

Novel Optical Multicast Overlay Control Schemes for WDM Passive Optical Networks

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Abstract—In addition to support two-way point-to-point data transmission, it is highly desirable to incorporate more data networking features on a WDM-PON. Multicast services can be provisioned on a WDM-PON, via the optical layer, such that the same data or video service can be flexibly delivered to a designated subset of subscribers in a more efficient way. The optical multicast overlay control is performed at the optical line terminal. In this paper, we provide a review of several novel techniques to support optical multicast overlay on a WDM-PON.

I. INTRODUCTION

The wavelength-division-multiplexed passive optical network (WDM-PON) is widely recognized as the next generation optical access network to deliver high speed or broadband services to business and residential subscribers. Common WDM-PONs support two-way point-to-point data transmission between the optical line terminal (OLT) and the individual subscribers, via the respective designated set of wavelengths. However, with more diverse multimedia and data services available for broadband access, the access network has to be flexible enough to cope with various different modes of data or video delivery such as broadcast and multicast, in addition to point-to-point transmissions. Hence, the same data or video service can be delivered to a designated subset of subscribers, which can also be flexibly reconfigured at the OLT.

Multicast provides a means of point-to-multipoint communication in which one source network node sends a common message over the network only once and the copies of the message are delivered to multiple destined network nodes. Thus, it significantly enhances the network resource utilization efficiency for multiple destination traffic and improves the cost effectiveness. It has found many point-to-multipoint bandwidth-intensive applications, such as high-definition video, video-conferencing, video-on-demand, optical storage area networks, database replication, etc. Multicast can be performed either on IP routing level, namely IP multicast, or on the optical layer, namely optical multicast. For IP multicast, the network routers create optimal distribution paths according to a multicast IP destination address spanning tree structure. For optical multicast, the one-to-many lightpaths are established on the optical layer, and thus can reduce the loading of the electronic network processors or routers on the network layer and can achieve much higher processing speed. The traditional way to realize

optical multicast is by means of optical power splitting [1-2], which is relatively more efficient than copying packets at the IP layer; and the problem is reduced to multicast routing and wavelength assignment. However, it suffers from power-budget constraints and increased network complexity. Alternatively, the multicast traffic can be overlaid onto the existing point-to-point wavelength channels using various feasible and practical optical signal processing techniques. In this way, the existing access network infrastructure can be gracefully upgraded to support such new kind of multicast traffic in a more cost-effective way. In this paper, we provide a review of several novel and feasible techniques to support optical multicast overlay on a WDM-PON.

II. NOVEL OPTICAL MULTICAST OVERLAY SCHEMES FOR WDM-PONS

The goal of supporting multicast, or selective broadcast services in a WDM-PON is to deliver the same data or video service to a designated sub-set of optical network units (ONUs), and the connections can be flexibly reconfigured at the OLT. Thus, in order to realize optical multicast overlay on a WDM-PON, two crucial features have to be carefully designed, namely how to overlay the multicast traffic to the existing network infrastructure which is carrying the two-way point-to-point traffic, as well as the overlay control technique for connection reconfiguration.

The provisioning of the multicast services over a WDM-PON can be realized by employing one or more additional dedicated light sources [3-4] at the OLT to carry the multicast traffic. The multicast wavelengths are usually chosen outside the wavelength bands of the point-to-point wavelengths such that they could be easily separated from others by WDM filters. By utilizing the periodic spectral property of the cyclic array waveguide gratings (AWG) at the remote node (RN), each of these multicast wavelengths could be routed to its destined ONUs, together with its respective point-to-point wavelength, via the same distribution fiber. Another alternative approach [4] is to employ a shared dedicated broadcast wavelength and multicast scheduling protocols are adopted to support multicast service delivery to the destined ONUs. However, most of these approaches have static multicast connections. Dynamic reconfiguration of these multicast connections may be achieved by employing tunable lasers for the dedicated multicast light sources at the OLT to alter the lightpaths.

Recently, several novel optical multicast overlay schemes have been proposed to selectively enable or disable the broadcast service superimposed on each downstream wavelength, such that only the designated ONUs can properly retrieve the broadcast service. Hence, optical multicast is realized without any additional dedicated light source for the multicast service. Two kinds of signal processing techniques have been adopted for such application, namely, *subcarrier multiplexing (SCM)* and *orthogonal modulation*.

