DSP Enabled Next Generation Flexible PON for 50G and Beyond

Borui Li[1], Derek Nesset[2], Dekun Liu[3], Zhicheng Ye[1], and Liangchuan Li[3]
(1) Access Optical Technologies Lab, Optical Business Product Line, Huawei Technologies Co.,Ltd. China
(2) Munich Research Centre, Huawei Technologies, Riesstrasse. 25, 80992, Munich, Germany.
(3) Optical Research Department, Optical Business Product Line, Huawei Technologies Co.,Ltd. China
liborui@huawei.com

Abstract: In fiber access, DSP is used for the first time in the ITU-T 50G-PON. Here, we review the benefits of DSP in enabling more flexible PON systems today with 50G-PON and into the future. © 2022 The Author(s)

1. Introduction

With the successful, wide-scale deployment of 10G-PON already under way, in 2018, the ITU-T started the Higher Speed PON project. This project accomplished a significant milestone in 2021 with the consent of a complete suite of recommendations for 50G-PON [1, 2]. Compared with what has gone before with GPON or 10G-PON, 50G-PON takes a big step forward for PON technology. DSP, as a powerful tool, plays a key role in the Higher Speed PON standards advancement.

Previous PON systems were specified in simple terms by the respective transceivers capability to satisfy the physical layer interoperability requirements like extinction ratio (ER), eye mask, optical path penalty (OPP) and output power. While, at the higher line rates of 50G-PON, the situation is more challenging. The trade-offs in the key optical components between the bandwidth and efficiency becomes more pronounced, especially in the case of PON systems [3, 4]. DSP techniques can help balance this trade-off and enable PON transceivers to be implemented in a flexible way.

50G-PON is a giant step compared to 10G-PON. The leap in capacity will enable the system to meet a wider range of emerging applications, like campus, industrial networks and x-haul. New KPIs such as low latency or smarter monitoring functions could be realized with the aid of DSP [5, 6]. Furthermore, in recent years, the flexible PON system beyond 50G received significantly more attention. Whether we think about flexible modulation formats such as DMT or flexible multiplexing methods we see DSP as a key enabler [7-9].

In this paper, we share views on the benefits of DSP for fiber access in aspects of flexibility for the next generation 50G-PON and beyond.

2. Flexible transceiver implementation

PON transceiver implementation is very important to guarantee the physical layer interoperability for network operators. Each new generation of PON deployment relies on the advancements in transceiver technology. In the past, the combination of ER, eye mask, output power and OPP provides the main constraints to the transmitter (Tx) implementation [10]. The 10G-class device progress helps avoid any physical layer interoperability problems. However, for 50G-PON, overlaid with the already installed optical distributed network (ODN), the power budget is very challenging.

The path penalty for 50G NRZ from the laser chirp and fiber dispersion interaction can’t be so easily controlled as before. Furthermore, with the bandwidth increase, the efficiency of optical active devices generally reduces, no matter whether we consider the gain of the detector (APD) or the output power (and modulation efficiency) of the Tx [11]. The current commercial 50G-class devices struggle to meet the PON system requirements. Many studies have shown that using 25G-class optical components, with DSP enabled receiver-side (Rx) equalization, can be effective in realizing high 50Gbps NRZ link budgets. These factors make the conventional PON Tx specification method seem too rigid and less appropriate. A new Tx metric is proposed, as transmitter and dispersion eye closure (TDEC) [12]. TDEC can capture the Tx penalty at back-to-back condition and OPP after fiber transmission no matter whether a 25G or 50G-class Tx is used. Then, we can use the “OMA minus TDEC” to define a compliant Tx [13]. This gives flexibility to the Tx vendors to choose the best technology and determine the minimum Tx OMA based on their achieved Tx TDEC value. For the Rx vendors, they only need to ensure they can meet the sensitivity requirement based on any Tx that can pass the TDEC compliance test. Thus, using DSP helps to maximize implementation flexibility, maintain a versatile supply chain and still guarantees the physical layer interoperability.

At the Rx, DSP can provide additional benefit in meeting the power budget challenge. For 50G-PON, the low-density parity check (LDPC) FEC code is adopted to improve the Rx sensitivity. By providing the linear equalizer's output or MLSE output through the BCJR algorithm to the LDPC input, a better coding gain can be realized [14].

Motivated by the above considerations, we built a first real-time 50G-PON prototype in a commercial PON chassis as shown in Fig. 1. With 50Gbps downstream and 25Gbps upstream, this prototype demonstrated all the key features of a 50G-PON system, such as ONU activation and ranging, in the China Telecom Lab trial [15].

