A Multicast WDM-PON Architecture Using DPSK/NRZ Orthogonal Modulation

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***Abstract*—We propose a novel scheme to overlay multicast data on a wavelength-division-multiplexed passive optical network (WDM-PON) with point-to-point data delivery. The differential phase-shift keying multicast signal is superimposed onto all point-to-point nonreturn-to-zero (NRZ) signals. By adjusting the extinction ratios of the individual NRZ point-to-point signals, multicast can be realized and only the designated optical network units can properly receive the multicast data. We successfully demonstrated the proposed WDM-PON with 10-Gb/s downstream point-to-point signals and 10-Gb/s multicast signals.**

***Index Terms*—Differential phase-shift keying (DPSK), multicast, nonreturn-to-zero (NRZ), orthogonal modulation, passive optical network (PON), wavelength-division multiplexing (WDM).**

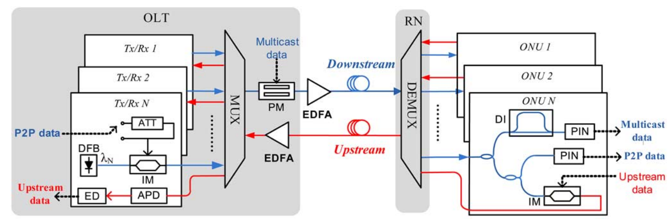

Fig. 1. Proposed WDM-PON architecture with multicast overlay. DFB: distributed feedback laser; APD: avalanche photodiode; EDFA: erbium-doped fiber amplifier; P2P data: downstream point-to-point data; ATT: attenuator; Tx/Rx: transceiver/receiver; MUX/DEMUX: wavelength multiplexer/demultiplexer; ED: error detector; PM optical phase modulator; PIN: p-i-n photodiode; IM: optical intensity modulator.

I. Introduction

THE wavelength-division-multiplexed passive optical network (WDM-PON) is regarded as a promising candidate to provide high-speed data service to subscribers. To realize more flexible network functions in WDM-PON, several schemes have been proposed to simultaneously deliver both point-to-point data and broadcast data to the subscribers [1]–[5]. Among these alternatives, one approach was to add additional light sources [1], which led to significant system costs and complexity. Another approach was to implement time-division multiplexing to support both kinds of services [2]. However, such a scheme sacrificed the bandwidth of the individual channels and added much complexity to the timing control. In [3] and [4], subcarrier multiplexing was used to support the broadcast channel. However, this solution was not cost-effective, as it required additional radio-frequency electronic devices at the transmitter and/or the receiver sides. Recently, a multicast-enabled WDM-PON architecture was proposed [5], which further allowed the service provider to deliver multicast data to the selected subscribers without any interruption of the individual data channels. However, this scheme employed inverse-return-to-zero modulation format for the point-to-point signal, thus it required high-speed logic circuits for the signal generation.

In this letter, we propose a WDM-PON architecture with multicast overlay based on differential phase-shift-keying/nonreturn-to-zero (DPSK/NRZ) orthogonal modulation. The multicast data is encoded in DPSK format and it is superimposed onto all point-to-point data channels which are modulated in the conventional NRZ format. The multicast operation is based on the principle that proper demodulation of the DPSK signal at an optical network unit (ONU) required sufficiently large extinction ratio of the NRZ point-to-point signal being superimposed. Hence, by carefully adjusting the extinction ratio of the individual NRZ point-to-point channel at the optical line terminal (OLT), the downstream multicast DPSK signal could flexibly be either transmitted or interrupted on the downstream wavelength channel. With this architecture, the proposed WDM-PON with centralized light source could offer both point-to-point data service and multicast service. The scheme has been validated using 10-Gb/s point-to-point data as well as 10-Gb/s multicast data. System feasibility and performance were also investigated.

II. System Architecture

Fig. 1 depicts our proposed WDM-PON architecture with multicast overlay. At the OLT, the transceiver of each individual point-to-point channel generates the downstream NRZ signal and receives the upstream remodulated signal from its respective designated ONU. The downstream signal is amplitude modulated by a Mach–Zehnder intensity modulator. In order to obtain optical NRZ signals with different extinction ratios, the input amplitude of the point-to-pint electrical data signal is properly adjusted via an electrical attenuator. All of the downstream point-to-point signals on different wavelength channels are multiplexed before being fed into a common optical phase modulator (PM), where the DPSK multicast data is further superimposed onto them. If the extinction ratio of a downstream NRZ point-to-point signal is set at a relatively low value, say 2 $\sim$ 4 dB, both the superimposed DPSK multicast data and the point-to-point NRZ data can be demodulated and

