Optical Overlay of Two Independent Multicast Streams on a WDM Passive Optical Network

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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 passive optical network. By controlling a sinusoidal clock signal and an optical switch at the optical line terminal, the delivery of the two multicast data, being carried by the generated optical tones, can be independently and flexibly controlled. Simultaneous transmissions of 10-Gb/s unicast downstream and upstream data as well as two independent 10-Gb/s multicast data are successfully demonstrated.**

***Index Terms*—Multicast, passive optical network (PON), wavelength-division multiplexing (WDM).**

I. Introduction

THE wavelength-division-multiplexed passive optical network (WDM-PON) is a promising infrastructure to provision high-speed services to business and residential subscribers. In order to enable more flexible data delivery, a robust and flexible network architecture which can support simultaneous unicast data as well as multicast data transmissions is highly desirable. Hence, the same data or video service can be delivered to a designated subset of subscribers, which can also be flexibly reconfigured at the optical line terminal (OLT). Recently, several interesting schemes [1]–[6] have been proposed to overlay a single multicast data stream onto a tree-structured WDM-PON carrying two-way unicast data streams. The multicast data in either differential phase-shift keying (DPSK) format [1], [2], inverse-return-to-zero (IRZ) format [3], or subcarrier multiplexed (SCM) form [4], were modulated onto all of the downstream unicast data wavelengths. At the OLT, on each downstream wavelength carrying nonreturn-to-zero (NRZ) amplitude-shift keying (ASK) unicast data, the superimposed multicast data were enabled or disabled by adjusting the extinction ratio [1], [3], [4] of the unicast data, or switching the unicast data format between IRZ and NRZ [2]. However, the unicast NRZ data might suffer from system penalty due to its reduced extinction ratio. In [5], a novel scheme employed double sideband DPSK modulation, where the central carrier was separated out to carry the multicast data. However, severe beating noise existed at the receiver and an extra electrical filter was needed. Another approach [6] employed optical carrier suppression technique to generate optical tones from a single optical carrier, one of which was used to carry the multicast data. In general, all of these reported schemes could support delivery of a single multicast data stream only.

In this letter, for the first time, we propose and demonstrate a novel WDM-PON which can simultaneously support two independent multicast data streams, in addition to the conventional two-way unicast transmissions. The control of the multicast transmissions is achieved by controlling the clock signal for optical tone generation as well as an optical switch at the OLT. We have carried out the proof-of-concept experiment of 10-Gb/s transmissions for all unicast and multicast data.

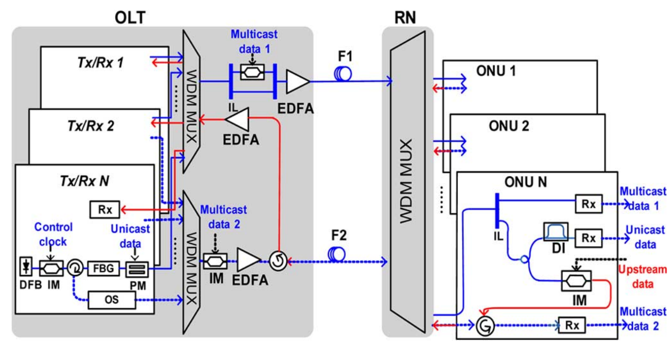

Fig. 1. Proposed WDM-PON with multicast overlay. IL: optical interleaver; MUX/DEMUX: wavelength multiplexer/demultiplexer; OS: optical ON–OFF switch.

II. Proposed Optical Multicast Overlay Scheme

Fig. 1 depicts the proposed WDM-PON architecture with N optical network units (ONUs), delivering two independent multicast data streams, labeled as "Multicast data 1" and "Multicast data 2." At the OLT, the continuous-wave (CW) light from each transmitter is first modulated by a clock signal, via a Mach–Zehnder intensity modulator (IM), biased at the quadrature point to generate three optical tones. The generated tones are then fed into a fiber Bragg grating (FBG), where one of the generated tones is filtered OFF and reflected into the optical switch, which is used as to control the ON–OFF of the multicast data stream (Multicast data 2). All of the optical tones for Multicast data 2 from all transmitters at the OLT are combined, via a WDM multiplexer, before being fed into a common optical intensity modulator (IM) for ASK modulation of the Multicast data 2. The 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 two optical tones present at the transmission output ports of the FBG at each transmitter are phase-modulated by the respective downstream unicast data in DPSK format, before being combined via a WDM multiplexer. The combined signal

