The Progress of Higher Speed Passive Optical Network Standardisation in ITU-T (Invited)

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Abstract *The ITU-T initiated a Higher-Speed PON (HSP) project to meet the need to upgrade PON systems beyond the 10Gbps line-rates of today. Line-rates up to 50Gbps are addressed by HSP and the first system to be consented at the ITU-T is 50G-PON.*

Introduction

Largely driven by the growing demand for ever higher broadband speeds, Passive Optical Networks have been deployed on a massive scale for FTTH since the early part of this century. The majority of PON systems deployed have been of the Gigabit-class i.e. GPON (ITU) [1] and EPON (IEEE) [2]. To date, about 700 million subscribers are served by PON globally and this number continues to grow as more operators choose to replace legacy copper based broadband with fibre.

During recent years, network operators have started to upgrade their Gigabit PON deployments to 10G-class PON technologies such as XG(S)-PON (ITU) [3, 4] and 10G-EPON (IEEE) [5]. In fact, it is expected that the annual number of XGS-PON OLTs shipped will overtake GPON OLTs within the next year.

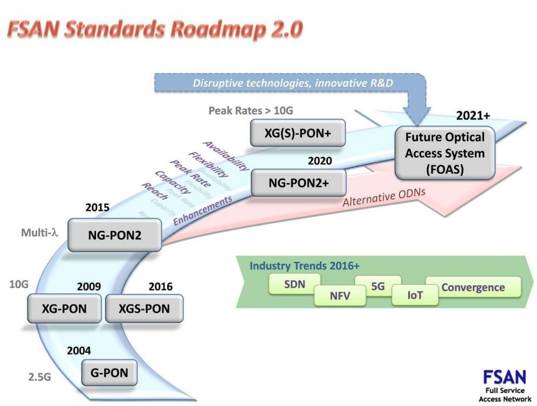

Figure 1: FSAN Roadmap 2.0

This demand for 10G PON systems caught the attention of the relevant standards bodies and they anticipated a need for the next PON capacity upgrade step. FSAN [6] released their updated Standards Roadmap (Fig. 1) in 2016 with >10Gbps standards indicated for the 2020 timeframe [7]. Also in 2016, Question 2 of Study Group 15 in the ITU-T started formally discussing PON technologies beyond 10Gbps. Following this initial study, it was agreed in 2018 to initiate a project to develop PON standards focussed on 50Gbps line-rate. This project was termed Higher Speed PON (or HSP) and addresses TDM, TWDM and PtP WDM PON systems. Based on past experience, the estimated timescale for demand for such a system is around 2025.

This invited paper reviews the Higher Speed PON project and provides a progress update. 50G-PON is covered specifically, as the first completed Higher-Speed PON, along with the key enabling technologies. Future developments of Higher Speed PON are also discussed.

Higher Speed PON in ITU-T

Higher Speed PON Requirements

In addition to pure capacity upgrade, network operators are looking to the HSP project to deliver a system able to meet emerging applications for PON. These include the widely discussed role for PON in mobile xHaul (e.g. 5G) and in industrial, campus and in-building networks. Some new requirements emerging from these applications include lower latency and enhanced security.

As for previous generations of PON, HSP must operate over the already installed PON fibre infrastructure (ODNs). This means compatibility with the link budgets of those ODNs; typically up to ~30dB or more is necessary. Furthermore, the HSP systems must be able to co-exist with the legacy PON systems on the same ODN. Typically, this requires a wavelength plan that puts HSP into separate wavelength bands to the legacy systems. Such co-existence is particularly crucial in the FTTH application as it enables individual subscribers to be upgraded to HSP on demand rather than through forced upgrade.

Steered by input from network operators, the HSP Requirements recommendation (G.9804.1) was consented by the ITU in 2019 [8]. A target for the service capacity was set at > 40Gbps per downstream wavelength channel. A set of upstream rates were requested, with an initial priority for 12.5Gbps and 25Gbps. There is demand for a symmetric line-rate system but the main applications are still not clear and these

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could, to some extent, drive technology decisions so this feature will come later.

Common Transmission Convergence Layer

A noteworthy decision in the development of the HSP standards was to develop a so called Common TC layer (ComTC) [9]. It was recognised that the PON TC layer has a high degree of functional similarity among the previous system generations. Rather than writing new, but slightly different TC Layer standards for each future PON system, the ComTC specification is designed to be easily extensible to support a multitude of future PON systems. It encompasses both single and multiple wavelength channel operation and parameterizes the nominal line rate using a fundamental rate and a set of integer factors as multipliers of this rate.

The sublayers in the ComTC layer stack for OLT to ONU transmission are illustrated in Fig. 2. The first feature of note is the FEC coding using LDPC (17280, 14592) with a code rate of 0.844. Additionally, anticipating the potential for correlated errors from DSP based equalisers [10], a block interleaver is used to interleave the bits across groups of 4 consecutive LDPC code words. This downstream interleaving may be disabled to reduce latency in some applications.

