A Novel Internetworking Scheme for WDM Passive Optical Network based on Remodulation Technique

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Abstract: We propose and demonstrate a novel internetworking optical network architecture using remodulation technique for WDM-PON. A special connection pattern of AWG in the Remote Node is used to broadcast the LAN traffic signal to ONUs.

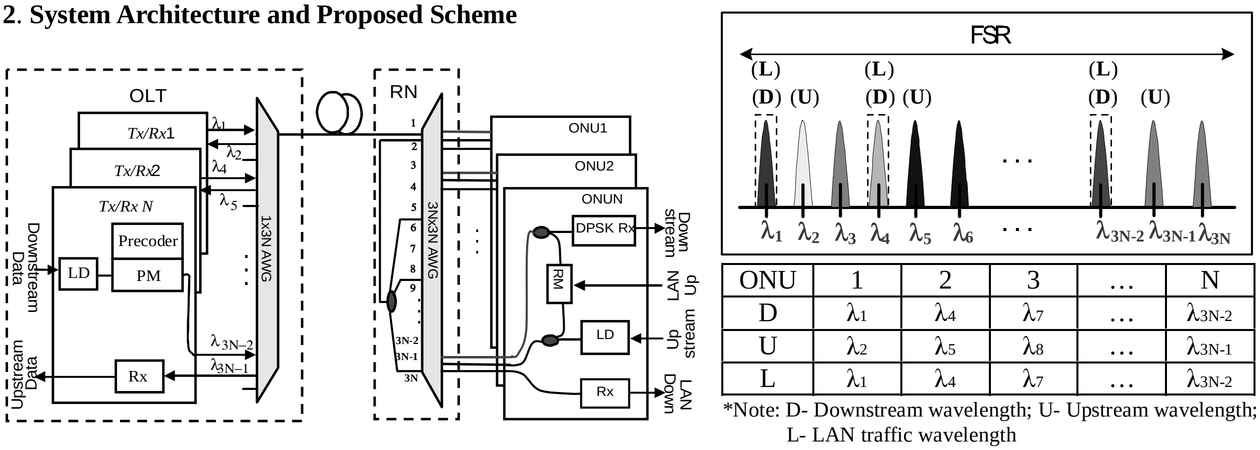
OCIS codes: (060.2330) Fiber optics communications; (060.4250) Networks

1. Introduction

As the increasing bandwidth demand from enterprises and households, WDM Passive Optical Network (WDM-PON) is one of the most promising technologies to meet the needed bandwidth. In the conventional WDM-PON architecture, each Optical Network Unit (ONU) cannot communicate with other ONUs directly. The internal traffic among ONUs must first be transmitted together with the upstream data to the Optical Line Terminal (OLT), then the OLT routes the internal traffic to the respective ONU. The internal traffic is routed electrically at the OLT, which increases the workload of the OLT and degrades the system performance. Thus, it is desirable to provide a dedicated way to serve internal traffic among ONUs in optical layer.

In [1], a local area network on PON was demonstrated using the Fiber Bragg Gratings (FBGs) and RF subcarrier. Compared to [2], the scheme in [1] reduced the number of working wavelengths and used only one wavelength channel for both upstream and Local Area Network (LAN) traffic using RF subcarrier multiplexing. However, as the optically modulated RF sidebands are reflected by the FBG and pass through the star coupler, the reflected signal will be broadcasted to all the ONUs, including the ONU sending the LAN traffic. Therefore, the outgoing LAN traffic from the ONU will be interfered due to the bi-directionally transmission of the same wavelength in the same fiber, which will limit the data rate of the LAN traffic. In this paper, we propose and demonstrate a novel internetworking scheme for WDM-PON based on remodulation technique. With the proposed connection pattern of the AWG in the Remote Node (RN), the LAN traffic will be routed optically at the RN without transmitting to the OLT, nor any interference on the existing point-to-point traffic between the OLT and ONUs. By using the channel-shifting input-output property of the AWG in the RN, the LAN traffic among ONUs can be transmitted to all the ONUs except the ONU which the LAN traffic is originated from. Consequently, the data rate of the LAN traffic can be significantly increased up to 1-Gb/s without any interference.

2. System Architecture and Proposed Scheme



ONU	1	2	3	…	N
D	λ_1	λ_4	λ_7	…	λ_{3N-2}
U	λ_2	λ_5	λ_8	…	λ_{3N-1}
L	λ_1	λ_4	λ_7	…	λ_{3N-2}

*Note: D- Downstream wavelength; U- Upstream wavelength; L- LAN traffic wavelength

(a) (b)

Fig1. (a) Proposed internetworking architecture for WDM-PON. RM is the remodulation module; (b) Wavelength assignment plan. Note λ_i (for i=1,…,3N) are the wavelength grid indices, and FSR stands for free-spectral range of 3N×3N of AWG in the RN.

