A Cost-effective Pilot-Tone-based Monitoring Technique for Power Saving in RSOA-based WDM-PON

Kam-Hon Tse, Wei Jia, and Chun-Kit Chan
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR, China.
Tel: +852-2609-8385, Fax: +852-2603-5032, Email: tkh008@ie.cuhk.edu.hk

Abstract: We propose and experimentally demonstrate a simple and novel monitoring technique with the modulation of RSOA's ASE by the pilot-tone monitoring signal at the ONU, to provide power saving in RSOA-based WDM-PON.

OCIS codes: (060.2330) Fiber optics communications, (060.4250) Networks.

1. Introduction

Recently, there has been an increasing attention to power consumption saving in many fields. In information and communication technology (ICT), it is estimated that access network consumes around 70% of overall telecom network energy consumption [1] due to the presence of huge number of active devices. In addition, an estimation shows that access networking equipments are less than 15% utilized [1] and large portion of energy is therefore consumed by the idle devices, as the networks are engineered for satisfying the peak traffic load requirement. Hence, reducing energy consumption in access networks can lead to major saving in Internet energy consumption.

There are some efforts on providing energy saving by allowing network elements to switch to sleep mode in time-division-multiplexed passive optical network (TDM-PON) [2], or wireless-optical broadband access network (WOBAN) [1], etc. Beside TDM-PON, wavelength division multiplexing passive optical network (WDM-PON) is a promising solution for next generation broadband access architecture due to its large dedicated bandwidth for each subscriber. When the WDM-PON architecture is deployed in home or enterprise arenas, the optical network units (ONUs) may be idle for certain time period in a day, e.g. in the morning or at night. From [3], 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. Moreover, WDM-PON can be integrated with wireless-mesh network as fiber-wireless (FiWi) architecture where multiple ONUs serve as gateways of a whole wireless-mesh network, similar to WOBAN which combines the advantages of both optical and wireless communications. Its multipath divergence characteristic of this architecture provides load balancing and failure restoration features. Therefore, the idle ONUs during off-peak hours can be switched off for power saving.

In WDM-PON, the centralized light source (CLS) is necessary such that a portion of the downstream signal power is re-modulated by the upstream data. Several re-modulation schemes have been proposed, including downstream differential phase shift keying (DPSK) and upstream on-off keying (OOK) [4], downstream frequency shift keying (FSK) and upstream OOK [5], etc. In the remodulating WDM-PON architectures, remodulation by a reflective semiconductor optical amplifier (RSOA) with OOK at the ONU is a promising solution as it provides gain to the remodulating signal and offers compactness and colorless properties to ONUs. However, the remodulating WDM-PON achitectures suffer from a power consumption problem. Without the downstream signal, the ONU cannot send the upstream data. Thus even if there is no traffic on the line, the optical line terminal (OLT) has to send the downstream signal all the time. Therefore, when the ONU and the corresponding transceiver at OLT are in sleep mode for energy saving, some techniques have to be employed for the ONU to send "wake-up" message to OLT to request for initiating data transmission. The work in [6] proposed using polling scheme of a tunable supervisory transceiver, while [7] utilized light-emitting-diode (LED) based monitoring signal.

In this paper, we propose a simple and cost-effective signal monitoring scheme supporting power saving mode in WDM-PON. By modulating amplified spontanous emission (ASE) spectrum in RSOA at the ONU with the pilot tone monitoring signal, "wake-up" message can be sent to the OLT without the need of remodulating downstream signal, using tunable supervisory transceiver or any dedicated light sources.

2. Proposed System Architecture

Fig.1 illustrates the proposed power-efficient WDM-PON architecture. At the OLT, all the downstream signals are wavelength-multiplexed by an arrayed waveguide grating (AWG) and transmitted to the remote node (RN) along the feeder fiber. At the RN, the downstream WDM signals are de-multiplexed by an AWG and distributed to the corresponding destined ONU. At the ONU, half of the signal power is fed into an optical receiver to retrieve the downstream signal while another half is re-modulated by a RSOA by the upstream data. The upstream signal is delivered to the OLT, via the AWG at the RN again and another feeder fiber to avoid possible Rayleigh backscattering.