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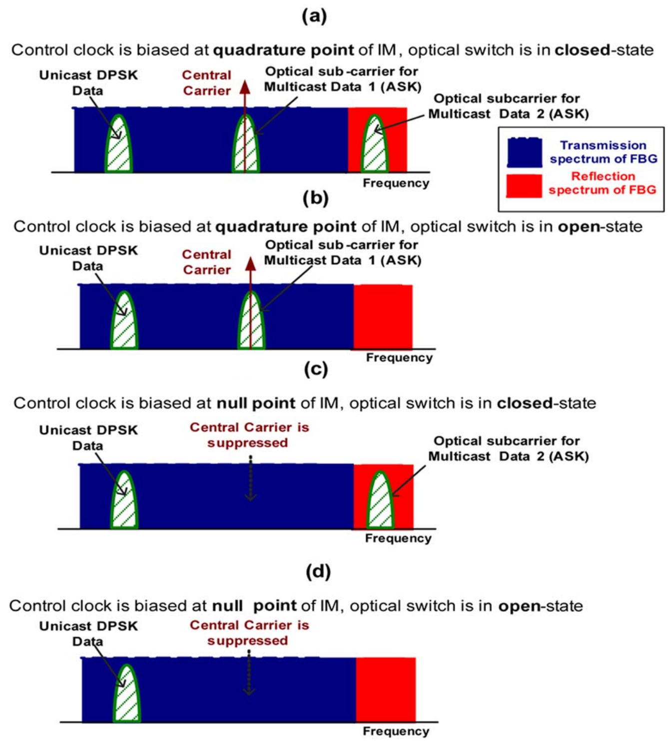

Fig. 2. Spectra of downstream carrier to illustrate the principle of multicast overlay fiber control via control clock and optical switch. (a) Both Multicast data 1 and Multicast data 2 enabled. (b) Only Multicast data 1 enabled. (c) Only Multicast data 2 enabled. (d) Both Multicast data 1 and Multicast data 2 disabled.

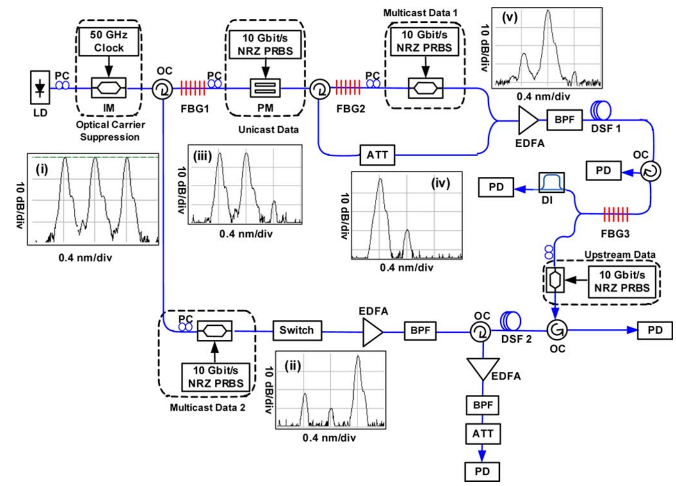

Fig. 3. Experimental setup. Insets show the (i) output spectrum of the IM; (ii) reflected spectrum of FBG1 (i.e., Multicast data 2); (iii) transmitted spectrum of FBG1; (iv) spectrum for unicast data; (v) spectrum for Multicast data 1. OC: optical circulator; BPF: bandpass filter; ATT: optical attenuator.

is then fed into an optical subsystem comprising a pair of optical interleavers (ILs) with an IM being placed in the upper arm, as illustrated in Fig. 1. In the upper arm, due to the periodic spectral response of the ILs, the set of central tones from all transmitters are extracted from the input combined signal, for common modulation of the Multicast data 1, via the IM. At the same time, the lower arm passes the optical tones carrying the individual unicast DPSK data from all transmitters. The combined signal is then delivered to the RN, via fiber feeder (F1). After being demultiplexed at the RN, the optical tones for unicast and two multicast data streams are delivered to their respective destined ONUs. At each ONU, the received optical tone carrying the Multicast data 1, is separated from that carrying the unicast data, via an IL. Part of the received unicast DPSK data signal is demodulated, via an optical delay interferometer (DI), before being directly detected; while the rest of the optical power is fed into an IM for upstream ASK data modulation before being delivered back to the respective receiver unit at the OLT, via the fiber feeder (F2). Since the same ILs can be used for all ONUs, the ONU remains colorless. 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 optical tones, though on the same fiber feeder, the possible Rayleigh backscattering effect is much alleviated.