Fig.1 (a) illustrates the architecture of our proposed internetworking optical network for WDM-PON. The wavelength assignment plan for our WDM-PON is depicted in Fig.1 (b). All wavelengths are in the range of one FSR of AWG. The wavelength λ_{3i-2} and λ_{3i-1} (for i=1,…, N) are the downstream wavelength and upstream wavelength of ONU (i). Note that wavelengths λ_{3i} (for i=1,…, N) are not used in our scheme. So at the OLT side, the input ports 3i (for i=1,…, N) of the 1×3N AWG are idle. Each differentially precoded downstream is modulated onto a specific wavelength through an external phase modulator. The RN side consists of a 1× (N-1) star coupler and a 3N×3N AWG. The input port of the 1× (N-1) star coupler is connected to the input port 2 of the AWG, and the output ports i (for i=1,…, N-1) of star coupler are connected to the 3(i+1) input ports of AWG. For each ONU, there are 3 fiber links connected to three consecutive output ports of the AWG, respectively being the downstream link, upstream link and LAN traffic link. The fiber coupler in each ONU is used to split the downstream signal. Part of the signal is fed into the DPSK receiver to detect the downstream data. The rest of the signal is remodulated by the re-modulation module, such as injection locking of FP-Laser. A 1×2 coupler is used to let the LAN traffic signal and outward upstream signal share the upstream link. The differential phase shift keying (DPSK) downstream signal is used to be re-modulate to become the LAN traffic signal and therefore the LAN traffic wavelength is the same as the downstream wavelength. In [3], the FP-laser was demonstrated to directly remodulate signal up to 2.5-Gb/s, with injected power can be as low as -14 dBm. It was also found that the use of optical DPSK modulation format for downstream can substantially suppresses the crosstalk between downstream and re-modulated signal. DPSK modulation suffers less nonlinear distortion during transmission due to its constant-intensity nature. Thus it can improve the system power budget for our scheme.

The routing principle of our proposed internetworking scheme will be demonstrated in this part. As depicted in Fig.1 (a), the LAN traffic wavelength is the same as the downstream wavelength for each ONU. However, the LAN traffic signal is fed into the output port next to the downstream port. Due to the channel-shifting input-output property of the AWGs, the LAN traffic signal is delivered to the input port 2 of the 3N×3N AWG and then fed into the 1×(N-1) star coupler. The LAN traffic signal power will be divided into (N-1) parts. Each part will be transmitted to the respective input port of AWG such that the LAN traffic signal will be broadcasted to the other ONUs in the network. Take ONU (i) as an example, the designated downstream wavelength and upstream wavelength are λ_{3i-2} and λ_{3i-1}. When ONU (i) needs to broadcast its LAN data to other ONUs, the downstream wavelength λ_{3i-2} will be re-modulated by the LAN data using the injection-locking of FP-laser. The re-modulated LAN signal is fed into the coupler and transmitted to output port (3i-1) of AWG. Then the AWG will route the LAN signal to the input port 2. The star-coupler connected to this port will tape off the LAN data signal to specific input ports of AWG as mentioned before. Therefore the LAN signal will be distributed to 3j (j=2,…, N) input ports. Due to the channel-shifting input-output property of AWGs, the LAN wavelength λ_{3i-2} incident on input port 3j (j=2,…, N) will be routed to output ports 3(i+j) mod 3N (j=1,…,N-1). Note that the output ports 3k (k=1,…, N) are designated to the LAN traffic link of ONU(k). So the LAN traffic signal of ONU (i) will be received by other ONUs except ONU (i) itself. Each ONU can use a broadband photodiode to receive the LAN traffic wavelength within the FSR. Because the LAN traffic signal and the upstream signal are transmitted in different wavelength and fiber links, the transmission synchronization protocol can be different between the LAN data and upstream data. Consequently, the LAN data synchronization protocol can be based on CSMA/CD or TDMA.

