Transmission Convergence Layer Analysis of Passive Optical Networks with a Novel FPGA Card

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ABSTRACT

Passive optical networks play an important role in access networks and in current 5G networks. Passive optical network (PON) recommendations are published for two sectors by the Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunication Union (ITU), covering transmission speeds from 1 to 100 Gbit with wavelength division multiplex (WDM). The recommendations of the ITU define different encapsulation methods for the Ethernet frame, and meeting these recommendations necessitates new tools for control and data transmission. We present a downstream frame bandwidth field analysis for the simple topology of an XG-PON with 2 ONUs. The main purpose is to prove that the current access networks do not rely only on Ethernet frame transmission.

Keywords: XG-PON, FPGA, OLT, ONU, Data processing, Parser

1. INTRODUCTION

As the popularity of online services grows, the demands for high-speed transmission rates in access networks increase year by year.[1] During the COVID pandemic, stable-connection and low-latency networks were used more often .[2] Passive optical network (PON) recommendations are published for two sectors by the Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunication Union (ITU). The current recommendations focus on 10 Gbit to 100 Gbit.[3] 100 G is obtained by four different wavelengths with 25 Gbit.[4] Research papers have addressed the physical layer of PON recommendations, such as the modulation format, line code, and reach of the system. We present a complex solution for real-time control data processing of a 10 Gigabit-capable symmetrical passive optical network (XG(S)-PON). The transmission convergence layer of the PON has been discussed according to implementation, but our purpose is to implement the frame structures and apply them to our self-developed field programmable gate array (FPGA).[5]

2. MEASUREMENT SCHEME

The paper proposes an XG-PON analysis system consisting of a transmitting frame interceptor and a software analyzer. A schematic diagram is shown in Figure 1a. The interceptor is highlighted in green, where the XG-PON frames are eavesdropped using a 2-by-2 3 dB coupler to capture both upstream and downstream directions. Both captured signals are converted from the optical domain to binary using a newly designed FPGA-based network interface card. The rest of the system performs software analysis and is highlighted in yellow. The proposed newly designed FPGA card is shown in Figure 1b. There are 4 SFP+ cages on the motherboard with the possibility of connecting optical network units (ONUs) and optical line termination (OLT) units for the GPON, XG-PON and XG(S)-PON standards, including combinations of them. The downlink and uplink must be connected to the board separately. The individual directions can also be analyzed independently, and in particular, for the downstream direction, it is not necessary to have information about the distribution of time windows sent by the individual ONUs. A peripheral component interconnect express (PCIe) interface for data transfer between the Jetson module and the FPGA and a nonvolatile memory express (NVMe) connection to the

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Jetson module are used. The Jetson module is wired as a PCIe Gen4 root point for speeds up to 16 Gbps and provides various combinations of controller wiring widths of ×8, ×4, ×2, and ×1. The FPGA PCIe endpoint enables the maximum transfer rate according to the Gen3 specification.