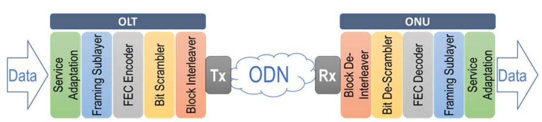

Figure 2: HSP Downstream Path TC Sublayers

50G-PON Physical Media Dependent Layer

It is envisaged that there will be multiple PMD layers within the HSP standards e.g. for conventional TDM-PON along with TWDM and WDM-PON (PtP WDM). The first PMD layer to be consented by the ITU is the 50G-PON [11]. This is a conventional, single wavelength channel per direction, TDM/TDMA PON operating at up to 50Gbps line-rate.

An early, and critical, decision in PON PMD standards is the wavelength plan. The main inputs into this decision are the legacy PON co-existence requirements, wavelength dependent fibre impairments and low cost diplexer implementation at the bi-directional transceivers. Taking these considerations into account, the wavelength plan shown in Fig. 3 was adopted.

The downstream wavelength (HSP-DS) for 50G-PON was selected as 1342±2nm. In the upstream, two 20nm window width options are available. Which one of these to use is determined by the legacy system that 50G-PON needs to co-exist with i.e. either GPON or XG(S)-PON. In addition, a 4nm wide upstream window at 1300nm is also available. This narrower option may ease isolation requirements for co-existence elements (WDMs) that may already be installed. Furthermore, such an option may be useful in the event that a pre-amplified Rx is used. Generally, the 20nm width options are expected to offer the lowest cost implementations as they allow for the use of uncooled ONU transmitters.

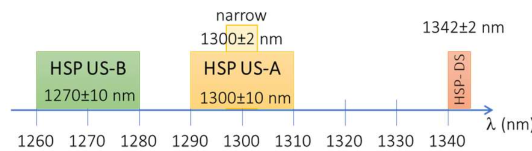

Fig. 3. 50G-PON Wavelength Plan

Due to the high loss budget in power splitter based PON networks, an NRZ modulation format was selected for 50G-PON. However, with the requirement to work over fibre infrastructure deployed for GPON and XG(S)-PON, some technical innovations are necessary to enable operation at 50Gbps line-rate. The receiver sensitivity is improved by LDPC FEC included in the ComTC with a reference input BER of 10^{-2}. In addition to this, compact optically amplified OLT transmitters may be used to meet the link budget requirements. For example, EMLs integrated with SOAs can deliver in excess of +10dBm [12].

In PON systems, it is a general objective to ensure that subscriber ONUs are low cost and a higher cost burden is placed at the OLT side. This is because the OLT costs are shared among all the subscribers on the PON and the ONU costs are incurred on a per subscriber basis. With this objective in mind, lower cost 50G-PON ONUs can be realised using mature 25Gbps APD Rx devices and DSP based equalisation [13]. Fig. 4 illustrates the downstream link as assumed in the 50G-PON standards development.

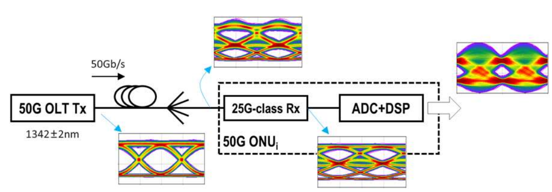

Fig. 4: Illustration of 50G-PON downstream transmission link.

At the OLT a 50Gbps NRZ Tx was assumed, although, thanks to flexibility in the specifications, lower bandwidth Tx devices are not precluded. At the ONU a 25G-class APD Rx was also assumed. Such devices are readily available and already shipping in volume. To overcome the Rx bandwidth limitation, DSP based equalisation is assumed in order to realise good sensitivity with 50Gbps NRZ signals. This equalisation also helps reduce the ISI penalty from 20km of G.652 fibre chromatic dispersion (CD_{max} = 77ps/nm @1344nm). Eye diagrams in Fig. 4 show the impact of fibre CD on the 50Gbps signal after 20km and then the impact of the limited bandwidth Rx. It can be seen that the additional eye closure from the 25G-class Rx is minimal. The signal after the Rx may be effectively equalised (as shown) with, for example, a 15-tap FFE. More advanced equalisation schemes such as DFE or MLSE may be implemented to further reduce the path penalty and improve the Rx sensitivity [14].

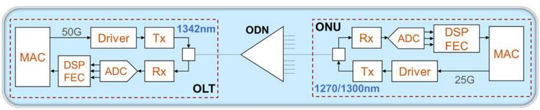

Fig. 5: Key functional blocks for 50G-PON.

In Fig. 5, the key functional blocks of the 50G-PON system are shown for what is expected to be the mainstream upstream line-rate option of 25Gbps. The main differences when compared to previous PON generations are the addition of ADC and DSP. These are shown here as separate blocks but may be integrated with the PON MAC. Furthermore, in the upstream, the ADC/DSP may not be needed at 25Gbps but they are shown here for completeness and may prove useful at 50Gbps.

It should be noted that the link assumptions in the standardisation process, as mentioned above, do not limit vendor implementations. Only performance at the optical interface is the subject of PMD standardisation.

ONU Management and Control Interface

As for previous generations of ITU-T PON, the G.988 standard [15] for ONU management is reused for HS-PON to complete the suite of necessary standards.