3. Experiments and Results

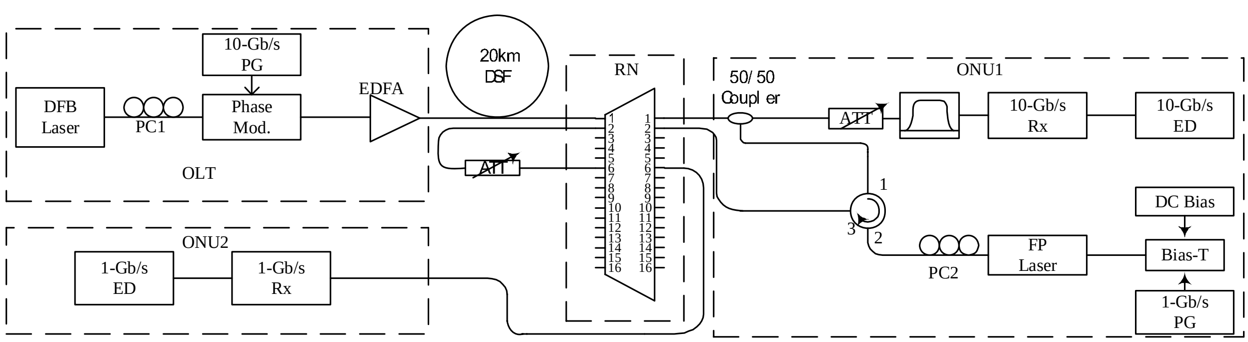
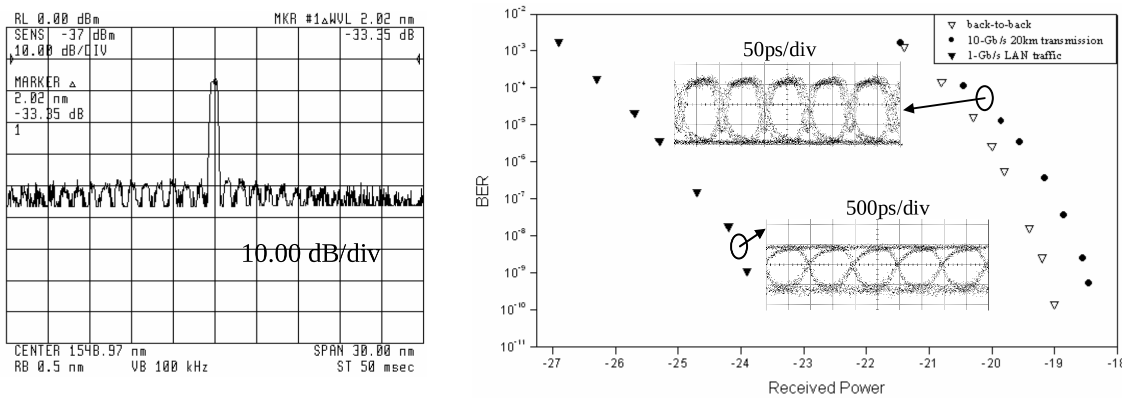


Fig.2 Experimental setup, PG - pattern generator, ED - error detector.

We have experimentally investigated the transmission performance and LAN traffic performance of our proposed scheme on one particular wavelength channel. Fig.2 is the experimental setup. At the OLT side, a DFB laser was externally modulated with a 10-Gb/s NRZ 2^{31}-1 pseudorandom binary sequence (PRBS) to form the downstream optical DPSK signal. The differential precoder can be omitted when a PRBS sequence was used here. The data rate for downstream channel was 10-Gb/s with DPSK modulation format. The data rate for the LAN traffic channel was 1-Gb/s. A 16×16 AWG with 100-GHz channel spacing and an FSR of 12.8nm was used for the RN. And the attenuator was used to simulate the star coupler as shown in Fig.1 (a). Here we assumed that the scheme had 8 ONUs. So we set the loss of attenuator was about 10dB nearly the same as the 1×8 star coupler. At the OLT side, an EDFA was inserted in front of the AWG in order to compensate the components' insertion losses and to achieve the required transmitted power. At the ONU side, the received downstream signal was splitted by a 50/50 fiber coupler. One part of the downstream signal was directly injected into an FP laser diode via an optical circulator and a polarization controller. The optical circulator was used to separate the reflected and injection-locked re-modulated signal from the downstream signal. Fig.3 (a) shows that the SMSR of the FP-LD improved to 33.35 dB and the measured output power was about -1.1dBm. The rest of the received signal was fed into a DPSK demodulator for downstream data demodulation. The demodulated downstream data was detected by 10-Gb/s pin receiver. We used a 10-Gb/s error detector (ED) for bit error rate (BER) evaluation. Respectively the re-modulated LAN signal was detected by 1-Gb/s APD receiver and a 1-Gb/s error detector (ED) was used for the LAN traffic signal bit error rate (BER) measurement.



(a) (b)

Fig.3 (a) Output optical spectra of the FP-Laser; (b) BER measurement.
Inset: corresponding eye diagrams for 10-Gb/s DPSK downstream and 1-Gb/s LAN traffic.

We have also measured the bit error rate (BER) performance of both 10-Gb/s DPSK downstream at the ONU1 and 1-Gb/s remodulated LAN signals at the ONU2. Fig.3 (b) shows the measurement results. The induced power penalty of 10-Gb/s DPSK downstream was only about 0.5dB compared to the back-to-back measurement. Such penalty was due to chromatic dispersion of the fiber. The insets in Fig.3 (b) show the received eye diagram of the transmitted downstream signal at ONU1 and re-modulated LAN signal at ONU2. They all showed clear eye openings. Therefore, this result shows that error-free operation was achieved for both the LAN traffic and the downstream data.

4. Conclusion

We have demonstrated a novel internetworking scheme for WDM-PON. By remodulating the downstream DPSK with the LAN traffic signal and using the channel-shift property of AWG, the LAN traffic will be routed optically at the RN without transmitting to the OLT. We experimentally demonstrated the proposed scheme with good signal quality for both 10-Gb/s downstream DPSK downstream signal and 1-Gb/s LAN traffic signal. This project was partially supported by a research grants from Hong Kong Research Grants Council (Project CUHK4216/03E).

5. References

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