Frame-level OEO-Regenerating GPON Reach Extender

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Abstract: We propose and experimentally demonstrate a frame-level OEO-regeneration technique for GPON reach extension which overcomes the limitations of bit-level OEO-regeneration with respect to upstream efficiency and transparency.

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1. Introduction

Passive optical networks (PONs) are the FTTx architecture of choice for network operators worldwide due to the low cost, low maintenance, and high reliability of the passive network elements involved. ITU-based GPON is one of the two prevalent PON implementations, the other being IEEE-based EPON. GPON supports a bit rate of 2.488 Gbps in the downstream (DS) direction and 1.244 Gbps in the upstream (US) direction. For a given GPON, the maximum reach (OLT to ONU physical distance) and the maximum split ratio (number of ONUs on the PON) are limited by the transceivers at the OLT and ONU. Although the GPON transmission convergence (TC) layer specification allows for a maximum reach of 60 km and a split ratio of 128, commercially available GPON Class B+ [1] transceivers, which support a 28-dB link budget and represent current state of the art, allow operators to realize a reach and split at best of up to 32 splits at 20-km reach or 64 splits at 10-km reach. While the ITU has also specified the Class C+ transceivers [2], they are useful only in specific scenarios since they offer only a marginal 4-dB improvement over Class B+ and also mandate use of Forward Error Correction (FEC).

The limited reach and split ratio realizable with current GPON systems constrains operators from leveraging PONs to their fullest economic benefits, especially in sparse subscriber take-ups (e.g., rural areas). It also leads to inflexible and non-optimal network architectures (e.g., requiring a higher than optimal number of central office (CO) locations to serve a given population) [3], which increase capital and operating expenditures. Driven by these constraints, operators have identified the need for a PON reach extender (RE) network element that resides between the CO and ONUs and enables the operators to achieve a higher number of subscribers and/or a longer reach from the CO than possible otherwise. GPON reach extension has been standardized in ITU Recommendation G.984.6 [4].

A GPON RE system can in general be realized using the technique of optical amplification (OA) or optical-electrical-optical (OEO) regeneration, each with unique pros and cons. OA-based REs operate at the optical layer and simply amplify the received optical signal, while OEO-based REs (OEO-REs) perform optical-to-electrical conversion of received optical signal into a bit stream, perform 3R (regenerate, reshape and retime) or 2R (regenerate and reshape) regeneration of the bit stream, and finally perform electrical-to-optical conversion of the regenerated bit stream. GPON OEO-REs employing bit-level regeneration are faced with special challenges due to the way GPON upstream works, as described below.

The GPON US direction employs TDMA and operates in burst mode, with the OLT scheduling, in a tightly controlled manner, the bursts from the ONUs by specifying the *Start* and *Stop* pointers in the Bandwidth-map field (BWmap) [5] in the DS frame. Since the dynamic range of the US bursts' signal level at the OLT receiver can be as high as 15 dB [1], US bursts are prepended with preamble bits which are used for training by the US receiver to (re)adjust the clock phase and decision threshold for a new burst. Due to the need in GPON to perform the latter two operations within a few bit periods, the MAC function of most commercial OLTs uses precise knowledge of burst arrival times to assert a reset signal to the CDR device and the transceiver just before a burst's expected arrival.

The US receivers of OEO-REs using bit-level regeneration cannot perform the above two operations since they do not know the burst arrival times upfront. While these REs can employ burst-acquisition mechanisms such as signal detection, these mechanisms are slow and require longer guard time (between bursts) and preamble, which reduces the US bandwidth efficiency and makes the RE non-transparent to the OLT. Another drawback with bit-level OEO-REs is consumption of some of the preamble bits by the RE US receiver, which also necessitates the OLT to allocate extra preamble bits for extended PONs. This also reduces US bandwidth efficiency and makes the RE non-transparent to the OLT. Some OEO-RE implementations restore lost preamble bits by searching for the fixed delimiter pattern in the receiver bit stream and reinserting them relative to the pattern. This method, however, is error prone since the delimiter pattern can appear as part of the data bits, and also increases operator overhead since the delimiter size and pattern can vary and are determined by the OLT.

This paper proposes an improved OEO-RE technique, which we refer to as *frame-level OEO-regenerating RE (FR-RE)*, that operates at the GPON TC layer, and regenerates GPON frames, both in the DS and US directions. With the ability to decode GPON DS frames, including the BWmap and PLOAMd fields, the FR-RE overcomes the drawbacks of the bit-level OEO-REs, while also enabling additional capabilities, as discussed later in the paper.

2. Frame-level OEO regeneration

A high-level block diagram of the FR-RE prototype that was implemented in this work is illustrated in Fig. 1. In addition to the processing blocks that exist in bit-level OEO-REs, the FR-RE comprises two new blocks, viz. the DS and US frame regeneration (DS-FR and US-FR) blocks, which were implemented using an FPGA and serializer / deserializer hardware. The DS-FR block de-serializes received DS bit stream, and recovers and decodes the DS frames to determine key US control information including: pattern and size of the preamble and delimiter, pre-assigned delay, ONU equalization delay (eq. delay), and the Start and Stop pointers in the BWmap field. The DS-FR block finally serializes the frames, which are then retimed and transmitted to the ONUs.