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received properly at its destined ONU. On the contrary, if the extinction ratio of the downstream NRZ signal is relatively high, say >5 dB, only the NRZ data can be received properly, as the superimposed DPSK multicast signal would suffer from excessive intensity fluctuation induced by the NRZ signal and thus could no longer be correctly demodulated at its destined ONU. Hence, by properly selecting the extinction ratio of the downstream NRZ point-to-point signal on individual wavelength channels at the OLT side, only those downstream channels with low extinction ratio are able to carry the multicast signal properly to the designated ONUs, thus multicast overlay is achieved. Since the DPSK and NRZ signals are orthogonal to each other, the downstream NRZ point-to-point signal on each wavelength channel can be successfully demodulated by destined ONU in both cases. The control of the multicast is centralized at the OLT by using a simple electronic switch. At each ONU, a portion of the received signal power is tapped off for the downstream data reception. The NRZ point-to-point data is detected via direct detection, while the DPSK multicast data is demodulated via a delay interferometer (DI) before detection. The rest of the received power is remodulated with the upstream data, via an intensity modulator, given the limited extinction ratio of the downstream NRZ signal (<8 dB). No light source is needed at the ONU. To avoid the possible Rayleigh backscattering induced performance degradation, a pair of feeder and distribution fibers is used to separate the downstream and the upstream data in the transmission link.

III. Experiment Demonstration

To verify the feasibility of our proposed scheme, we have experimentally demonstrated the multicast WDM-PON architecture based on the setup shown in Fig. 1. At the OLT, a continuous-wave light source at 1546.8 nm was first fed into an intensity modulator and NRZ modulated by a 10-Gb/s $2^{31}-1$ pseudorandom binary sequence (PRBS) as the downstream point-to-point signal. In this experimental demonstration of the multicast operation, we have adopted an extinction ratio (ER) of 3.5 dB for the multicast-enabled mode and an ER of 6.5 dB for the multicast-disabled mode at each transceiver. After being multiplexed by a standard 100-GHz grid array waveguide grating (AWG) with a 3-dB bandwidth of 0.35 nm, all of the downstream point-to-point wavelength channels were further modulated by another decorrelated 10-Gb/s PRBS data via an optical PM, such that the DPSK multicast signal could be superimposed on them. The point-to-point data and the multicast data were bit synchronized by using a common clock signal. This synchronization could be saved if the point-to-point data and superimposed multicast data have a relatively large difference in their data rates. After being amplified to around 6.5 dBm, the downstream signal was then coupled into a piece of 20-km dispersion-shifted fiber to emulate the dispersion-compensated transmission between the OLT and the remote node (RN). No waveform distortion induced by nonlinear effect was observed. At ONU, the optical signal power was 3-dB split for detection of the DPSK multicast data and the NRZ point-to-point data, respectively. The delay interferometer (DI), stabilized by a temperature controller, was set to have a 94-ps relative delay.

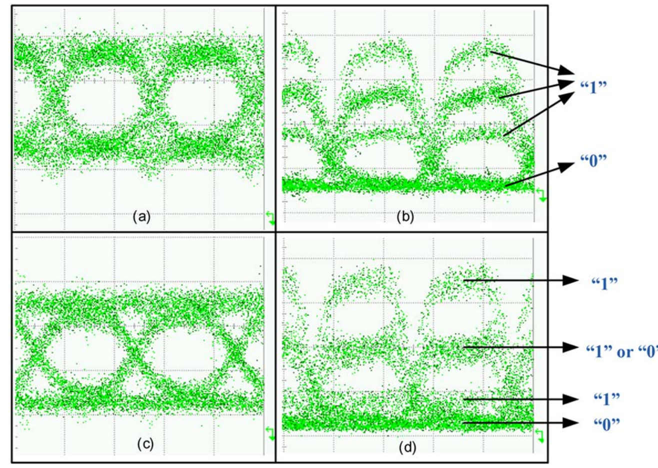

Fig. 2. Eye diagrams of (a) 10-Gb/s downstream NRZ data with low extinction ratio (multicast enabled), (b) 10-Gb/s multicast DPSK signal after DI when multicast was enabled, (c) downstream NRZ signal with high extinction ratio (multicast disabled), and (d) downstream DPSK signal after DI when multicast was disabled (detection failed). Time scale: 50 ps/div.

Fig. 2 depicts the eye diagrams of the downstream signals measured at different modes. When a downstream channel was set at the multicast-enabled mode, that is, when its NRZ point-to-point signal was at low extinction ratio, the superimposed DPSK signal could be correctly demodulated at the receiver. As both the high level and the low level of the NRZ signal provided enough power for the DPSK multicast signal, the demodulated DPSK signal showed a clear eye diagram with three intensity levels, as depicted in Fig. 2(b). On the other hand, when the multicast was disabled by setting a high extinction ratio value to the NRZ point-to-point signal, the NRZ point-to-point signal was still properly detected, while the superimposed DPSK multicast data could no longer be demodulated properly, as shown in Fig. 2(c) and (d), due to excessive fluctuation induced by the NRZ data.

Fig. 3 depicts the bit-error rate (BER) of the measured downstream signals. The signal power was measured in front of the pin receiver. When the multicast was enabled, both the DPSK and the NRZ signals could achieve error-free detection. We observed some phase-to-amplitude conversion after the AWG at the RN, as shown in Fig. 2(a), due to nonflat frequency response of the AWG. With proper bit synchronization, this influence on NRZ performance was minimized and a power penalty of around 1 dB was measured. The relatively low receiver sensitivity was mainly due to the combined effect of low extinction ratio and phase-to-amplitude-converted noise. The DPSK multicast signal had a negligible penalty after 20-km transmission. When the multicast was disabled by applying high extinction ratio to the NRZ signal, the NRZ signal was still properly detected, while the superimposed DPSK signal [as shown in Fig. 2(d)] could not be demodulated at the ONU and thus its BER is too high to be measured.

