Optical Overlay of Multicast Stream on a Survivable WDM Passive Optical Network

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***Abstract*— We propose a novel scheme to perform an optical multicast overlay on a survivable wavelength division multiplexed passive optical network. By flexibly controlling a sinusoidal clock signal and an optical switch at the optical line terminal, optical sub-carriers, which enable not only protection for distribution and feeder fibers, but also multicast data delivery, are generated. 10-Gb/s transmissions under both normal working and protection modes are experimentally demonstrated.**

***Index Terms*— Multicast, passive optical network, survivable, wavelength division multiplexing.**

I. Introduction

THE wavelength-division-multiplexed passive optical network (WDM-PON) is a promising solution to provision broadband access to business and residential subscribers. In order to enable more flexible and reliable data delivery, a self-protected survivable network architecture which can also support simultaneous unicast and multicast data streams is highly desirable. Recently, several interesting schemes [1]–[5] have been proposed to overlay a multicast data stream onto a conventional 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 amplitude-shift keying (ASK) unicast data wavelengths by adjusting the extinction ratio of the unicast data. However, the unicast data might suffer from system penalty due to their reduced extinction ratio. In [4], [5], unicast data and multicast data are superimposed onto different sub-carriers generated from a single optical carrier. Such approaches avoid the power penalty from the reduced extinction ratio of the unicast data and therefore improve the system performance. However, none of these schemes have considered the survivability of the whole network, and a single fiber failure may interrupt the high speed services and cause enormous loss in data and business.

In this letter, for the first time, we propose and demonstrate a novel survivable WDM-PON which can also support multicast data stream, in addition to the conventional two-way unicast transmissions. The manipulating of the multicast transmission and the protection switching is achieved by controlling the clock signal as well as an optical switch at the OLT. We have carried out the proof-of-concept experiment of 10-Gbit/s transmissions under both normal working and protection modes.

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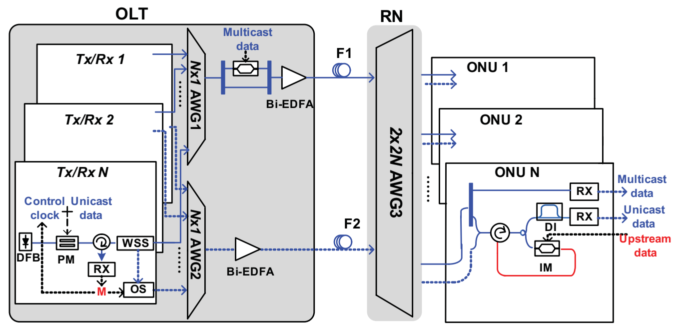


Fig. 1. Proposed multicast enabled survivable WDM-PON. IL: optical interleaver. AWG: arrayed waveguide grating. WSS: wavelength selective switch. Bi-EDFA: bidirectional Erbium-doped fiber amplifier. OS: optical on/off switch.