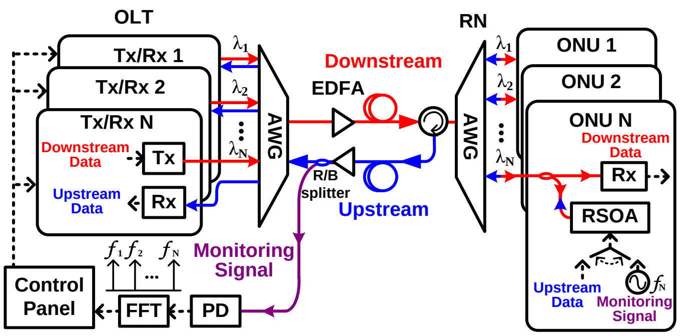

Fig. 1. Proposed power-efficient WDM-PON architecture

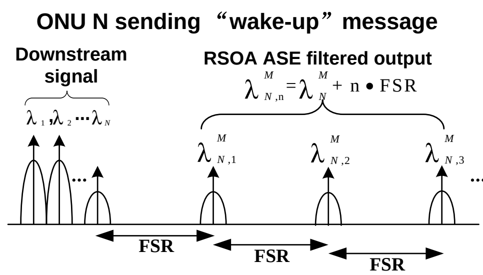

Fig. 2. WDM signals' spectrum after AWG of RN when ONU *N* operates in power efficient mode

If there is no downstream and upstream data on any channel for more than a certain time period, the respective ONU module and the corresponding transceiver at the OLT will enter sleep mode to provide energy saving. For instance, when there is an upstream data request from ONU *N*, the RSOA at ONU *N* will be modulated by an ONU-specific low frequency sinusoidal monitoring signal f_N. As there is no downstream signal, the RSOA is not injection-locked and its broadband ASE signal is modulated by the sinusoidal monitoring signal. It will then be spectral sliced by the AWG at the RN, as shown in Fig. 2, such the only the wavelengths ($\lambda_{N,n}^{M} = \lambda_N + n\text{FSR}$, for n=1,…,) are transmitted to the OLT, due to the cyclic spectral property of the AWG. At the OLT, one portion of the received monitoring signal is extracted by the R/B splitter and detected by a dedicated pilot-tone monitoring module. After detected by photodiode, Fast Fourier transform (FFT) will be performed on the detected electrical signal to examine if any specific pilot tone sent from any ONU is present. If yes, it will activate the respective transceiver at the OLT and returns to normal operation mode, which delivers the downstream signal power in continuous wave or with data.

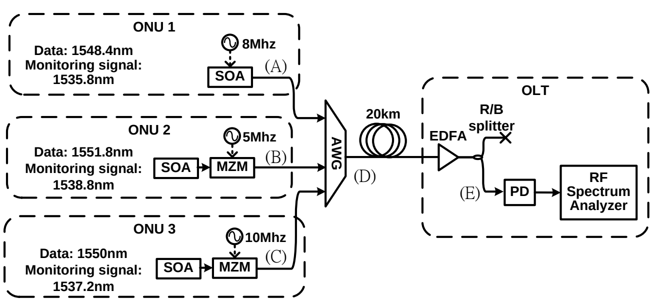

Fig. 3. Experimental setup. (SOA: semiconductor optical amplifier, MZM: Mach Zehnder Modulator, PD: photodector)

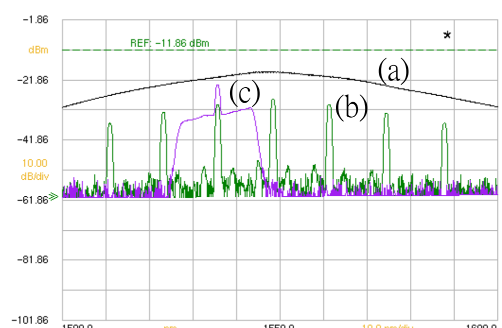

Fig 4. (a) The spectrum of the SOA output at ONU1 (point A in Fig. 3), (b) After AWG (point D in Fig. 3), (c) After R/B splitter (point E in Fig. 3)