Figure. 1: real-time 50G-PON prototype in the form of commercial chassis

3. Emerging PON applications

As the last mile to subscribers, PON's point to multi-point (P2MP) architecture is expected to flexibly handle a multitude of different services. On one hand, the passive optical local area networks (POL) market, is already served by TDM-PON, especially for the wireless router backhaul link. With the adoption of multi-user MIMO, higher order QAM and OFDMA techniques, the WiFi6 backhaul capacity is rapidly increased. The 10G-PON couldn't carry several ceiling type WiFi6 routers. On the other hand, XGS-PON is currently supporting 4G mobile fronthaul in some cases which is sensitive to the latency. The typical, mature and commercial method is to allocate multiple burst opportunities per frame for each ONT. However, this will increase the PON protocol overhead and reduce overall throughput. Considering the coming 5G era, there are a number of small cell base stations with larger bandwidth to backhaul transport. Obviously, 50G TDM-PON shows great capacity advantages over 10G-PON. Furthermore, the DSP technique can help 50G TDM-PON satisfy these currently emerging PON applications. A 5G small cell backhaul field trial supported by 50G TDM-PON was demonstrated by China Mobile [16]. The schematic setup is shown in Fig. 2. The system can support multiple end users with more than 1000Mbps download speed. It opens up great opportunities for 50G-PON to flexibly handle different applications with the aid of DSP.

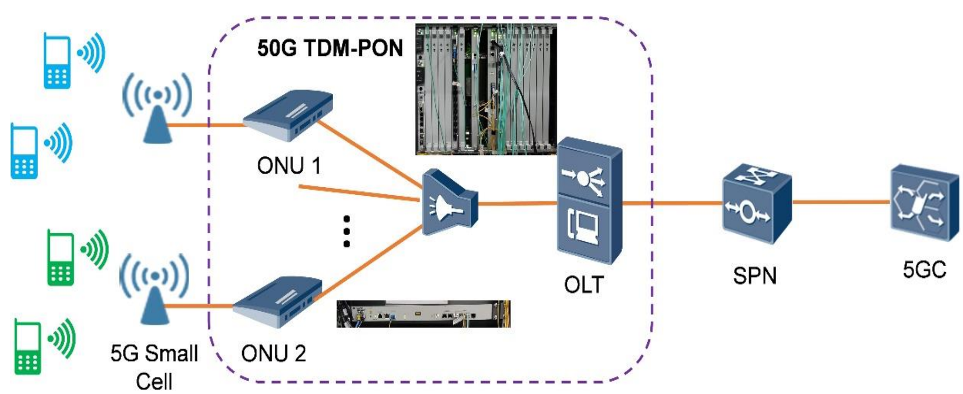

Figure. 2: Schematic of Field Trial of 50G-PON based small cell backhaul [16]

In terms of low latency metric, it's worth mentioning that in [17], a novel method of ONU activation and ranging was proposed. With the low speed signal transmitted from joining ONU's spontaneous emission and handled by the OLT side DSP, the quiet window size can be reduced to only 5µs long, compared with normal 250µs. Although this method has a problem of mutual influence between joining ONU and online ONU, it still shows the DSP's another benefit to realize some specified function according to the scenario requirement.

4. Flexible future PON system

The current PON system's line rate is essentially fixed. With the huge capacity increase, flexible rate is appropriate for the P2MP PON architecture where different users experience different channel conditions that could support different access link capacity [18]. Considering that DSP is already the basis for the coming 50G-PON, there will be considerable scope to build on this in future PON generations to make PON systems more flexible. In [7], a flexible TDM-PON line rate from 33.67Gbps to 88.89Gbps was realized through flexible modulation formats (NRZ and PAM4) and flexible FEC (shortening/puncturing LDPC mother code). In this case, the Rx side digital clock data recovery is the key factor keeping the ONU online and only selecting its own data time slot. To further increase fine granularity, probabilistic and geometric shaping may be utilized, at the risk of further increasing the complexity [8].

From the point of view of flexibility, DMT modulation is a natural choice. In [19], flexible-rate PON achieves the rate adjustment from 25Gb/s to 100Gb/s with a granularity of ~ 50Mbit/s by bit and time slot allocation with the optical power budget varying from 36dB to 26dB. These aforementioned systems show flexible features predicated on the condition of availability exact ONU-OLT link status information. However, the link status is rather complex, and also the current monitoring methods such as the received signal strength indicator (RSSI) are not so accurate. To realize the full benefits of DSP enabled PON flexibility, considerable further research is required concerning the practical issues. One of the key issues for standardization and for network operators is interoperability.