Future HSP Extensions

HSP already has a pipeline of further systems in development. Firstly, the 50Gbps line rate extension to TWDM-PON is under study as part of the HSP project. Furthermore, the PtP-WDM overlay system seen in NG-PON2 is also in scope for extension to 50Gbps line rates. Each of these systems will need specific PMD recommendations to be developed but will build upon the ComTC as mentioned previously.

In addition to these new HSP systems, there will inevitably be amendments to the relevant 50G-PON recommendations. Generally, these amendments will target new features and capabilities not included in the first version of the completed suite of 50G-PON recommendations. Features already identified include the addition of the specifications for the 50Gbps upstream link.

There are several ideas for how the 50Gbps upstream link can be realised but, as mentioned earlier, these technical decisions are dependent on the target applications for a symmetric 50G-PON system. In simple terms, this may come down to whether the ONU is for relatively niche applications such as businesses or backhauling. Such applications may be able to afford higher capability ONU optics and may tend to shift the balance of difficulty between the OLT and ONU.

In addition to the PMD amendments, there are also ComTC updates required as the default LDPC FEC code for 50Gbps upstream remains unspecified. At 12.5Gbps and 25Gbps there are ideas for optional FEC codes that could be implemented to potentially give operational flexibility in deployments.

Further ComTC enhancements being discussed include the support for network slicing and additions to the security features.

Summary

In 2018, the Higher Speed PON project in the ITU-T was initiated and in 2021 it accomplished a significant milestone with the consent of the first complete suite of recommendations in the HSP family i.e. 50G-PON. In addition, other PON systems within the HSP family are also in progress.

50G-PON marks a significant shift in ITU-T PON technology compared to what has gone before. This is the first system to be built on the foundations of the ComTC and include powerful features of LDPC based FEC. Furthermore, 50G-PON is the first PON system to be specified assuming Rx-side DSP. Both of these choices rely on the recent progress in CMOS integrated circuits to ease the requirements for the optical transceivers.

Following the successful standardisation of the 50G-PON system, it may be expected that products will be released with the next 1-2 years in order to be ready for trials and deployments according to the original demand for 2025 readiness. Already, prototype 50G-PON systems in commercial PON platforms have demonstrated key features of 50G-PON.

Acknowledgements

The author would like to recognise the hard work and dedication of all the contributors to the HSP project in Q2/SG15 of the ITU-T.

References

[1] "Gigabit-capable passive optical networks (GPON)," ITU-T G.984.x Series Recommendations, (2004).

[2] Ethernet in the First Mile (EPON), IEEE Std 802.3ah, (2004).

[3] "10-Gigabit-capable passive optical networks (XG-PON)," ITU-T G.987.x Series Recommendations, (2010).

[4] "10-Gigabit-capable symmetric passive optical network (XGS-PON)," ITU-T Recommendation G.9807.1, (2016).

[5] "10G-EPON Physical Layer Specifications and Management Parameters for 10 Gb/s Passive Optical Networks," IEEE Std 802.3av-2009, Oct. 2009.

[6] D. Faulkner, R. Mistry, T. Rowbotham, K. Okada, W. Warzanskyj, A. Zylbersztejn, Y. Picault, "The full services access networks initiative," IEEE Communications Magazine, Volume 35, Issue 4, pp. 58-68 (1997).

[7] https://www.fsan.org/roadmap/

[8] "Higher Speed Passive Optical Networks: Requirements," ITU-T Recommendation G.9804.1 (Requirements), approved Nov. 2019.

[9] "Higher Speed Passive Optical Networks: Common Transmission Convergence layer Specification" G.9804.2 (ComTC), consented April 2021

[10] Xiang Liu, Andy Shen, Ning Cheng, Yuanqiu Luo, and Frank Effenberger "Performance Improvements in Bandwidth-Limited and Digitally-Equalized 50G-PON Downstream Transmission via Block-Interleaving over Four LDPC Codewords," OFC 2021, paper M3G.6

[11] "Higher Speed Passive Optical Networks: Physical Media Dependent (PMD) Layer Specification" G.9804.3, consented April 2021

[12] R. Rosales, I. Cano, D. Nesset, Y. Zhicheng, R. Brenot, N. Dubrovina, E. Duran-Valdeiglesias, H. Debregeas, D. Carrara, and F. Lelarge, "First demonstration of an E2 class downstream link for 50 Gb/s PON at 1342 nm," ECOC 2020, paper Tu2J-5.

[13] M. Tao, J. Zheng, X. Dong, K. Zhang, L. Zhou, H. Zeng, Y. Luo, S. Li, and X. Liu, "Improved dispersion tolerance for 50G-PON down-stream transmission via receiver-side equalization," OFC 2019, paper M2B3

[14] B. Li, K. Zhang, D. Zhang, J. He, X. Dong, Q. Liu, and S. Li, "DSP enabled next generation 50G TDM-PON," JOCN, 12, D1–D8 (2020).

[15] "ONU Management and Control Interface (OMCI) Specification," ITU-T G.988 Recommendation.