In [5], a selective broadcasting scheme was proposed to deliver the SCM video channels in a WDM-PON. The SCM binary phase-shifted keying (BPSK) video channels were frequency multiplexed before being modulated onto all of the downstream wavelengths, each of which carried non-return-to-zero (NRZ) baseband point-to-point data, via direct modulation of the respective DFB laser diode at the OLT. Selective broadcasting of the videos was achieved by controlling the laser bias of individual DFB transmitter at the OLT, which in turn altered the power level of the zero bits of the NRZ amplitude shift keying (ASK) point-to-point data. If the “0” bits of a particular point-to-point data was set at much higher non-zero power level (i.e., the extinction ratio was lowered), the SCM video could be properly received at the respective destined ONU. Otherwise, if the “0” bits of the point-to-point data was set to null power, the reception of the SCM video of the respective destined ONU would be disabled. Due to the spectrum sharing nature of SCM and the direct modulation of the DFB lasers for the point-to-point data, the allowable bit-rate for the point-to-point signal was limited (<1.5 Gb/s). Similar mechanism was also reported in [6], except that externally modulated laser sources were adopted for the downstream wavelengths and the control of the selective broadcasting was achieved through the voltage bias setting of the individual external modulator so as to vary the extinction ratio of the NRZ-ASK point-to-point data. In [7], a dual-drive Mach-Zehnder intensity modulator was employed at each downstream transmitter at the OLT to generate a SCM double-sideband differential phase-shift keying (DPSK) signal as the downstream point-to-point signal. The two sidebands carried the downstream point-to-point data, while the central carrier was extracted, via an optical interleaver, and modulated with the multicast data. By adjusting the DC voltage applied to one of the arms of each intensity modulator, the presence of that central carrier in the respective DPSK signal could be dynamically controlled, via optical carrier suppression technique. If the central carrier was suppressed, for instance, the multicast traffic on the respective channel would be disabled. In this way, multicast overlay control could be achieved.

In [8-14], optical multicast overlay was achieved by means of orthogonal modulation, such that the multicast data was superimposed onto the point-to-point data of all downstream wavelengths at the OLT, before being delivered to the destined ONUs. For instance, the multicast data, modulated in DPSK or inverse-return-to-zero (IRZ) format could be superimposed onto all downstream wavelengths, which were

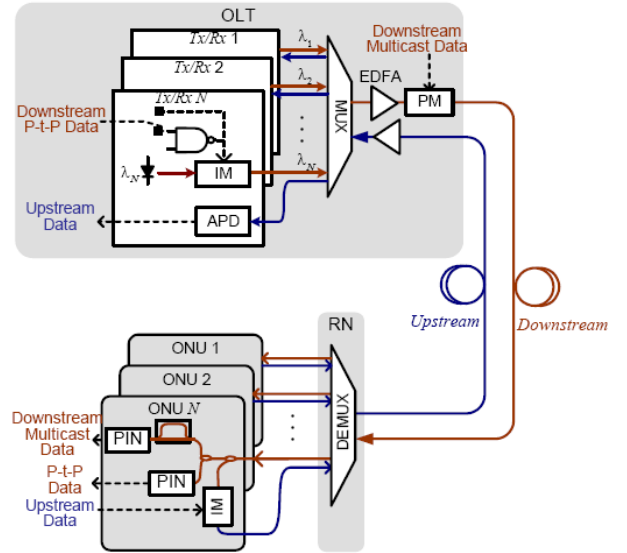


Fig. 1. A WDM-PON with optical multicast overlay, via orthogonal modulation [8]. P-t-P: point-to-point; PM: optical phase modulator; IM: optical intensity modulator.

carrying NRZ-ASK point-to-point data, via a common optical modulator at the OLT. Under normal operation, the multicast data could be demodulated and detected by all ONUs. To stop a particular ONU(s) from properly receiving the multicast data sent from the OLT, various special techniques could be adopted to deteriorate the quality of the multicast data on the respective downstream wavelength(s). In [8], two alternate modulation formats, namely, NRZ and IRZ were adopted for the ASK point-to-point data on each downstream wavelength, while the multicast service, modulated in DPSK format, was then superimposed, onto all downstream wavelengths, via a common optical phase modulator, placed after the WDM multiplexer in the downstream fiber link, as shown in Fig. 1. At a particular transmitter at the OLT, when IRZ was chosen as the format for the point-to-point data, due to the intrinsic non-zero power for all bits of the IRZ format, the superimposed DPSK multicast data could be properly demodulated and received at its destined ONU. On the contrary, by switching the modulation format of the point-to-point data from IRZ to NRZ, via a simple electronic circuitry, the superimposed DPSK multicast data could no longer be properly demodulated at the ONU, due to excessive intensity fluctuation of the signal envelope. Therefore, by switching the format for the point-to-point data for individual downstream wavelength at the OLT, multicast overlay operation was achieved. Another approach [9] was to vary the extinction ratio of the downstream NRZ-ASK point-to-point data, instead of switching between two modulation formats. The superimposed multicast data was modulated in DPSK format. By switching the respective extinction ratio of the downstream NRZ-ASK point-to-point data between a high value (say > 4.5 dB) and a low value ($<< 4.5$ dB), the superimposed DPSK multicast data could or could not be demodulated properly at the receiving ONU, respectively, thus the multicast overlay was realized. Nevertheless, system

design optimization would be required to assure the system performance of both multicast and point-to-point data. A similar approach reported in [10] adopted the same extinction ratio control principle, except that the multicast data was modulated in IRZ format, instead. In [11], the downstream point-to-point data was modulated in IRZ format while the multicast data was in DPSK format. The network architecture was similar to that in [8,9]. The multicast data on a particular downstream wavelength could be disabled by applying temporal delay to the respective downstream IRZ point-to-point data, based on the principle that any excessive temporal bit misalignment between the DPSK multicast data and the IRZ point-to-point data would induce excessive intensity fluctuation to the DPSK multicast data. Thus, the DPSK multicast data would not be properly demodulated at the destined ONU.