II. Proposed Multicast Enabled Survivable WDM-PON Architecture

Fig. 1 depicts the proposed multicast enabled survivable WDM-PON architecture with N ONUs. At the OLT, the continuous-wave (CW) light from each transmitter is first fed into a phase modulator (PM) driven by a composite signal of a control clock and the downstream unicast data to generate optical sub-carriers, which are carrying the downstream data in DPSK format. Then the generated sub-carriers are fed into a 1×2 wavelength selective switch (WSS), where the sub-carriers are separated into two groups, either for normal working transmission or protection transmission. Under normal working mode, the red-side and central sub-carriers of the generated sub-carriers present at one output port of the WSS at each transmitter are combined via an $N \times 1$ arrayed waveguide grating (AWG1). The combined signal is then fed into an optical subsystem comprising a pair of optical interleavers (IL) 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 red-side sub-carriers from all transmitters are extracted from the input combined signal, for common modulation of the multicast data, via a Mach–Zehnder intensity modulator (IM). At the same time, the lower arm passes the central sub-carriers carrying the individual unicast DPSK data. The sub-carriers are recombined and amplified by a bidirectional Erbium-doped fiber amplifier (EDFA), which can be constructed by two conventional EDFAs and two optical circulators. The amplified composite signal is then delivered to the remote node (RN), via the first fiber feeder (F1). At the RN, a $2 \times 2N$ AWG (AWG3) is employed. Its 1^{st} and $(N/2{+}1)^{\text{th}}$ input ports are connected to the first and the second fiber feeders respectively, while its i^{th} and $(N+i)^{\text{th}}$ output ports are connected to optical network units (ONU_i). After being demultiplexed at the RN, The optical sub-carriers for unicast and multicast data streams are delivered to their respective destined ONUs. At each ONU, the received_red-side sub-carrier carrying the multicast data, is separated from the central sub-carrier, via an IL before directly detected. The remained central sub-carrier carrying the unicast data, is then fed into an optical circulator before tapped off by a 3-dB optical coupler where half of the received optical power is demodulated via an optical delay interferometer (DI) to retrieve the unicast DPSK data, while the other half is fed into an IM for upstream data re-modulation in ASK format. The upstream signal is then delivered back to the respective receiver unit at the OLT via F1, where part of the received upstream power is fed into the monitoring unit (M) for fault detection. When there happens a fiber failure, a sudden drop of the received power can be detected by M, which will then trigger the optical switch for protection while keeping the control clock on. In the protection mode, the generated blue-side sub-carrier present at another output port of the WSS is combined with all other protection blue-side ones from other transmitters, via another $N \times 1$ AWG (AWG2). The combined protection sub-carriers are amplified and fed into the second fiber feeder (F2). The protection sub-carriers are then demultiplexed at RN and delivered to their destined ONUs. At each ONU, part of the received protection power is demodulated to recover the unicast DPSK data, while the rest is reused for upstream ASK modulation. The control of multicast transmission and protection switching for individual downstream channel is realized by manipulating the on-off states of the control clock signal and the optical switch at the OLT, as shown in Fig. 2. When the control clock and the optical switch are both set in off-state as illustrated in Fig. 2(a), only a central carrier is present for normal unicast transmission. When the control clock is in open-state and the optical switch is in off-state, the optical sub-carriers for unicast and multicast data are generated as shown in Fig. 2(b). Hence the transmissions for unicast and multicast data in normal working mode are enabled, while the transmission for protection is blocked by the optical switch. Considering a fiber failure in the network, transmission for protection is enabled by setting the states of control clock and the optical switch both into open-state, as shown in Fig. 2(c). In this way, the sub-carrier for protection transmission is generated, while the sub-carriers for normal working transmission are blocked by the fiber failure.

III. Experiment and Results

Fig. 3 shows the set-up of our proof-of-concept experiment for the proposed survivable WDM-PON with optical multicast overlay. 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 sub-carriers, λ_{sub1} at 1546.89 nm, λ_{sub2} at 1547.29 nm and

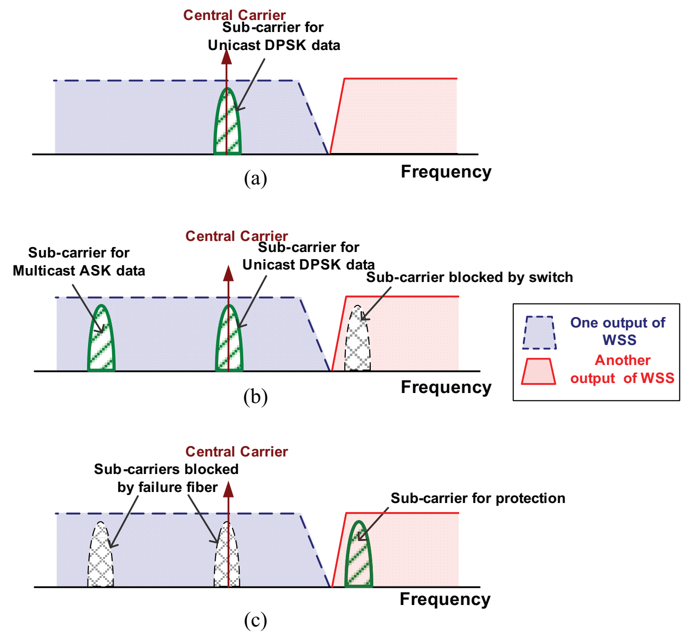


Fig. 2. Spectra of downstream carrier to illustrate the principle of multicast and protection via control clock and optical switch. (a) Normal unicast: without control clock f and optical switch off at OTL. (b) Normal multicast enabled: with control clock f and optical switch off at OTL. (c) Protection enabled: with control clock f and optical switch on at OLT.