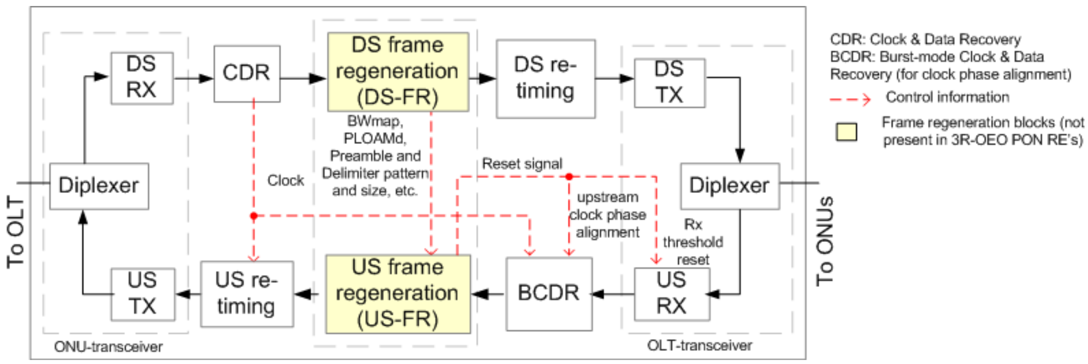

Fig. 1: Frame-level OEO regeneration

In order to determine the US burst arrival times, the FR-RE first needs to determine the start, from its own view point, of the US frame relative to the DS frame's arrival time. We refer to this time delta as the *Sync delay*, which is equivalent to the OLT's Zero-distance eq. delay (Teqd). The FR-RE employs the procedure shown in the left half of Fig. 2, during the ranging of the first ONU, to determine the Sync delay based on the round trip delay from FR-RE to that ONU and the eq. delay assigned to that ONU by the OLT[*]. Subsequently, the FR-RE applies the decoded Start and Stop pointer values relative to the US frame start time, as shown in the right half of Fig. 2, to determine the expected burst arrival times and accordingly assert the reset signal to the US RX and BCDR. After it delineates and receives the upstream bursts, the US-FR block de-serializes them, restores lost preamble bits, and finally serializes the bursts, before they are re-timed and transmitted to the OLT.

Besides overcoming the shortcomings of the bit-level OEO-REs, frame-level regeneration in the FR-RE enables accurate per-burst optical power measurements and the following additional capabilities that improve the OLT-ONU end-to-end link performance: correction and re-encoding of FEC-encoded payload, and repair of the delimiter pattern and PSync (physical synchronization) downstream field.

3. Experiments and results

The setup shown in Fig. 3a was used to study the performance of the prototype FR-RE system that was used in this work, shown in Fig. 1. The variable optical attenuators VOA-1 and VOA-2 were used to adjust the trunk and access optical budgets, respectively. Bidirectional Ethernet flows were setup between the OLT and ONUs. The OLT uses a short 64-bit preamble. The trunk vs. access optical loss budget operating contour was plotted for an end to end (OLT-ONU) system BER of 10^{-10} between the OLT and ONUs, representing all usable combinations of trunk and access loss values meeting 10^{-10} BER. The BER was measured using Ethernet frame loss as measured and reported by an Ethernet test set. As shown in Fig. 3b, the FR-RE system is compatible with both Class B+ and Class C+ budgets on the access side, and enables the latter to be extended by a wide 6-31.5 dB trunk budget. This allows a GPON reach of 60 km at 128 splits, and CO consolidation by allowing an existing Class B+ or C+ OLT-port (e.g., in a remote-OLT) to be replaced with a RE which is connected to an OLT port that can be located as far away as 60 km from the RE. Furthermore, no trunk-access loss interdependence for a wide 6-31.5 dB trunk budget range and 13-33 dB access budget range (shaded area in the figure) allows flexible placement of the FR-RE in the network.

[*] The Sync delay of the FR-RE is same for bursts from all ONUs since the US frame start time at the FR-RE precedes the OLT's Teqd value by a fixed duration. Also, the first ONU can be the embedded management ONT within the FR-RE [4].

