Bidirectional WDM–PON architecture using a reflective filter and cyclic AWG

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We proposed and demonstrated a bidirectional SCM–WDM PON using a reflective filter and cyclic AWG where up/downlink data could be provided using a single optical source. In the proposed scheme, the signal for downstream was modulated by a single CW laser diode and remodulated in the optical network unit as an upstream, the proposed WDM–PON scheme can offer the SCM signal for broadcasting service. In this paper, 1 Gb/s signals both for up- and downstream were demonstrated in 10 km bidirectional optical fiber link.

1. Introduction

Future access networks will have to meet the ever increasing demand large capacity. Wavelength-division-multiplexing passive optical networks WDM/PONs are an attractive option due to its high capacity, easy management, network security, protocol transparency, and easy upgradability. So the WDM PONs can provide broadband access for next generation [1]. PON systems in fiber-to-the-home (FTTH) networks have been widely deployed to fully support “triple-play” services including data, voice, and video services. Among various PON technologies, WDM/PONs, which offer point-to-point connectivity via a dedicated wavelength to each customer, are believed to eventually provide an optimal FTTH architecture [2].

However, the network complexity and its subsequent cost have been the most critical issues for the practical deployment. To overcome this problem, it has been proposed to implement WDM PON by using spectrum-sliced incoherent light sources such as light-emitting diodes (LEDs) and amplified spontaneous emission sources [1,3]. The advantage of such a network would be the use of identical light source at every subscriber site. In addition, these networks could be robust to the optical crosstalk and the temperature-induced drift of the arrayed-waveguide grating (AWG) placed at the remote node (RN) [4,5]. However, when the spectrum-slicing technique is used, it is often difficult to secure an adequate amount of system margin due to the large slicing loss and low output power of LED. This problem could be relaxed to some extent by using high-power LEDs and sensitive receivers such as avalanche photodiodes (APDs). To solve this problem, it has also been proposed to use optical amplifiers at the central office (CO) [2]. Also, it has been demonstrated a bidirectional WDM PON using directly modulated spectrum-sliced LEDs [6]. The spectrum-slicing was achieved automatically at the AWG used for WDM channels. However, when a cyclic AWG was used, the spectrum-sliced light would have multiple peaks separated by the free-spectral-range (FSR) of the AWG. Previously, only one of these peaks was selected and used for the transmission to avoid excessive dispersion penalty [2,3]. However, in the proposed network, we utilized all these peaks for the transmission of each channel to improve the optical power budget as well as the beat-noise-limited signal-to-noise ratio (SNR) of the spectrum-sliced light. The use of multiple peaks could also reduce the difference in the optical powers of spectrum-sliced channels, and prevent the additional losses caused by the temperature-induced drifts of AWG and LED.

However, the failure of the feeder fiber link from the optical line terminal (OLT) to the remote node (RN) leads to the loss of data for all users. Thus fault monitoring methods [7–10] and a self-restartable network are needed. Various schemes have been proposed for survivable or self-restartable WDM/PONs. In previous schemes, 3 dB optical couplers are required, thus reducing the loss budget [11–13]. In Refs. [14–16], duplicated network resources such as fiber links and optical network units (ONUs) are implemented, leading to solutions quite expensive and/or complicated for access network applications. Korea Telecom (KT) has deployed a WDM–PON featuring wavelength reuse in a fiber-to-curb network and has successfully provided sixteen 1.25 Gb/s WDM channels. Also, KT has deployed a colorless gigabit WDM/TDM hybrid PON system, which has been successfully supporting commercial triple-...
play service in a new residential area in Korea since early March 2009 [17].

In this paper, we propose a new self-restorable architecture for bidirectional WDM–PON. It utilizes one different wavelength assignments and $1 \times N$ AWGs, as 16 channels each channel of AWGs is coupled to optical network units (ONUs) by using a reflective filter such as a fiber bragg grating (FBG) filter. This is for achieving sixteen 1 Gb/s downstream and upstream signals.

2. PON/WDM architecture

Fig. 1 shows the proposed PON/WDM architecture for transmitting subcarrier multiplexing (SCM) encoded channels over a bidirectional single mode optical fiber (10 km). At the central office (CO), a narrow bandwidth continuous wave (CW) (1550 nm) from laser diode is modulated via a LiNbO3 Mach-Zehnder modulator. Downlink data signal is mixed with local oscillator signal (10 GHz) and a carrier generator having a number of RF subcarriers. An ideal EDFA pre-amplifies optical carrier. A simple AWG that supports both dedicated wavelengths and power-splitting bandwidth sharing is used at the remote node (RN). At the optical network unit (ONU), a bidirectional reflective filter (Fiber Bragg Gratings—FBG) is used. The reflected optical signal is detected by a PIN-photodiode. Then the generated downlink microwave signal is boosted by an electrical amplifier. For uplink connection, the transmitted (remaining) optical signal from the FBG bidirectional reflective filter is amplitude modulated and sent back over the fiber to the central station. Uplink optical sidebands produce crosstalk when uplink data was detected at central station. Crosstalk can be reduced by using Bessel optical filter.

3. Results and discussion

This section presents the simulation results for the WDM–PON architecture which was modeled using a commercially available package [18]. Data signals are analyzed using optical and RF spectrum analyzers. Oscilloscopic visualization of NRZ modulation format is analyzed at central control station. The eye diagrams for the output of both the downlink and uplink are shown in Figs. 2 and 3 respectively. The results show that the Eye closure penalty is smaller for the uplink than that of the downlink which is expected, as the signal travel twice the distance for the uplink. Chromatic dispersion induced by bidirectional fiber will not cause downlink microwave signal a power penalty problem. So, the maximum eye amplitude for downlink stage after signal transmission took place over 10 km of bidirectional fiber at base station.

BER simulations were carried out for both uplink and downlink with a bit rate of 1 Gb/s. The variation of BER with input power is shown in Fig. 4. It is clear that both uplink and downlink do provide good BER performances, however the BER results for the downlink

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**Fig. 1.** The proposed PON/WDM architecture.

**Fig. 2.** Eye diagram of downlink.

**Fig. 3.** Eye diagram of uplink.
are better than those of the uplink. For example when the input power is 10 dBm, the BER is $4.4 \times 10^{-20}$ for the downlink while it is $5.4 \times 10^{-10}$ for the uplink. This can be attributed to the mixing noise between unsuppressed SCM signal in downstream and the digital signal of upstream which is generated in the remodulation process. This noise which influences the upstream signal could be reduced by using low pass filter after the photo detector in the CO.

The variation of BER with no. of subcarriers is plotted in Fig. 5. It is clear from the results that increasing the number of subcarrier channels degrade the system performance. For example, when RF channels increase from 10 to 90, corresponding BER decreases from $9.8 \times 10^{-13}$ to $5.9 \times 10^{-13}$ for the downlink, while it decreases from $1.9 \times 10^{-14}$ to $4.8 \times 10^{-8}$ for the uplink. This can be explained by the fact that, as the number of sub-carrier channels increases, their frequency spacing decreases which results crosstalk or noise.

4. Conclusion

The WDM–SCM PON model has been proposed as a solution for bandwidth demand. The combination of two different types of modulated has been performed to provide high bit rate data and bandwidth in PON. We presented a demonstration of 1 Gb/s signal for up/downstream in 10 km bidirectional link. The upstream traffic is obtained by remodulating the downstream traffic at the ONU. The results obtained here show that increasing total number of sub-carriers channels has a significant impact on performance of WDM–SCM PON system. These results may be implemented in real system used for broadband and cable TV services.

References

[18] Optisystem from optiwave.