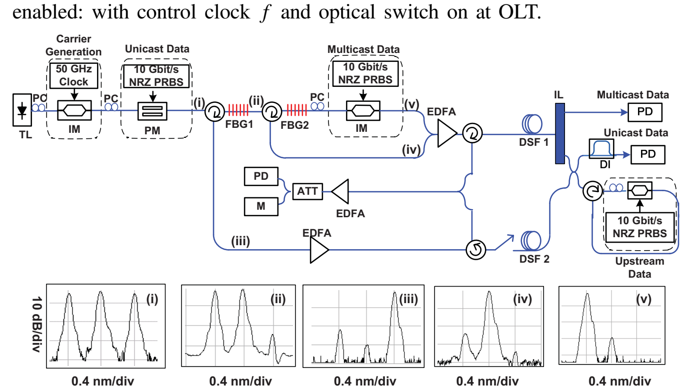
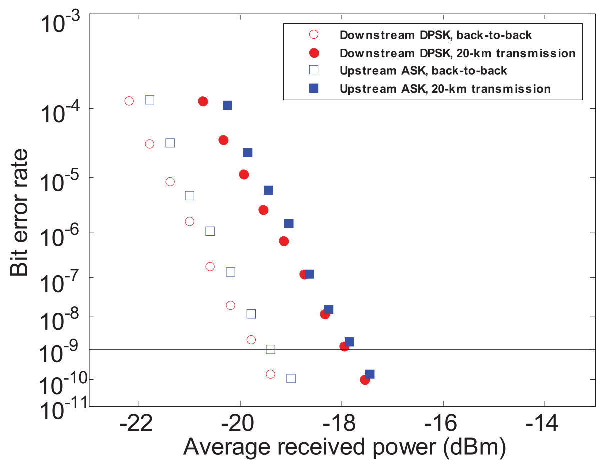
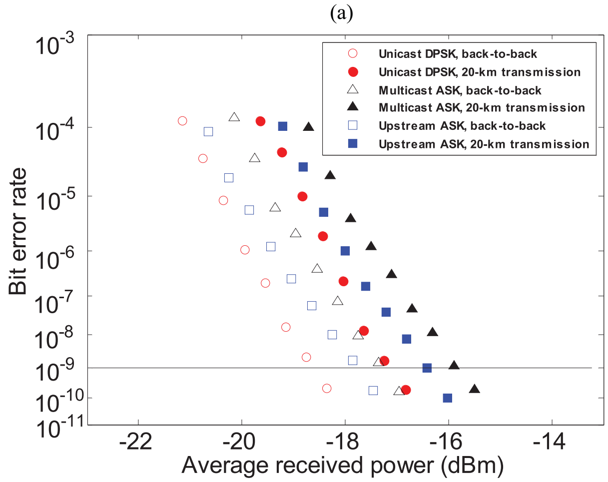


Fig. 3. Experimental setup. OC: optical circulator. IL: interleaver. ATT: attenuator. DSF: dispersion-shifted fiber.

λ_{sub3} at 1547.69 nm. The generated three sub-carriers were then phase modulated by the 10-Gbit/s $2^{31}-1$ PRBS unicast data as in Fig. 3 inset (1) before fed into FBG1 with a reflection passband of 0.2 nm Full width at half maximum (FWHM) and a reflectivity of 99%. FBG1 was employed to separate out the carrier λ_{sub3} for protection transmission, as shown in Fig. 3 inset (3). Under normal working mode, the remained λ_{sub1} and λ_{sub2} present at the transmission output port of FBG1as in Fig. 3 inset (2), were fed into FBG2 with a reflection passband of 0.2 nm FWHM and a reflectivity of 99%, which further separated λ_{sub1} from λ_{sub2}. At the transmission output port of FBG2, λ_{sub1} as in Fig. 3 inset (5) was intensity modulated by the 10-Gbit/s $2^{31}-1$ PRBS NRZ multicast data before being combined with λ_{sub2}, as in Fig. 3 inset (4). The composite signal was then optically amplified to about 5 dBm before being delivered to the ONU, via a piece of 20-km dispersion-shifted fiber (DSF), denoted as DSF1. DSF fiber was employed in our experiment to emulate dispersion compensated transmission path. It could be replaced by using standard single-mode fiber