For the downstream DPSK/NRZ signal in which the DPSK multicast data has been imposed onto the NRZ point-to-point signal, the DSPK component is more vulnerable to the optical filtering effect as it is carried at a relatively higher frequency region, as compared to the NRZ component at the same data rate.

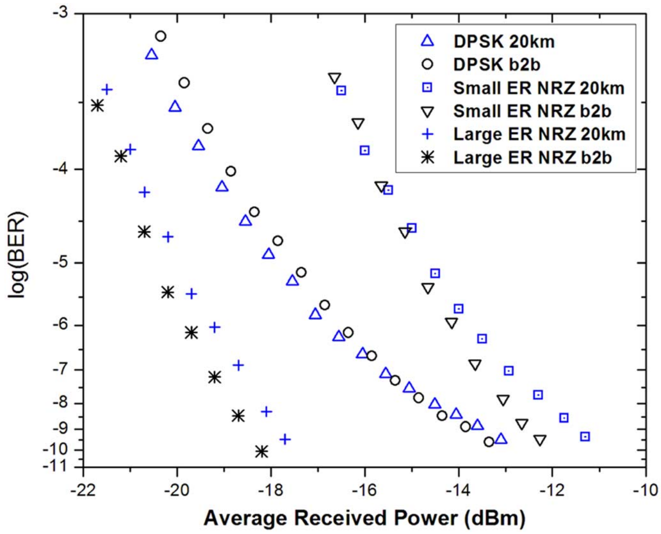

Fig. 3. BER measurements of NRZ point-to-point tributary and the multicast DPSK tributary of the DPSK/NRZ downstream signal, under multicast enabled (small ER) and disabled (large ER) modes.

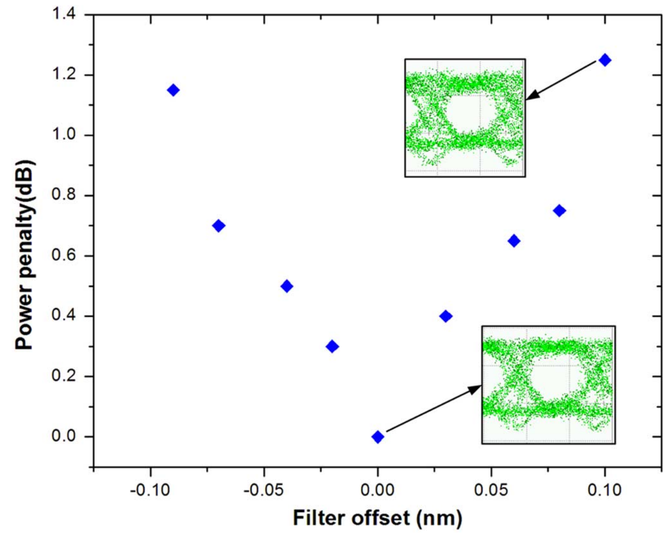

Fig. 4. Power penalty of downstream NRZ signal (ER = 3.5 dB) with respect to filter offset at the multicast enabled mode.

Thus, the phase-to-amplitude conversion present at the DPSK component would ruin the NRZ component with low extinction ratio. In our experiment, such phase-to-amplitude conversion originated from the possible wavelength misalignment induced filtering effect at the AWG at the RN. As Gaussian type AWG was used in our experiments, any wavelength misalignment would lead to excessive phase-to-amplitude conversion at the phase transition region of the filter passband. Our measurement results showed that it could tolerate up to 0.15-nm filter offset for 1-dB power penalty, as depicted in Fig. 4. Nevertheless, this kind of degradation could be alleviated by employing AWGs with flat-top passband. On the contrary, the NRZ component in multicast-disabled mode would not suffer from this kind of degradation, as the extinction ratio of the signal was high enough to combat the influence of such intensity fluctuations.

In our demonstration, the signal power fed into the transmission link was around 6.5 dBm. The downstream loss caused by the transmission link and the optical demultiplexing at the RN was around 10 dB. After 50/50 power splitting at the ONU, the measured powers for the NRZ and the DPSK detection were around −6.5 dBm and −9.5 dBm, respectively, implying that at least 2-dB margin for both downstream NRZ point-to-point signal and the DPSK multicast signal when the multicast was enabled. For multicast-disabled mode, the system margin was around 8 dB.

IV. Conclusion

We have proposed and demonstrated a multicast overlay scheme for a WDM-PON with NRZ point-to-point data and DPSK multicast data, using DPSK/NRZ orthogonal modulation. Multicast is simply realized by adjusting the extinction ratio of the NRZ point-to-point signal. A 10-Gb/s experiment showed the effectiveness of the proposed scheme.

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