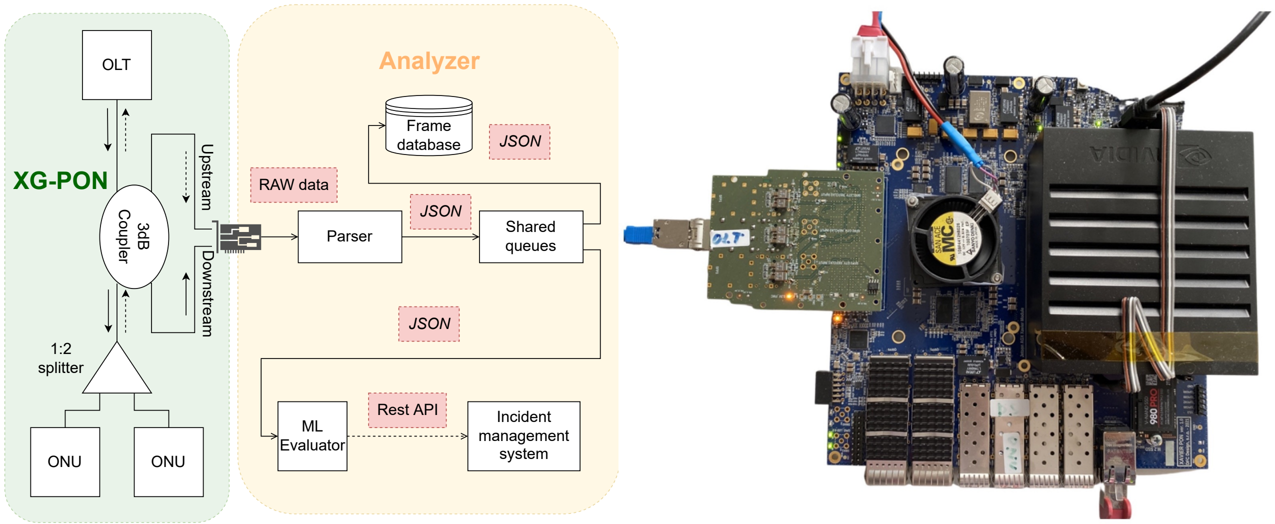

Figure 1: (a) Schematic diagram of the proposed analyzer deployed in a real XG-PON. (b) Newly designed FPGA-based network interface card used for XG-PON frame capturing.

3. MEASUREMENT RESULTS

The results of data processing are shown in Table 1. The allocation identifier (Alloc-ID) represents the unique ONU identifier (ONU-ID). The first value of Alloc-ID equals ONU-ID, and ONU-ID is obtained for OLT during the activation process.[6] The first column contains the unique identifiers of Alloc-ID (14336, 10, 2570, 3082, 14337, 9, 2569, and 3081). Based on these values, it is possible to determine the number of unique ONU-IDs (9 and 10). Values higher than 1024 are reserved if more than a single Alloc-ID is needed for an ONU, for example, if the ONU handles more transmission containers (T-CONT). An ONU can report buffer occupancy if a flag bit is present; if not, the dynamic bandwidth report upstream (DBRu) is not transmitted. The next column identifies the StartTime of upstream transmission (bit expression). The GrantSize field contains a 16-bit number for the total length indication of the XGTC payload with the DBRu field. GrantSize should be 0 during the activation process of the physical layer operation administration and maintenance (PLOAM) grant only. The forced wake-up indication (FWI) field indicates forced ONU wake-up if a bit is present. In our case, FWI is 0, which means that the ONUs are not in low-power mode. Burst Profile indicates the index of a burst profile on the OLT side. The last column represents the hybrid error correction (HEC) field of the frame.

Table 1: BWmap allocation for separate Alloc-IDs.

	Alloc-ID	**Flags**	**StartTime**	**GrantSize**	**FWI**	**Burst Profile**	**HEC**
1	0x3800	0x00	0x0000	0x0001	0x00	0x00	0x1D9F
2	0x000A	0x00	0x002F	0x0005	0x00	0x01	0x0D10
3	0x0A0A	0x00	0xFFFF	0x03D1	0x00	0x01	0x0E72
4	0x0C0A	0x02	0xFFFF	0x0002	0x00	0x01	0x1D9E
5	0x3801	0x00	0x04AB	0x0004	0x00	0x00	0x009D
6	0x0009	0x00	0x04C1	0x0014	0x00	0x01	0x1500
7	0x0A09	0x00	0xFFFF	0x0F42	0x00	0x01	0x0187
8	0x0C09	0x02	0xFFFF	0x0005	0x00	0x01	0x123A

4. CONCLUSION

The proposed system is capable of dealing with real-time data analysis of passive optical networks. The downstream generates data at up to 10 Gbit/s with 125 μs frame durations. The ONUs receive all data due to the point-to-multipoint (P2MP) topology but process only data with matching ONU-IDs. The remaining data are dropped. The final solution is capable of extracting unique fields of the frame (BWmap allocation, control messages, etc.).

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