Design of a hybrid PON system for GPON Reach Extension on the basis of colorless DWDM-PON and 3R Regenerator

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Abstract—This paper proposes a hybrid passive optical network (PON) system based on a dense wavelength division multiplexing-PON (DWDM-PON) and reach extender (RE) for increasing the optical link budget and link capacity in an existing gigabit PON (GPON) system. A DWDM-PON is applied to the feeder fiber and is interfaced with the RE. The RE provides a wavelength conversion between the DWDM-PON and GPON through frame regeneration, and controls upstream burst signals. The hybrid PON system enables a legacy GPON system to operate over a minimum 40 km distance with a 128-way split per WDM wavelength.

Keywords-Hybrid-PON; Long Reach GPON; Reach Extender; Colorless DWDM-PON;

I. INTRODUCTION

A GPON is one of the fastest access technologies currently attracting market interest. GPON consists of an optical line terminal (OLT) at the central office (CO); an optical distribution network (ODN) including a passive splitter connected via a common feeder fiber; and an optical network unit (ONU) at the subscriber’s location. A GPON can reduce capital expenditures (CAPEX) and operational expenditures (OPEX) much more than other access technologies because no active components are used. Current commercial GPON systems can only support a maximum distance of 20 km on a 64-way split. Thus they require many COs in order to cover the entire area of a broadband access network. Also, many operators have recently considered a consolidated CO to reduce the operational expenditures of their access network and simplify their network architecture [1], [2], [3]. In addition, operators hope to apply WDM technology to the feeder fiber as a means of increasing their link capacity, and research on integrating a WDM with a time division multiplexing-PON (TDM-PON) is being conducted [4], [5]. Therefore, a hybrid PON system as a reach extension technology for existing GPON is required. The standard for a GPON optical reach extension was ratified by ITU-T G.984.6 in 2008. This standard includes the architecture and interface parameters for GPON systems with extended reach using a physical layer mid-span extension between the OLT and ONU that uses an active device in the remote node (RN). The GPON reach extender allows operation over as much as 60 km of fiber, with split ratios as high as 1:128. Such higher split ratios can reduce the cost per subscriber for PON systems [6]. Therefore, using a newly developed 2.5Gbit/s colorless 32-channel DWDM-PON based on a reflective semiconductor optical amplifier (RSOA) and the reach extender, we have designed a hybrid PON system that has over a 40 km reach and accommodates a maximum of 4,096 subscribers on a single feeder fiber. Our RE provides OEO conversion, upstream burst signal detection, and remote management via physical layer OAM (PLOAM) and ONU management and control interface (OMCI) messages. As in [7], our system is also designed in dual-port architecture by utilizing an FPGA (XC5VLX-30T) for lower cost than in OA-based solutions. Moreover, according to G.984.6 standard, our system can also operate as an OEO-based reach extender.

II. THE PROPOSED HYBRID PON SYSTEM

Fig. 1 shows an idealized geographic distribution of COs when a legacy GPON and hybrid PON are applied in an access network. The maximum physical distance of a legacy GPON is 20 km due to its optical power budget.

![Figure 1. Distribution of COs in an access network using a (a) legacy GPON and (b) hybrid PON](image-url)
The hybrid PON system designed in this paper can support a physical distance of 40 km and accept 4,096 subscribers per single feeder fiber.

III. EXPERIMENTAL SETUP AND RESULTS

The experimental setup used for a performance measurement of the proposed hybrid PON system is shown in Fig. 3. An SFP type DWDM-PON OLT transceiver is directly installed into the PON port on a legacy GPON OLT system. For configuration of the DWDM-PON system, along with a C-band broadband light source (BLS), we use a 2-channel C-band MUX/DEMUX module including two circulators and 2-channel C-band AWG, each with 100GHz spacing based on a thin film filter. The reach extender is connected to GPON ONTs via a 10 km single mode fiber (SMF) spool, and a 1:4 optical splitter followed by a 1:32 optical splitter. We also connect the GPON link using an optional 50 km SMF spool between the GPON OLT and RN [11]. The GPON transceivers used are Class B+ commercial products.