As system line-rates go higher, it becomes increasingly difficult to handle the total capacity. In [9], the frequency dimension is introduced to share the processing burden. Based on the digital sub-carrier multiplexing and flexible assignment of modulation formats and sub-carrier number, 100Gbps flexible rate time-frequency division multiplexing (TFDM) PON system is demonstrated. To process the signal appropriately, coherent detection is necessary and the use of DSP comes naturally and with considerable benefits. Given the challenges already at 50Gbps, it seems that coherent detection is an interesting research direction for PON evolution and flexible features.

5. Summary

The ITU-T accomplished consent of the complete suite of 50G-PON of recommendations in 2021. Although the standard doesn't limit vendor implementations, DSP has clear benefits and can play a key role in such systems. More importantly, DSP can help pave the wave for accelerating the 50G-PON implementation given the current status of optical device performance. Furthermore, such systems may exploit DSP to meet the emerging application requirements. These aspects have also been demonstrated in a world first commercial chassis based 50G-PON prototype. For higher speed PON beyond 50G, DSP seems necessary for transmission and may be used to make these systems more efficient in assigning and processing resources although there is still a lot of research ahead for truly flexible PON.

6. References

[1] Higher Speed Passive Optical Networks, ITU-T G.9804.x Series Recommendations.
[2] D. Nesset, "The Progress of Higher Speed Passive Optical Network Standardisation in ITU-T," in ECOC 2021, paper We3F.1.
[3] M. Huang, et al., "56GHz waveguide Ge/Si avalanche photodiode," in Optical Fiber Communication Conference (OFC) (2018), paper W4D.6.
[4] "Higher Speed Passive Optical Networks: Physical Media Dependent (PMD) Layer Specification," G.9804.3, consented April 2021.
[5] R. Bonk, et al., "Optical Access Networks – From FTTH-Centric to New Use-Cases," Broadband Coverage in Germany, 15th ITG-Symposium, 2021.
[6] T. Pfeiffer, et al., "PON going beyond FTTH," JOCN, 14, A31-A40.
[7] R. Borkowski, et al., "FLCS-PON-A 100Gbit/s Flexible Passive Optical Network: Concepts and Field Trial," JLT, 39, 5314-5324.
[8] N. Kaneda, et al., "First Experimental Demonstration of Flexible Rate PON Beyond 100Gb/s with Probabilistic and Geometric Shaping," in Optical Fiber Communication Conference (OFC) 2021, paper F2H.2.
[9] J. Zhang, et al., "Rate-flexible single-wavelength TFDM 100G coherent PON based on digital subcarrier multiplexing technology," in Optical Fiber Communication Conference (OFC) (2020), W1E.5.
[10] 10-Gigabit-capable symmetric passive optical network (XGS-PON), ITU-T Recommendation G.9807.1.
[11] V. Houtsma, et al., "Transceiver technologies for passive optical networks: past, present, and future," JOCN, 13, A44-A55 (2021).
[12] G. L. Cheminant, et al., "TDEC (transmitter dispersion and eye-closure) method for equalizer-enabled 50G-PON," in ITU-T Q2/15 Meeting (2019).
[13] D. Liu, "TDEC for 50G PON OLT transmitter," in ITU-T Q2/15 Meeting (2021).
[14] B. Li, et al., "DSP enabled next generation 50G TDM-PON," JOCN, 12, D1-D8 (2020).
[15] D. Zhang, et al., "Carrier Lab Trial of a Real Time 50G-PON Prototype," in European Conference on Optical Communication (ECOC) (2021), We3F.5.
[16] N. Wang, et al., "A Field Trial of 50G TDM-PON Based 5G Small Cell Backhaul," in Optical Fiber Communication Conference (OFC) (2022), Tu3F.2.
[17] R. Bonk, et al., "Demonstration of ONU Activation for In-Service TDM-PON Allowing Uninterrupted Low-Latency Transport Links," in Optical Fiber Communication Conference (OFC) (2019), W3J.4.
[18] R. van der Linden, et al., "Utilizing Unused Power Budget to Increase Network Capacity in Practical PON Deployments by Introducing Flexible Modulation," in ECOC 2015, paper P.7.12.
[19] J. Zhou, et al., "First 100Gb/s Fine-Granularity Flexible-Rate PON Based on Discrete Multi-Tone and PAPR Optimization," in Optical Fiber Communication Conference (OFC) (2022), Th2A.23.