Experimental Demonstration of a Cost-Effective Broadcast Overlay for a Commercial WDM PON

P. P. Iannone[(1)], K. C. Reichmann[(1)], J. Pastor[(1)], C.G. Brinton[(1)], C-H. Lee[(2)], H-Y. Rhy[(2)], and Y-L. Lam[(3)]
(1) AT&T Labs – Research, 200 S. Laurel Ave., Middletown, NJ 07748, ppi@research.att.com
(2) LG-Ericsson, GS Tower 679 Yeoksam-dong, Gangnam-gu, Seoul, Korea 135-985
(3) Denselight Semiconductors, 6 Changi North Street 2, 498831, Singapore

Abstract: We demonstrate a simple cost-effective broadcast overlay for WDM PON which uses a single directly modulated superluminescent diode to deliver an RF video or baseband gigabit-Ethernet service to all 32 users.

OCIS codes: (060.4510) Optical communications; (120.4820) Optical systems

1. Introduction

Wavelength-division multiplexed passive optical networks (WDM PON) with "colorless" upstream transmitters have recently been commercialized and are regarded by many to be a higher performance alternative to today's widely deployed time-division multiplexed (TDM) PONs such as EPON [1] and GPON [2]. One perceived shortcoming of WDM PONs relative to TDM PONs is the lack of a reliable low-cost method for broadcasting to all users at the optical layer. Since TDM PONs employ a *1:N* passive splitter at the remote node, broadcasting is easily accomplished by adding an additional downstream wavelength [3], which is segregated from the TDM downstream signal at each optical network terminal (ONT) by a demultiplexing filter incorporated into the ONT triplexer (PONs without a broadcast overlay use a diplexer to segregate the upstream and downstream wavelengths). WDM PONs employ a *1:N* arrayed-waveguide grating (AWG) at the remote node, so a single laser cannot be used as a broadcast source. In this paper, we demonstrate a cost-effective overlay system for WDM PON, which uses the broad spectrum of a superluminescent diode (SLED) transmitter in conjunction with the cyclic property of the AWG to efficiently broadcast to all 32 users. We measure the performance of both an RF subcarrier-based video broadcast service as well as a gigabit-Ethernet (GbE) broadcast, and show that the performance of the WDM PON is unaffected by these overlays.

2. Experimental configuration

The experimental configuration, shown in Fig. 1, consists of a commercial LG-Ericsson EA 1100 WDM PON along with the SLED-based broadcast overlay system. The EA 1100 is a 32-user system with 100 Mb/s dedicated bi-directional links for each user [4]. Thirty-two downstream/upstream wavelength pairs are formed by injection seeding Fabry-Perot (FP) laser transmitters with amplified spontaneous emission which has been sliced by the AWG multiplexer/demultiplexer (mux/demux) in the optical line terminal (OLT) and the AWG mux/demux in the remote node, respectively [5]. The downstream band runs from 1574.2 nm to 1599.6 nm and the upstream band runs from 1533.5 nm to 1558.2 nm. The channel spacing, set by the AWG, is 100 GHz. The OLT transceivers (not shown) are connected to corresponding ONTs through: an AWG included in the OLT (not shown), a course mux which adds the broadcast light, 20 km of OFS Allwave fiber which serves as the feeder, the AWG at the remote node, a short length of distribution fiber, and a coarse demux which separates the broadcast light from the WDM PON wavelengths. A pair of circulators and a variable optical attenuator are inserted before the PON ONT under test to permit independent attenuation of the downstream signals during the measurements. Our EA 1100 was equipped with 8 out of 32 ONTs, so all measurements were recorded with 8 ONTs operating simultaneously.

Two versions of the broadcast overlay were constructed. The first, shown in Fig. 1, was derived from a commercial satellite broadcast system. A band of 16 QPSK RF subcarriers, carrying over 100 standard definition channels in all and spanning 500 MHz of RF spectrum from 950 – 1450 MHz, were block converted in an RF mixer down to 200 – 700 MHz, since the directly modulated SLED has limited RF frequency response. This RF spectrum was then amplified and equalized with a microstrip printed circuit board frequency compensator before driving the SLED. The SLED is based on an InGaAsP quaternary multi-quantum well epi-structure with separate optical carrier confined single transverse mode emission, with output spectrum centered around 1435-nm wavelength and output power of 4 dBm. To limit the output spectrum of the SLED to one free-spectral range (FSR) of the AWG, the SLED output was shaped by a 35-nm wide optical bandpass filter whose response is shown in relation to the cyclic wavelength bands of the AWG as an inset to Fig. 1. This optically filtered SLED spectrum is then combined with the WDM PON wavelengths in the coarse multiplexer, traverses the 20-km feeder fiber, and is spectrally sliced through the AWG, with one distinct 0.43-nm wide slice directed to each ONT, where it is demultiplexed onto a commercial APD receiver. The electrical signal is then mixed back up into the 950 – 1450 MHz band and connected to the video set-top box.

