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A Novel Scheme to realize a Power-efficient WDM Passive Optical Network

Wei Jia*, Dong Shen*, Kam-Hon Tse*, Jing Xu*, Ming Li* and Chun-Kit Chan*

* jw009@ie.cuhk.edu.hk, Department of Information Engineering, The Chinese University of Honkong, Shatin, N.T., Hong Kong SAR, China

***Abstract*—We propose and experimentally demonstrate a simple power efficient scheme for WDM-PON, using a LED-based monitoring signal to save the power consumption of the optical transceivers for the inactive subscribers.**

I. Introduction

Wavelength division multiplexing passive optical network (WDM-PON) is a promising solution for next generation broadband access architecture. The approach of centralized light sources (CLS) [1] at the optical line terminal (OLT) is commonly adopted for cost-effective and flexible implementation. At each optical network unit (ONU), a portion of the downstream signal power is re-modulated by the upstream data, before being delivered back to the OLT. Consider if there is no data traffic on a certain downstream carrier, the OLT still has to send out the downstream signal at the normal average optical power, so as to facilitate data re-modulation for the upstream transmission at destined ONU. Nevertheless, the respective ONU may not have upstream data in its output data queue all the time. The network usage from the network subscribers is time-varying at different periods within day. From [2], it was stated that the number of active network subscribers during the period between 0200 and 0800 are much less than that between 1700 and 2200. Hence, during that period that there is no active data traffic in both downstream and upstream directions, simultaneously, on any downstream carrier, the optical power delivered by the OLT on that downstream carrier is wasted. In [3], a simple power saving scheme for WDM-PONs was proposed to use a tunable laser to poll individual ONUs in the network to monitor their upstream transmission status or request. Thus, the respective optical transmitter at the OLT would stop its downstream signal transmission to save power, when there is no active data in both downstream and upstream directions, simultaneously.

In this paper, we propose a simple and cost-effective power efficient scheme for a WDM-PON by incorporating a broadband light emitting diode (LED) at the OLT, which generates monitoring signals for all individual ONUs, via spectral-slicing at the remote node (RN). Such continuous monitoring signals can help to trigger and stop the downstream signal transmission of any optical transmitter at the OLT, in case there is no active data traffic in both of its downstream and upstream directions, simultaneously. Thus, power efficiency of the WDM-PON is greatly enhanced.

II. Proposed Power-Efficient WDM-PON

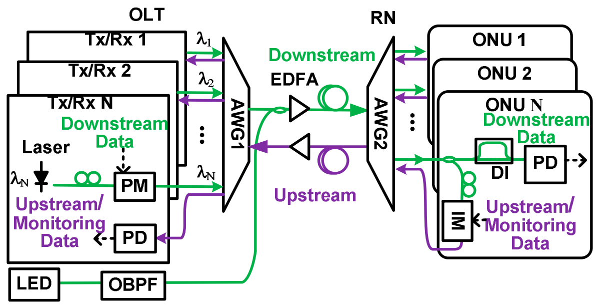

Fig. 1. Proposed power-efficient WDM-PON architecture.

Fig. 1 illustrates the proposed power-efficient WDM-PON architecture. To facilitate illustration of the proposed scheme, the network is assumed to have CLS at the OLT and employ downstream differential phase-shift keying (DPSK) signals and upstream amplitude-shift keying (ASK) signals, with data re-modulation via an optical intensity optical modulator (IM) at each ONU. Our proposed power efficient scheme can also be applied to WDM-PONs using other modulation formats for the downstream and the re-modulated upstream signals. In this example, at the OLT, the downstream DPSK signals on all wavelength channels are generated and wavelength-multiplexed by cyclic arrayed waveguide grating (AWG), denoted as AWG1. On the other hand, an LED is also employed, at the OLT, as a broadband light source to generate the monitoring signals for all ONUs. The un-modulated LED output is filtered, via an optical band pass filter (OBPF), so as to match with wavelength band at about one free-spectral range (*FSR*) of AWG2, away from the downstream data wavelengths (λ_1, …, λ_N), at the RN, as shown in Fig. 2(a). Note that the FSR values of both AWG1 and AWG2 are identical. Then the multiplexed downstream signals and the filtered LED broadband signal are combined before being fed in to the downstream fiber feeder for delivery to all destined ONUs, via the AWG2 at the RN.

At the RN, the optical carriers for the monitoring signal ($\lambda_i^M = \lambda_i + FSR$, for $i=1, \ldots, N$) are generated, via spectral slicing by AWG2, as shown in Fig. 2(b). With the cyclic spectral property of AWG2, each monitoring signal carrier can pass through the same transmission pass-band of AWG2, together with the respective downstream data wavelength. At the ONU, a portion of the received power is fed into an optical DPSK

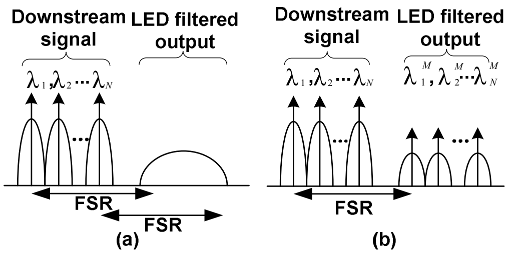

Fig. 2. Optical spectra (a) before, and (b) after, AWG2 at RN.

demodulator to recover the downstream signal, whereas the remaining optical power is injected into an IM for upstream data re-modulation.