(a)



(b)

Fig. 4. BER measurements of 10-Gb/s transmissions under normal working mode. (a) Multicast is disabled. (b) Multicast is enabled.

with dispersion compensating module in practical implementation. At the ONU, multicast data on λ_{sub1} was separated from λ_{sub2} via an optical interleaver and directly detected. The unicast DPSK data on λ_{sub2} was 3-dB split, half for reception and half for upstream re-modulation 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 DSF1, before it was separated from the downstream signal and detected. When a fiber cut happened in the above transmission path under normal working mode, protection switching was realized by setting the state of the optical switch into open-state. λ_{sub3} present at the reflection output port of FBG1 was amplified to about 5 dBm and delivered to the ONU, via another piece of DSF (DSF2). At the ONU, half of the unicast DPSK data on λ_{sub3} was demodulated, via a DI, before being directly detected, while the other half was reused for upstream re-modulation by the 10-Gb/s $2^{31}-1$ PRBS NRZ upstream data. The upstream ASK signal was then sent back to the OLT, via DSF2, before it was separated from the downstream signal and detected.

The bit error rate (BER) performances in both normal working and protection mode have been measured. Fig. 4(a) shows the measured BER performances when multicast data was disabled in normal mode. About 1.5-dB penalty was observed for the unicast, and the upstream data after 20-km transmission, which might be mainly attributed to possible

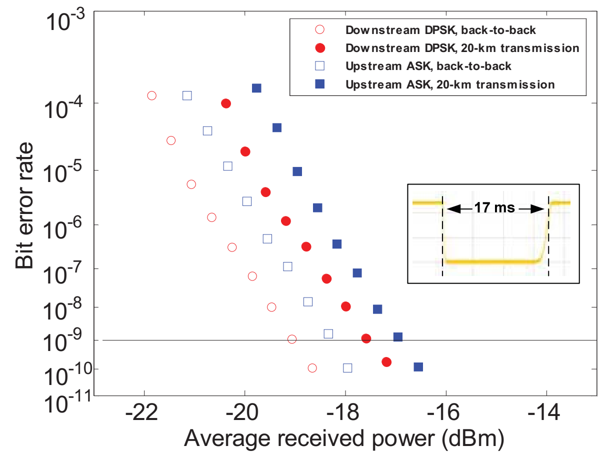


Fig. 5. BER measurements of 10-Gb/s transmissions under protection mode.

Rayleigh backscattering in the bi-directional transmission. Fig. 4(b) shows the measured BER performances when multicast data was enabled in normal mode. With the addition of multicast data transmission, the receiver sensitivities for downstream unicast and upstream signals were degraded by 1.0 and 1.4 dB, respectively, after transmission, as compared with the multicast-disabled case. This could be attributed to the imperfect filtering effects of FBG1 and FBG2 used in the experiment. Fig. 5 shows the measured BER performances in protection mode. About 0.4 and 0.9-dB penalties were observed for downstream unicast and upstream signals, respectively after transmission, compared with the performance in Fig. 4(a). This might be attributed to the non-ideal filtering effects of FBG1 used in the experiment. The traffic restoration time was also measured at the monitoring unit, as shown in the inset of Fig. 5. About 17-ms switching time was experimentally observed. This switching time is mainly limited by the optical switch employed in the experiment.

IV. Conclusion

We have proposed and experimentally investigated a novel optical multicast overlay over a survivable WDM-PON. By flexibly controlling a sinusoidal clock signal and an optical switch at the OLT, the architecture has both enabled the multicast transmission and protection for any fiber cut in either feeder or distribution fiber. Error-free transmissions at BER $= 10^{-9}$ for in either working or protection mode were successfully demonstrated.

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