The control of multicast transmissions for an individual downstream channel is achieved by setting the bias condition of the IM driven by the control clock signal, as well as setting the state of the optical switch, at the respective transmitter at the OLT, as illustrated in Fig. 2. When the control clock is biased at the quadrature point of the IM and the optical switch is in closed-state, the optical tones for the two multicast data and the unicast data are generated, as shown in Fig. 2(a). Hence, the simultaneous delivery of the two multicast data streams is realized. When the control clock is biased at the quadrature point of the IM and the optical switch is in open-state, only the transmission for Multicast data 1 is enabled, while the optical tone reflected by the FBG is blocked by the optical switch, thus disabling the transmission for Multicast data 2, as depicted in Fig. 2(b). When the control clock is biased at null point of the IM and the optical switch is set in closed-state, the central tone is suppressed, thus Multicast data 1 is disabled, as shown in Fig. 2(c), while only Multicast data 2 is transmitted. When the control clock is biased at null point of the IM and the optical switch is set in open-state, the central tone is suppressed and the optical tone reflected by the FBG is blocked by the optical switch, as depicted in Fig. 2(d). Hence, both of the two multicast data streams are disabled.

III. Experiment and Results

Fig. 3 shows the setup of our proof-of-concept experiment for the independent control of the two multicast signals. 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 optical tones, λ_{sub1} at 1546.89 nm, λ_{sub2} at 1547.29 nm, and λ_{sub3} at 1547.69 nm, as in Fig. 3 inset (i). They were then fed into FBG1 with a reflection passband of 0.2-nm full-width at half-maximum (FWHM) and a reflectivity of 99%, so as to separate out the carrier λ_{sub3}, as in Fig. 3 inset (ii). λ_{sub3} was then reflected into an IM, where it was intensity modulated by the 10-Gb/s $2^{31}-1$ pseudorandom binary sequence (PRBS) NRZ Multicast data 2 before being amplified to about 3 dBm and delivered on a piece of 20-km dispersion-shifted fiber (DSF) feeder (DSF2). DSF fiber was employed in our experiment just to emulate dispersion compensated fiber feeders. In practical implementation, a dispersion compensating module may be used to compensate the fiber chromatic dispersion in the deployed single-mode fiber feeders. At the transmission output port of FBG1, λ_{sub1} and λ_{sub2} as in Fig. 3 inset (iii), were modulated by the 10-Gb/s $2^{31}-1$ PRBS

