm implying around 10.7 dB system margin. Another portion of the unicast power was remodulated by an IM, which induced about 5 dB loss, by using amplifier before multiplexer, the system

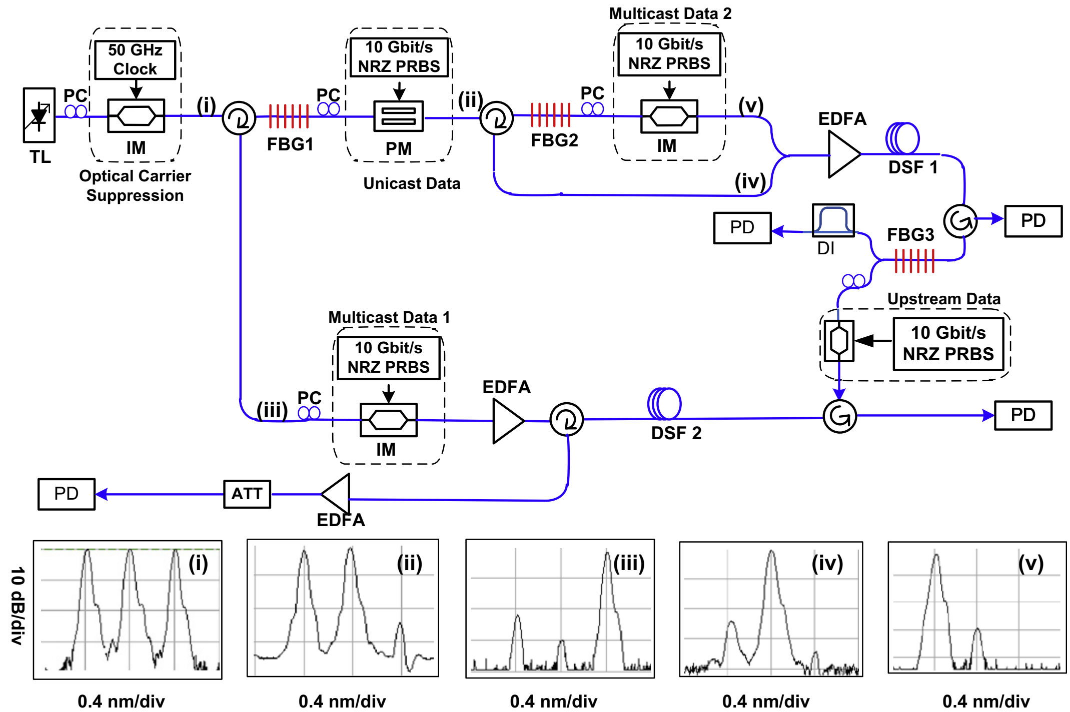

Fig. 3. Experimental setup.