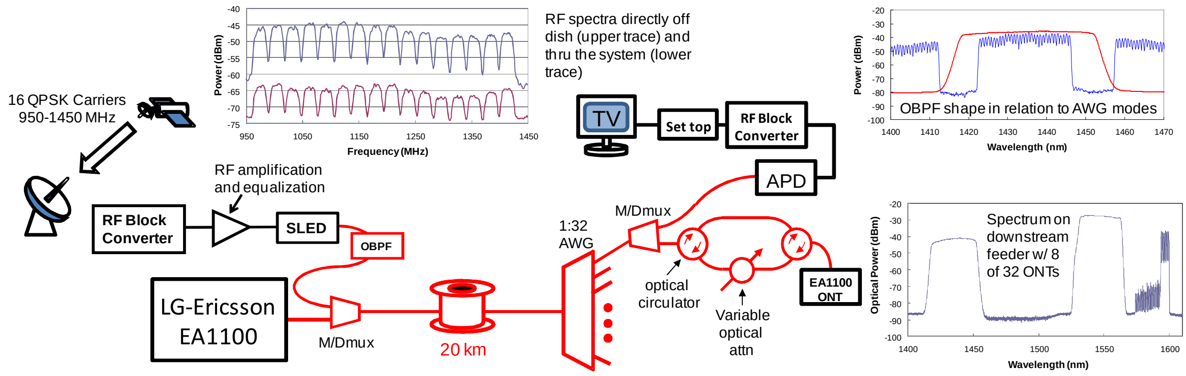

Fig. 1. Schematic of the commercial WDM PON with broadcast video overlay. Insets show RF and optical spectra.

The second version of the broadcast overlay (schematic not shown) is conceptually simpler, featuring a baseband transmission of a GbE service. The configuration differs from that described above in that a bit-error rate tester (BERT) followed by an equalizer and electronic amplifier are used to directly modulate the SLED at 1.25 Gb/s and the APD receiver at the user location is followed by a 750 MHz electronic low-pass filter (LPF), the output of which is connected to the BERT analyzer.

3. Results

We measured the performance of the WDM PON and the overlay systems independently and together. Fig. 2a shows the WDM PON frame drop rate as a function of received power for ONTs connected to AWG ports 1 and 32 for 64-byte packets and 100 Mb/s line rate. Open symbols represent performance without the video overlay operating and solid symbols represent performance with the video overlay operating. There was no significant effect caused by the presence of the broadcast overlay.

Since the RF video overlay is based on a commercial satellite service, its performance was measured by observing a video monitor and recording the received optical power corresponding to the onset of errors, generally observed as blockiness in the video picture. These video sensitivity measurements are plotted in Fig. 2b as a function of AWG port for 4 video channels, each associated with a particular RF subcarrier. Overall, the sensitivities are quite good due to the use of forward error correction coding (FEC). The worst case sensitivity was -39.8 dBm for the 358-MHz subcarrier on AWG port 30. This subcarrier had the worst sensitivity by several dB since it had the lowest power among all subcarriers immediately after the satellite dish. Presumably, this would not be an issue in an optimally designed system, since the subcarrier amplitudes could be individually adjusted.

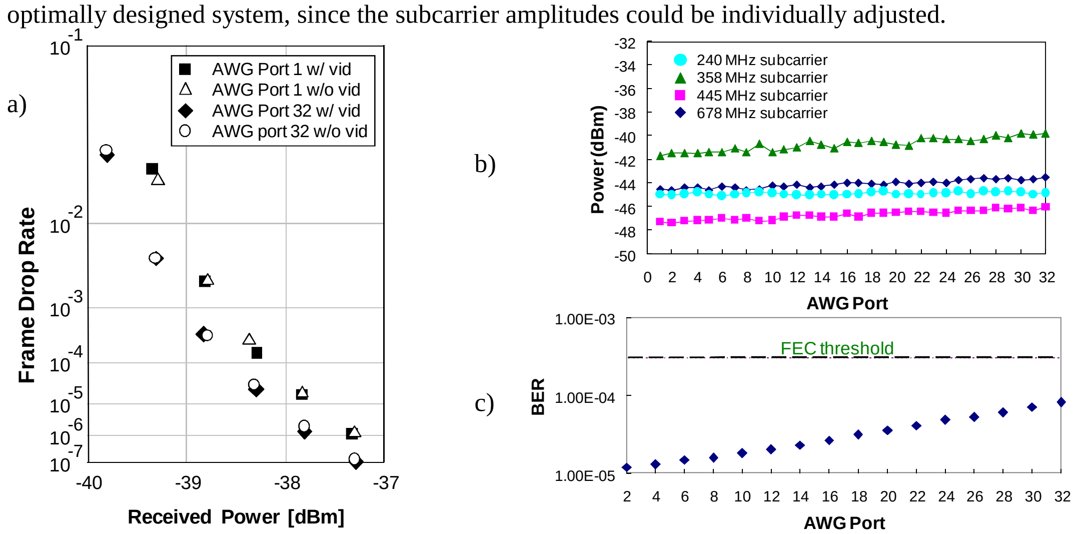

Fig. 2. a) Frame drop rate for the WDM PON, b) sensitivity of the RF overlay and c) BER performance of the GbE overlay.