Under the conditions that either downstream or upstream data on a particular data wavelength, or even both, are active, the received monitoring signal at the ONU, which is un-modulated, is sent back to the OLT, via the IM at the ONU and the upstream fiber feeder. Whenever the OLT finds that there are no downstream data to be sent and no upstream data received at a particular optical transceiver, for a certain period of time, it triggers its power-saving mode and stops its optical transmitter from sending out any downstream power. When there is any upstream data to be sent from the respective ONU, a sinusoidal signal at a certain RF frequency (f_M), which serves as the monitoring tag, will be applied to its IM. Thus the received monitoring signal at the respective transceiver at the OLT will contain a frequency component of f_M, which in turn restores the normal power transmission from the respective optical transmitter. After the downstream signal is received again at the respective ONU, the monitoring tag will be disabled.

Although the proposed scheme requires an additional LED residing at the OLT, which may add extra cost and power consumption to the network, it can generate monitoring signals for all ONU, via spectral slicing at the RN, thus its cost is shared by all ONUs and all ONUs can be monitored continuously. Moreover, a typical optical data transceiver at the OLT requires thermal control and precise current control, for stable wavelength and power control, the required circuitry consumes much higher power than that for driving a typical LED, which does not require any thermal and wavelength control. Hence, the overall power consumption of our proposed network is still much reduced.

III. Experiment and Results

We have demonstrated single channel experiment of the proposed WDM-PON architecture based on the setup shown in Fig.1. At the OLT, a continuous-wave (CW) light at 1550nm was modulated by a phase modulator with a 10-Gb/s 2^{31}-1 pseudorandom binary sequence (PRBS) as the pre-coded downstream data. An LED was biased at 350mA with an output power of 5.8 dBm. Since only one channel was investigated, an OBPF centered at 1562.9 nm with a 3-dB bandwidth of 0.8 nm was set after the LED to simulate one channel of an AWG with a channel spacing of 100GHz. The optical DPSK and LED signals combined with a 9:1 coupler were amplified and coupled into a piece of 20-km dispersion-shifted fiber (DSF) to simulate a dispersion-compensated transmission link. At the ONU, the received downstream signal power was divided by a 3-dB optical power splitter. One half of the received downstream signal power was demodulated by an optical delay interferometer (DI) before being detected by a photodiode. The remaining received power was fed into an optical IM, driven by a 10-Gb/s 2^{31}-1 PRBS NRZ data during normal operation or a 300-MHz sinusoid periodic monitoring data during power efficient operation. The re-modulated upstream signal was transmitted back to the OLT, via another piece of 20-km DSF.

Fig. 4 shows the waveform and the respective RF spectrum of the received monitoring signal at the OLT, under power-saving mode. A 300-MHz signal with a power change of 27.2dB was detected at a received optical power of -18.4 dBm. Fig. 4 shows the bit-error-rate (BER) measurements. It was shown that less than 0.5-dB power penalty (at BER≤10^{-9}) for both the downstream and the upstream signals, mainly due to the presence of the additional monitoring signal, was observed.

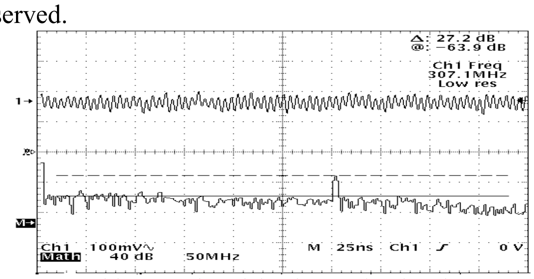

Fig 3. Detected low-speed modulated LED signal at the OLT. (Upper trace is time waveform; and the lower trace is the corresponding RF spectrum)

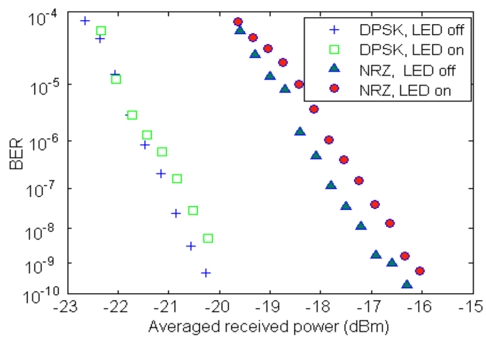

Fig. 4. BER measurements for downstream DPSK signal and Upstream NRZ signal when LED is off and on

IV. Conclusions

We have proposed a simple and cost-effective scheme using LED-based monitoring signal to realize a power-efficient WDM-PON. Experiments have demonstrated its feasibility and effectiveness.

References

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