In this experiment, we used C-band wavelength signals of 1555.04 nm and 1559.79 nm. The output power of the DWDM-PON OLT transceiver is adjusted to 0 dBm using the BLS. The output power of the DWDM-PON ONT transceiver ranges from -5 to 2 dBm depending on the injection of downstream light. The RSOA-based DWDM-PON uses a modulated downstream signal as a seed light for an upstream transmission. In this experimental setup, the total insertion loss is about -11 dB for a downstream transmission and -10 dB for an upstream transmission respectively.
Fig. 4 shows eye-patterns measured at each test point (TP) of the experimental setup for the hybrid PON system. The hybrid PON system performs signal recovery via the OEO-based reach extender, and this recovery signal is recovered again at the GPON ONT. Nevertheless, we can confirm that the eye-diagram output (TP2) at the RN is decreased compared with the eye-diagram received (TP3) at the RN with roughly 11 ps of jitter through 3R regeneration. TP4 includes a signal based on re-modulation in the DWDM-PON ONT transceiver.

Fig. 5 shows the results of a wavelength conversion between the DWDM-PON and GPON through the reach extender. In the feeder fiber, the 1490 nm wavelength signal for a GPON downstream is converted into a C-band wavelength signal of 1535.04 nm via the DWDM-PON OLT. A reflective 1535.04 nm wavelength signal from the DWDM-PON ONU transceiver in reach extender is converted into a 1310 nm wavelength signal for the GPON upstream.

To verify the transmission performance of the hybrid PON system, we measured the packet loss rates (PLRs) using Ethernet packets with random lengths ranging from 64 to 1518 bytes. For measurement of the downstream PLRs, we transmitted 1Gbit/s traffic to each GPON ONT through the GPON OLT, while we assigned 250Mbit/s traffic at each GPON ONT for measurement of the upstream PLRs.

Fig. 6 shows the PLR measurement results at one GPON ONT for the downstream transmission performance according to the optical power received at the RE based on the VOA1 attenuation value. The figure also shows the PLR measurement results according to the forwarding error correction (FEC) and wavelength band. In this experiment, the proposed hybrid PON system satisfies a PLR of $10^{-10}$ up to -25 dBm using a 1559.79 nm wavelength, as well as -27.5 dBm with a 1535.04 nm wavelength when FEC is used.

This means that a short wavelength is more efficient than a long one. If downstream FEC is not used for a long wavelength, only PLR of about $10^7$ can be provided. Thus, downstream FEC is necessary for a hybrid PON system with packet loss free. Fig. 7 shows the PLR measurement results for an upstream transmission performance according to the optical power outputted at the DEMUX based on the VOA2 setting. We also measured the PLRs according to the injection power as well as upstream FEC. The injection power utilizes a downstream optical signal as a seed light for upstream transmission. As a result, we can achieve a PLR of $10^{-9}$ up to received optical power of -31 dBm at the DWDM-PON OLT transceiver when the injection power is -11 dBm. However, a 32-channel DWDM-PON link requires a power budget of about -17 dBm for a 20 km transmission due to use of the AWG-based MUX/DEMUX. The dotted line in Fig. 7 shows that the proposed system provides a PLR of $10^{-9}$ up to -23 dBm. This means that a 32-channel colorless DWDM-PON link can be applied to the proposed hybrid PON system providing a PLR of $10^{-9}$. Upstream FEC is also necessary for packet-lossless service.

Fig. 8 shows the PLR measurement results for a 60 km GPON reach extension. Using a GPON link in the feeder fiber, we confirmed that the proposed system satisfies a PLR of $10^{-10}$ in upstream and downstream transmissions up to -30dBm, -29 dBm respectively. This is superior to the optical amplifier (OA) based RE in [6] with loss budget of about 5 dBm.
If the received optical power is below -31 dBm, the reach extender may detect bit interleaved parity (BIP) errors, causing a loss of upstream packets from an inaccurate burst reset control. However, the reach extender provides a packet loss free in a downstream transmission up to -33 dBm due to the error correction feature in the GPON ONT.

IV. CONCLUSION

We have developed a hybrid PON system by utilizing an RSOA-based DWDM-PON and OEO-based reach extender on the feeder fiber in order to provide a reach extension for a legacy GPON system and an increase of link capacity. Our proposed hybrid PON system can support a PLR of $10^{-9}$ during upstream and downstream transmission at a distance of 40 km on a 1:128 split ratios. We also found that a legacy GPON system can support 60 km reach with a 1:128 split ratios and a 59 dBm power budget when the reach extender is used according to the G.984.6 standard. Currently, the cost of DWDM-PON components is still expensive. However, this technology is applied to a long reach feeder fiber, and thus it can reduce fiber cost and be configured efficiently in a green network using a consolidated CO.

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REFERENCES