We similarly measured the performance of the 1.25 Gb/s baseband GbE broadcast overlay as a function of AWG port. We assume this system would employ standard FEC, with a BER threshold of 3 x 10^{-4}. Figure 2c is a plot of BER for a fixed power of –34.6 dBm at the receiver and pseudo-random bit sequence (PRBS) length of 2^7-1. This short pattern is sufficient for emulating the 8B10B-coded GbE link (A 2^{31}-1 PRBS resulted in a substantial power penalty relative to 2^7-1). All values exceed the FEC threshold. The presence of the WDM PON signals did not affect the performance of either broadcast overlay.

3. Discussion and conclusion

In recent years, scores of research papers have addressed the problem of broadcasting over an AWG-based WDM PON, many by adding clever but complex techniques which combine the broadcast data with the existing downstream wavelengths. Based on the example of standardized TDM PONs that use the video enhancement band [3] for delivering broadcast video, we feel that a practical broadcast overlay must be simple, low-cost, and modular. The use of a broadband incoherent light source to establish broadcast connections over a WDM network is well known. This basic technique was first demonstrated over an AWG-based WDM PON over 14 years ago [6]. The present result differs from [6] in that affordable high-power SLEDs are now available over a range of wavelengths, as are practical deployable WDM PONs. Naturally, the use of a directly-modulated SLED presents challenges relative to a semiconductor laser diode: Not only do the gain dynamics limit the frequency response of LEDs, but it is well known that the signal-to-noise ratio (SNR) of incoherent sources is proportional to B_O, the optical bandwidth [7]. Of course, arbitrarily increasing B_O is not an option since B_O is set at the receiver by the channel bandwidth of the AWG, not to mention the fact that the allowable optical bandwidth is also limited by chromatic dispersion. Some of these issues are highlighted by the BER curves in Fig. 3, which show the BER performance of the GbE link back-to-back without optical filtering (solid circles), back-to-back with the optical filtering of the AWG (open circles), and through the entire 20-km system including the AWG (solid triangles). The best performance is associated with the full ~ 35-nm bandwidth of the 1435-nm SLED spectrum. Filtering down to the 0.43-nm bandwidth of the AWG mode degraded performance by 2 dB at 10^{-5} BER, but permitted transmission through the entire 20-km system with negligible added penalty. In contrast, an attempt to transmit the full spectrum completely degraded performance to the point that the BERT could not synch to the incoming data.

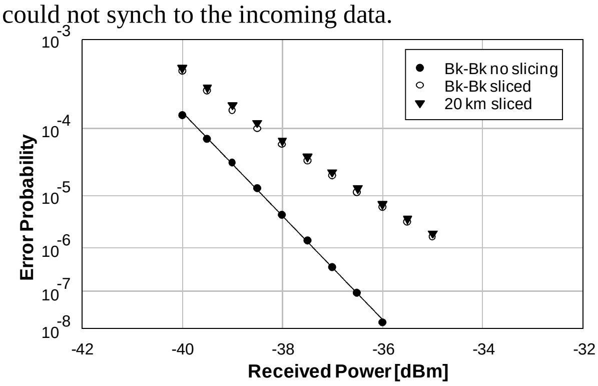

Fig. 3. BER as a function of received optical power for the GbE overlay and its dependence on optical bandwidth and fiber length.

In conclusion, we have demonstrated a practical low-cost broadcast overlay for WDM PON using a high-power SLED transmitter. The 1435-nm directly modulated output is tailored to match an available FSR of the AWG, so each user receives a single slice of the broadcast signal. The performance of an RF subcarrier-based broadcast TV service and a GbE broadcast service were unaffected by the presence of the WDM PON and did not adversely affect the PON (aside from the slight increase in link loss associated with the addition of coarse WDM couplers to segregate the services).

4. References

[1] IEEE Std. 802.3ah
[2] ITU-T Recommendations G.984 series
[3] ITU-T Recommendation G.983.3
[4] http://www.lgericsson.com/index.html
[5] H.D Kim, S.-G. Kang, and C.-H. Lee, "A Low-Cost WDM Source with an ASE Injected Fabry-Perot Semiconductor Laser," *Photon. Technol. Lett*., vol.12, pp. 1067-1069, 2000.
[6] P.P Iannone, K.C Reichmann, and N.J. Frigo, "Broadcast Digital Video Delivered Over WDM Passive Optical Networks," *Photon. Technol. Lett*., vol. 8, pp. 930 – 932, 1996.
[7] J.S. Lee, Y.C. Chung, and D.J. DiGiovanni, "Spectrum-Sliced Fiber Amplifier Light Source for Multichannel WDM Applications," *Photon. Technol. Lett*., vol. 5, pp. 1458-1461, 1993.