In [12], a polarization-assisted optical multicast overlay control scheme was proposed. At the OLT, the continuous-wave (CW) optical power at λ_k (for $k=1, 2, \dots, N$, for N ONUs) from the downstream transmitter # k was split into two parts. The first part was modulated with the respective downstream NRZ-ASK point-to-point data, via external modulation, before being combined with the other modulated downstream point-to-point wavelengths, for delivery to the RN over the first fiber feeder. The second part of the CW optical power from each downstream transmitter was fed into a polarization control unit before being combined with that from all other downstream transmitters. The combined signal was then modulated with the multicast data in DPSK format, via the common optical phase modulator (PM), before being delivered to the RN, via the second fiber feeder. From the wavelength assignment, $\lambda_j \{j=[(i-1)+N/2] \bmod N+1\}$ was the multicast wavelength destined for ONU# i . In order to enable the multicast data for ONU# i , the polarization control unit at the j^{th} transceiver at the OLT should be set to align the polarization of λ_j with the principal axis of the crystal in the PM, so as to maximize the degree of phase modulation. In contrast, the multicast data could be flexibly disabled by switching the polarization of λ_j to be orthogonal with the principal axis of the crystal in the PM, so as to minimize the degree of phase modulation. Hence, optical multicast overlay control for individual ONUs could be achieved. Instead of using polarization control, a similar approach [13] based on a simple 1×2 optical switch in each downstream transceiver at the OLT was also reported to control the presence of the multicast data on each downstream wavelength.

In [14], an optical multicast overlay control scheme, based on optical carrier suppression (OCS) was proposed. At the OLT, the CW light from each transmitter was first modulated by a composite signal, which comprised a sinusoidal control clock signal and the downstream NRZ-ASK point-to-point data, via a Mach-Zehnder intensity modulator (IM), biased at its null transmission point. The peak-to-peak driving voltage (V_{pp}) of both the control clock and the point-to-point data should be twice of the half-wave voltage (V_π) of the IM. In

this way, the optical central carrier was suppressed, while the

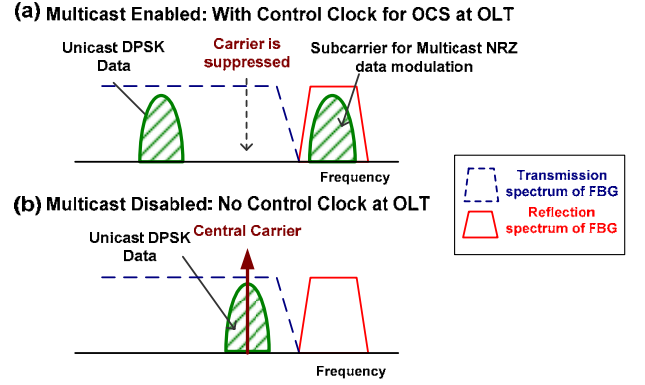


Fig. 2: Spectra of downstream carrier to illustrate the principle of multicast overlay control via optical carrier suppression (OCS).

two generated sidebands (subcarriers) were carrying the downstream point-to-point data in DPSK format. This was also known as OCS-DPSK format. One of the generated subcarriers was then filtered off and reflected, via a fiber Bragg grating (FBG). The reflected subcarriers from all transmitters at the OLT were combined, via a WDM multiplexer, before being fed into a common IM for multicast NRZ-ASK data modulation and delivered to the destined ONUs. On the other hand, the subcarrier at the transmission output port of the FBG is transmitted to the respective ONU, via another fiber feeder to deliver the downstream point-to-point data to the destined ONUs. The control of multicast transmission for individual downstream channel was achieved by turning on or off the control clock signal at the respective transmitter at the OLT. As illustrated in Fig. 2, when the control clock was present, the subcarrier for multicast data modulation was generated, hence multicast transmission was enabled. On the contrary, when the control clock was absent, the subcarrier was no longer generated, thus there was no optical power available to carry the multicast data and thus disabled the multicast transmission. The multicast control of all transmitters was performed at the OLT only.

III. SUMMARY

WDM-PON is evolving to be more robust for broadband data networking. More networking functionalities are being incorporated in the network design to meet the practical networking requirements. We have reviewed several novel techniques to enable optical transmission of high-speed multicast data destined for a designated subset of ONUs on a WDM-PONs. The multicast traffic is overlaid onto the existing point-to-point downstream wavelength channels using various feasible and practical optical signal processing techniques. Hence, the existing access network infrastructure can be gracefully upgraded to support such new kind of multicast traffic in a more cost-effective way.

ACKNOWLEDGMENT

This project was partially supported by a research grant from Research Grants Council, Hong Kong (Project No. CUHK4105/08E).

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