3. Experimental Setup and Result

We demonstrated the feasibility of the proposed WDM-PON monitoring scheme based on the experimental setup, as shown in Fig.3. In the experiment, we only demonstrated the sending of the monitoring signal upstream and the detection of the pilot tones from all ONUs at OLT, because the monitoring scheme was non-intrusive to the in-service data transmission. As an example, we emulated that only ONU 1 sent "wake-up" message. The SOA at the ONU, which was used to enumerate the RSOA was directly modulated by an 8-MHz sinusoidal signal. The output signal from the SOA had 1.9-dBm power and the spectrum of the directly modulated SOA was shown in Fig 4(a). It was then spectrally sliced by an AWG and the output power was -21.1 dBm, with the spectrum shown in Fig. 4(b). After passing through 20-km single-mode fiber (SMF), the signal was amplified by an EDFA followed by a R/B splitter, which extracted 1529.3 nm to 1542.39 nm range wavelengths at one output. The output power was -18.2 dBm, with the spectrum shown in Fig. 4(c). In the experiment, due to the characteristic of R/B splitter employed, in order to allow the data channels to be occupied between 1545-60nm region, only monitoring signals at 1529.3 nm to 1542.39 nm were selected such that only one monitoring signal per one channel was detected. However, by using a filter which extracted the data channels from the monitoring signals, the monitoring signals of a channel at multiple wavelengths could be detected by the pilot-tone detector instead. After detection, via a photodiode, the electrical signal was then analyzed using an RF spectrum analyzer. The RF spectrum was shown in Fig. 5(a). It was observed that there existed higher-order harmonic frequency tones due to the imperfect modulation of the SOA with sinusoidal signal, though the power of the second-order harmonic frequency tone was 20-dB lower than that of the fundamental one. From Fig. 4(c), it was observed that although the optical signal-to-noise ratio (OSNR) of the amplified signal was not very high, due to the ASE noise of EDFA, there was still about 50-dB difference in power level between the pilot tone and the noise floor in the RF spectrum. This showsed the superior performance of the proposed pilot-tone monitoring scheme under low OSNR condition. We then performed a multi-ONU monitoring experiment by adding two more ONUs, each comprised an SOA followed by an optical intensity modulator to enumerate the RSOA. The optical modulators were driven by electrical sinusoidal signals at 5 MHz and 10 MHz, respectively. Due to the insertion loss of the optical modulators, the ONU2's output power at point B (denoted in Fig. 3) was -2.25 dBm, while the ONU3's output power at point C was -5.9 dBm. Figs. 5(b)&(c) shows the RF spectra when ONU 1&2, and all three ONUs were sending "wake-up" message, respectively. Due to the lower-power of the monitoring signals of ONU2 and ONU3, their pilot-tone monitoring signals in the RF spectrum had lower power level than that of the ONU1.

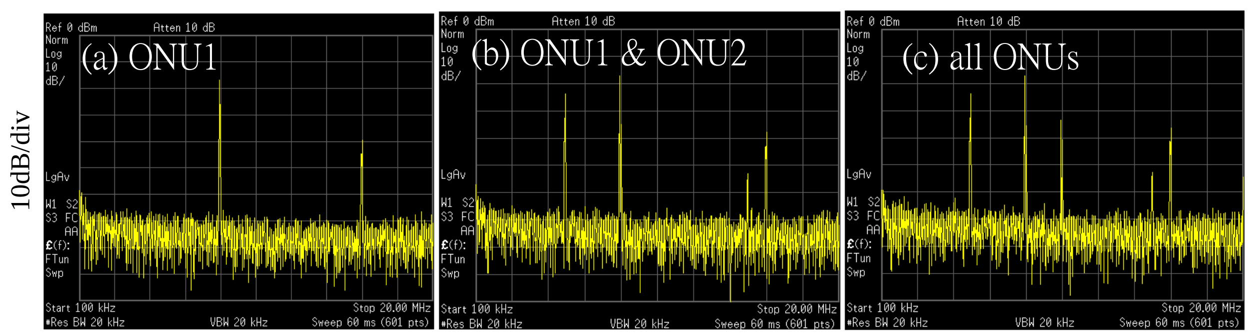

Fig. 5. RF spectrum of the detected signal with different ONU sending "wake-up" message(a) only ONU 1, (b) ONU1&ONU2, (c) all ONUs.

4. Summary

We have proposed a simple and cost-effective monitoring scheme using pilot tone-based monitoring signal in WDM-PON to provide power saving, by allowing the ONU and the corresponding transceiver at OLT to enter sleep mode during idle time. Feasibility of the scheme has been demonstrated through experiments.

5. References

[1] P. Chowdhury, M. Tornatore, S. Sarkar and B. Mukherjee, "Building a Green Wireless-Optical Broadband Access Network (WOBAN)," Journal of Lightwave Technology, 2010

[2] S.-W. Wong, L. Valcarenghi, S.-H. Yen, D. R. Campelo, S. Yamashita and L. Kazovsky, "Sleep Mode for Energy Saving PONs: Advantages and Drawbacks," GLOBECOM, 2009

[3] http://www.sandvine.com/downloads/documents/2009%20Global%20Broadband%20Phenomena%20-%20Executive%20Summary.pdf

[4] W. Hung, C.K. Chan, L.K. Chen and F. Tong, "An Optical Network Unit for WDM Access Networks with Downstream DPSK and Upstream Re-modulated OOK Data Using Injection-Locked FP Laser," Photonics Technology Letters, 2003

[5] N. Deng, W. Hung, C.K. Chan, L.K. Chen and F. Tong, "A novel wavelength modulated transmitter and its application in WDM passive optical networks," OFC, 2004

[6] T. Uchikata, and A. Tajima, "A novel power saving scheme for WDM-PON with centralized light sources", OECC 2009

[7] W. Jia, D. Shen, K.H. Tse, J. Xu, M. Li and C.K. Chan, "A novel scheme to realize a power-efficient WDM passive optical network", OECC 2010