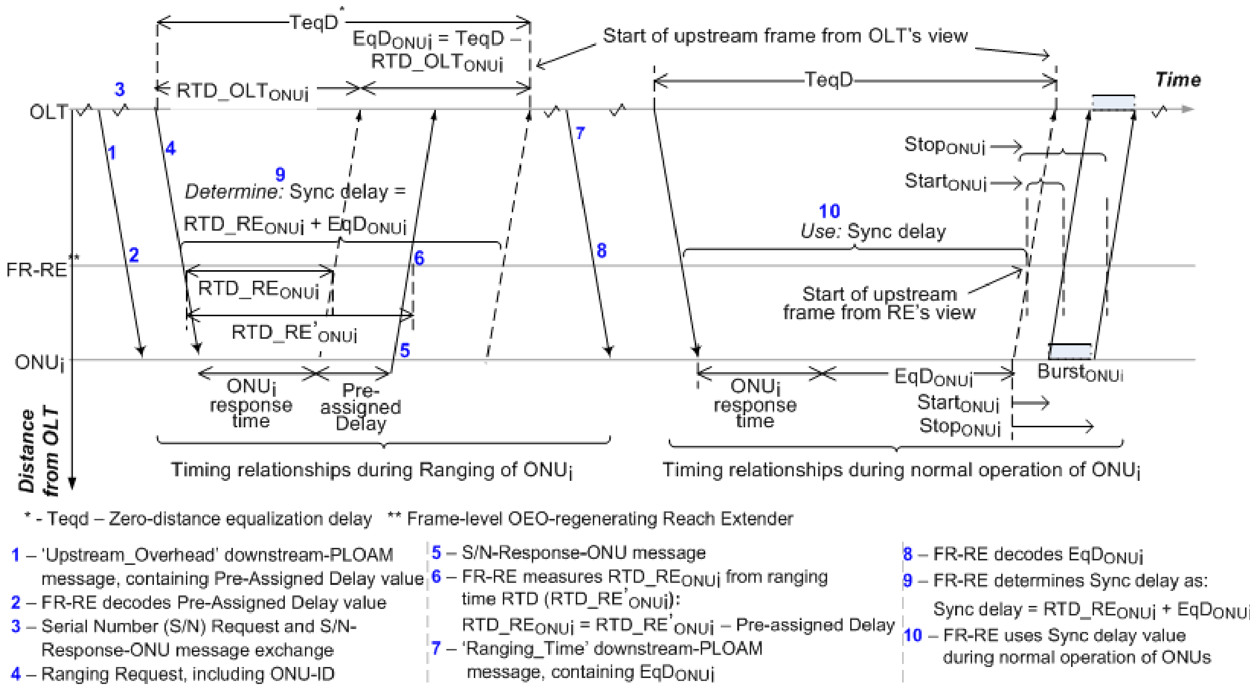

Fig. 2: Frame-level regeneration timing relationships

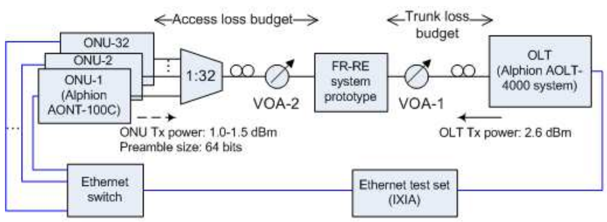

Fig. 3a) Experimental setup

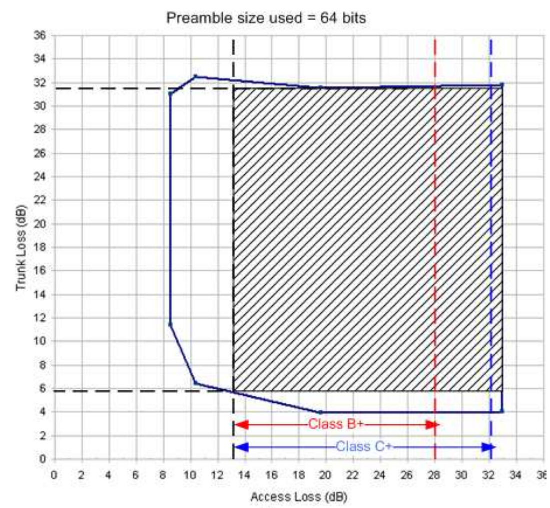

Fig. 3b) BER=10^{-10} operating contour plot

4. Conclusion

We have experimentally demonstrated a frame-level OEO-regeneration technique for GPON reach extension that overcomes the limitations of bit-level GPON OEO reach extenders with respect to upstream efficiency and transparency. The frame-level regenerator uses minimal inspection of downstream frames to determine upstream burst arrival times. We have presented a 10^{-10} BER contour plot of trunk and access loss, which shows a realizable 6-31.5 dB trunk budget and 13-33 dB access budget, allowing a PON reach of 60 km at 128 splits and CO consolidation, even using a short 64-bit preamble. Furthermore, no trunk-access loss interdependence in these ranges allows flexible placement of the frame-level regenerator in the network.

5. References

[1] ITU-T G.984.2 (2003)-Amendment 1, Industry Best Practice for 2.488 Gbps downstream and 1.244 Gbps upstream G-PON, Feb. 2006.
[2] ITU-T G.984.2 (2003) – Amendment 2, PMD layer specification, March 2008.
[3] R P.Davey, et al. "Long-Reach Passive Optical Networks," in J. Lightwave Tech., VOL. 27, NO. 3, Feb. 2009, pp. 273-291.
[4] ITU-T G.984.6 – GPON reach extension, March 2008.
[5] ITU-T G.984.3, GPON Transmission convergence layer specification, March 2008.