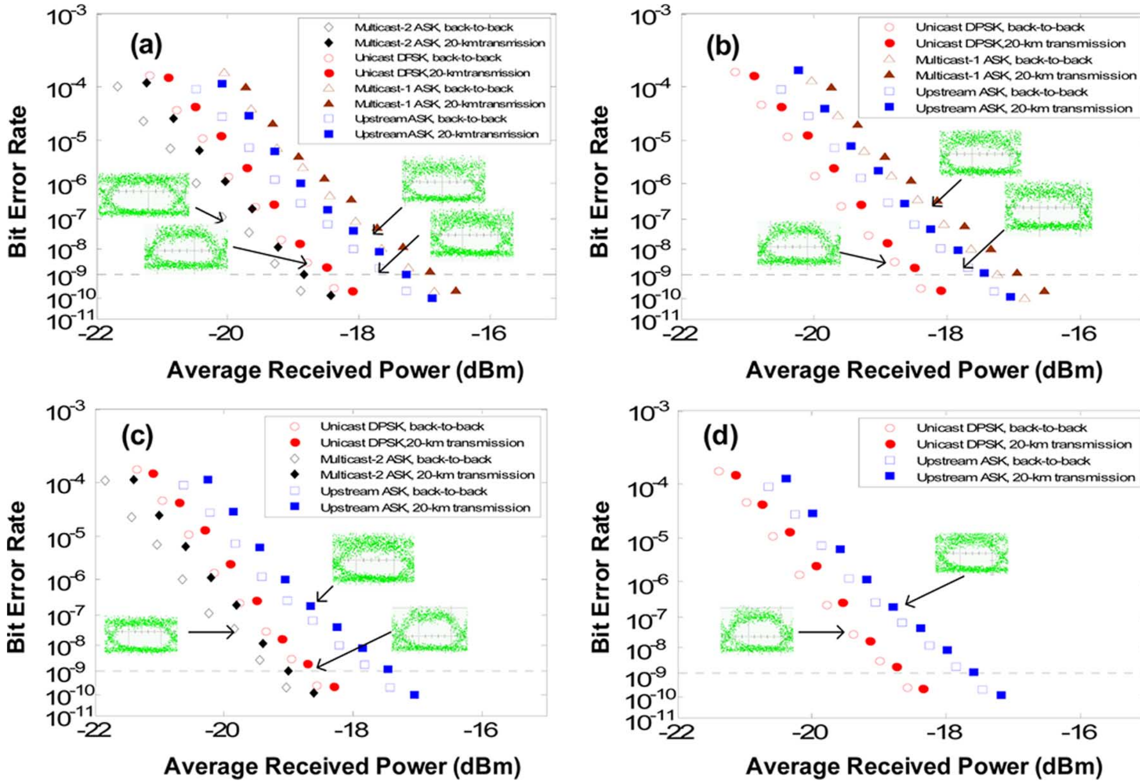

Fig. 4. BER measurements of 10-Gb/s transmissions. (a) Both multicast data streams are enabled; (b) only Multicast data 1 is enabled; (c) only Multicast data 2 is enabled; (d) both multicast data streams are disabled. Time scale for eye diagrams: 50 ps/div.

unicast data, via the optical phase modulator (PM) and separated by the FBG2 with a reflection passband of 0.2 nm (FWHM) and a reflectivity of 99%. The optical tone $\lambda_{\rm sub2}$, as in Fig. 3 inset (v), was intensity modulated by the 10-Gb/s $2^{31}-1$ PRBS NRZ Multicast data 1 before being combined with $\lambda_{\rm sub1}$ as in Fig. 3 inset (iv). The powers of both optical tones were equalized, via an optical attenuator. The composite signal was then optically amplified to about 5 dBm before being delivered to the ONU, via another piece of 20-km DSF fiber feeder (DSF1). At the ONU, Multicast data 2 on $\lambda_{\rm sub3}$ was directly detected, while the Multicast data 1 on $\lambda_{\rm sub2}$ was separated from $\lambda_{\rm sub1}$ and detected. The unicast DPSK data on $\lambda_{\rm sub1}$ was 3-dB split, half for reception and half for upstream remodulation by the 10-Gb/s $2^{31}-1$ PRBS NRZ upstream data, via another IM. The upstream ASK signal was then sent back to the OLT, via DSF2, for detection.

The bit-error-rate (BER) performances of different data streams have been measured. Fig. 4(a) shows the measured BER performances when both of the two multicast data streams were enabled. Less than 0.5-dB penalty was observed for the unicast, the multicast and the upstream data after transmission. Figs. 4(b), (c), and (d) show the BER performances when only Multicast data 1, only Multicast data 2, and no multicast data, were enabled, respectively. When we compared the BER plots of both of the downstream unicast and the upstream data as depicted in Fig. 4(d) with those depicted in Figs. 4(a)–(c), it was observed that negligible power penalty was induced to the downstream unicast and the upstream data in the presence of either one or both multicast data streams. This might be attributed to the fact that the individual data streams were carried on different optical tones, thus avoiding the interference among them. The varied performances of different kinds of data streams were due to the imperfect filtering of the FBGs used in the experiment.

IV. Summary

We have proposed and experimentally investigated a novel optical multicast overlay scheme to support simultaneous 10-Gb/s transmissions of the downstream unicast, two independent multicast data, as well as the upstream data, in a WDM-PON. The two multicast data streams can be controlled independently and flexibly, via appropriate setting of the control clock signal and the optical switch in the individual optical transceivers at the OLT.

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