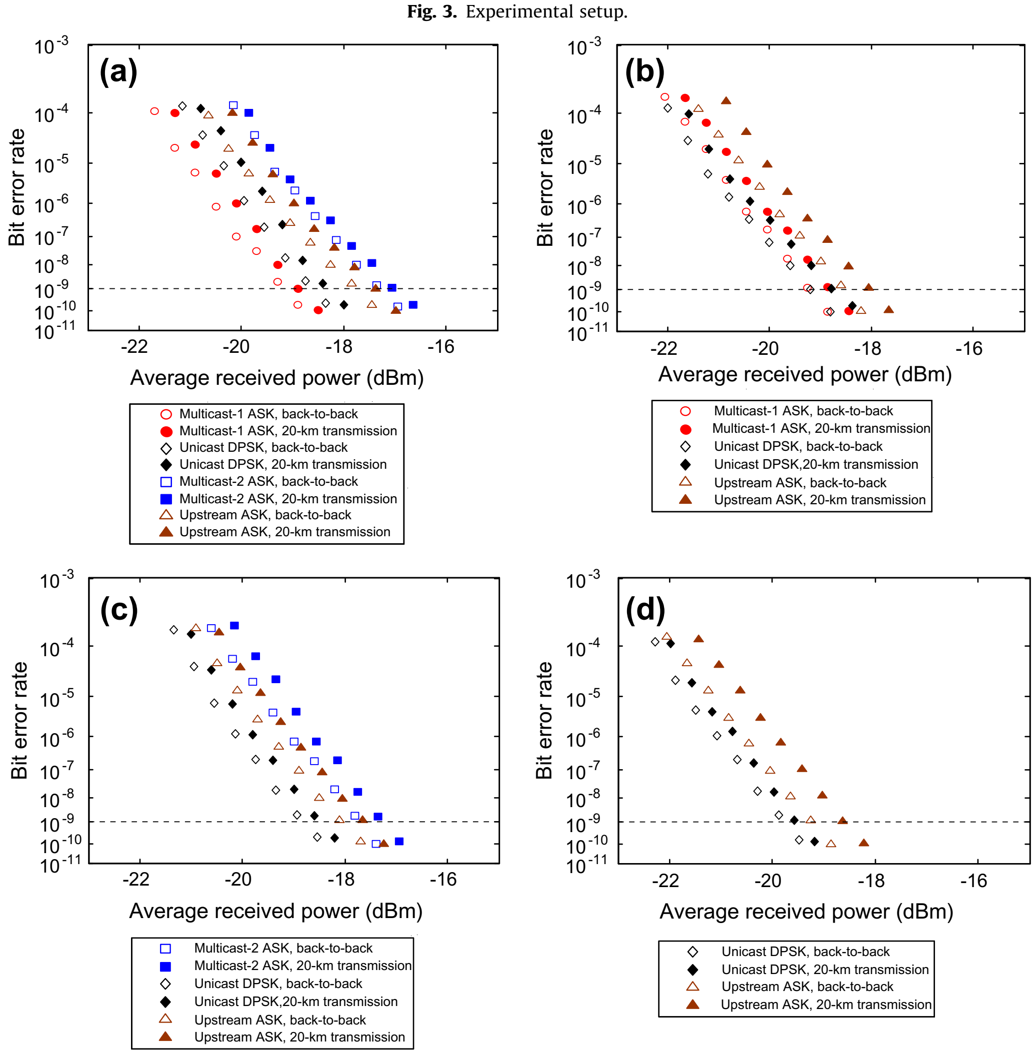

Fig. 4. BER measurements of 10-Gb/s transmissions: (a) both two multicast data streams are enabled; (b) only multicast data 1 is enabled; (c) only multicast data 2 is enabled; (d) both multicast data streams are disabled.

Table 1
Receiver sensitivity at 10^{-9}: (a) both two multicast data streams are enabled; (b) only multicast data 1 is enabled; (c) only multicast data 2 is enabled; (d) both multicast data streams are disabled.

	Receiver sensitivity at 10^{-9} for B2B transmission (dBm)	Receiver sensitivity at 10^{-9} for 20-km transmission (dBm)
Panel (a)		
Multicast data 1	−19.20	−18.91
Multicast data 2	−17.06	−16.75
Unicast data	−18.65	−18.38
Upstream data	−17.85	−17.40
Panel (b)		
Multicast data 1	−19.25	−18.85
Multicast data 2	Disabled	Disabled
Unicast data	−19.20	−18.78
Upstream data	−18.61	−18.06
Panel (c)		
Multicast data 1	Disabled	Disabled
Multicast data 2	−17.75	−17.40
Unicast data	−18.94	−18.62
Upstream data	−18.21	−17.75
Panel (d)		
Multicast data 1	Disabled	Disabled
Multicast data 2	Disabled	Disabled
Unicast data	−19.48	−19.17
Upstream data	−19.25	−18.63

can provide enough power margin for the upstream transmission. For the 20 km transmission, when the DSF is replaced by the combination of SMF and DCF, an extra 2 dB power penalty will be caused during the transmission. However, the system can still provide enough power budgets for the transmissions of two multicast and unicast data.

4. Summary

We have proposed and experimentally investigated a WDM-PON with simultaneous 10 Gb/s transmissions of the downstream unicast and two multicast data, as well as the upstream data. The downstream unicast data and the two multicast data are carried on different wavelengths, greatly improving system flexibility and performance. The control of the multicast transmission is achieved by employing a control clock and shifting the downstream laser wavelength at the OLT. This project was partially supported by RGC GRF No. CUHK4105/08E.

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