Network Operator Upgrade Opportunities With 50G-PON

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***Abstract*—50G-PON is the next evolution step for ITU-T PON systems beyond 10G that opens up opportunities for new services and applications. This paper reviews the 50G-PON technology itself and different upgrade opportunities for network operators.**

Keywords—50G-PON, upgrade

I. Introduction

In the previous 7 years, network operators have been upgrading their fibre access networks with 10G-class PON technologies such as the ITU-T, and 10-Gigabit Passive Optical Network (XG(S)-PON) [1]. Industry analysts expect that 30 million 10G-PON ports will be shipped in 2023 [2]. Just as the rollout of 10G-class PON was increasing, standardization bodies began to discuss what technologies were needed after 10G. Within the FSAN forum, network operators developed a Passive Optical Network (PON) Roadmap [3] calling for beyond 10 Gbps PON in the ~2020 timeframe (Fig. 1).

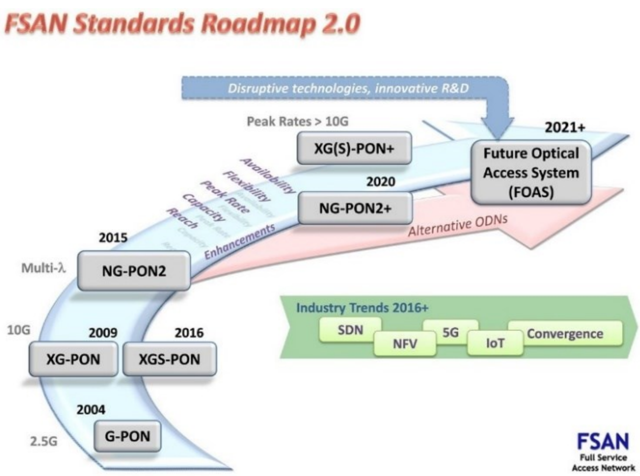

Fig. 1. FSAN Standards Roadmap 2.0

As a response to the FSAN operator demands, an ITU-T study was initiated in 2016 to analyze the beyond 10G PON technologies. The conclusions were captured in the G.Sup64 document [4] that reviewed the most promising options. After this initial study, and some considerable debate, it was agreed that the next ITU-T PON standard should be based on a 50 Gbps line-rate. Strong consideration was given to a 25 Gbps line rate but this does not meet the expectation for a ~4x capacity increment between PON generations from those network operators deploying PON at a massive scale.

The first full suite of 50G-PON recommendations was published by the ITU-T in September 2021 and in the same month, remarkably, a report of carrier lab trials of 50G-PON prototype equipment was made at ECOC [5]. This prototype 50G-PON was housed in a commercial PON system chassis and was able to demonstrate many key features of 50G-PON, thus, demonstrating the significant early progress towards product implementations. A 25 Gbps upstream line rate was implemented as that was the maximum upstream rate option standardized at that time. The trial was run over an ODN with a 1:32 optical split and up to 10 km fibre distance. The reported results included ~40 Gbps of useful downstream service capacity with ~80 µs latency. In this prototype, the Optical Distribution Network (ODN) loss budget was largely limited by the use of an Electroabsorption Modulated Laser (EML) with low launch power. In a subsequent operator lab trial, an EML integrated with a semiconductor optical amplifier (EML-SOA) based prototype was able to achieve more than 29 dB ODN budget with 20 km fibre [6]. In a further technology milestone, a 50G-PON field trial was reported in July 2022 in a live network setting [7].

We can see clearly that the underlying technologies are demonstrating good progress towards maturity, with many of the key optoelectronic components already at the sampling stage from vendors. Given this background, it is little surprise that the first announcements of 50G-PON products have recently been made. At the 2023 Mobile World Congress, Huawei announced the industry's first commercial 50G-PON solution [8]. Based on the current state of progress, it may be expected that commercial 50G-PON systems will be released by more vendors within the next year or so.

In this paper, we review the key technologies for 50G-PON and the respective industry progress toward standards-compliant and deployable solutions. Furthermore, we discuss possible network operator upgrade schemes and migration strategies from already massively deployed PON system technologies. Finally, we give some insights into the application landscape for 50G-PON systems, covering

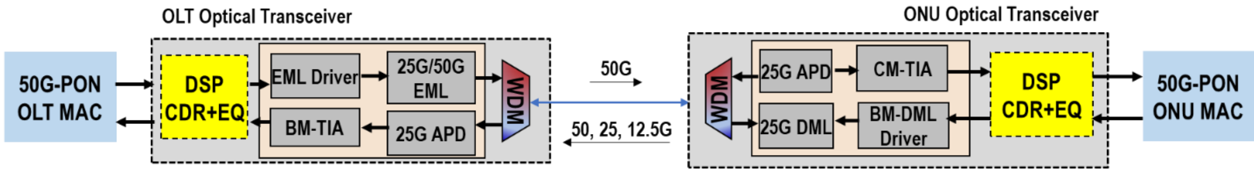

Fig. 2 50G-PON System Architecture

conventional FTTH but also emerging applications such as Industry 4.0.

II. Key Technologies and Industry for 50G-PON

The typical system architecture of 50G-PON is shown in Figure 2. The downlink line rate is 50Gb/s, and the uplink supports three line rates: 50Gb/s, 25Gb/s, and 12.5Gb/s. To meet the high power budget requirement of the C+ class (32dB), optical transmitters with high launch power and high bandwidth are required. Furthermore, technology needs to be improved to achieve the receiver sensitivity requirement in 50G-PON. At the same time, Digital Signal Processing (DSP) is introduced to overcome the challenges of chromatic dispersion and high-speed burst-mode reception. At present, the development of the technologies supporting 50G-PON has entered the fast lane, and all the key components are entering the commercial development phase.

A. *Key optical components:*

OLT transmitter: 50G EML+SOA.

To meet the ODN link budget requirements of C+ (32 dB), the optical power transmitted by the Optical Line Terminal (OLT) must be increased. ITU-T G.9804.3 has defined the optical interface specifications of the OLT optical transmitter and the minimum transmit power for the C+ class power budget is +8.5 dBm at an operating wavelength of 1340-1344 nm. Conventional EML transmitters can achieve very high bandwidth, but the emitted optical power generally only reaches about 0 dBm to +2 dBm. Therefore, the current mainstream solution is to use an EML integrated with an SOA as a booster amplifier for the 50G-PON downstream transmitter [9]. At present, many of the leading suppliers have released samples or commercial roadmaps of 50G EML+SOA devices, and this technology is close to maturity. Research has shown some promising high-power EML-only devices might also be possible for use in 50G-PON in the future [10].

ONU transmitter: 25G/50G Directly Modulated Laser (DML).

For 50G-PON upstream, considering that the ONU is more cost-sensitive than the OLT, DML transmitters are usually preferred. Compared with XGS-PON, besides increasing the modulation bandwidth, for 50G-PON the ONU optical launch power also needs to be increased. Due to the receiver sensitivity degradation at high speed, ITU-T G.9804.3 specifies that the minimum ONU launch powers are +5dBm and +6.8dBm for 25Gb/s and 50Gb/s upstream respectively. The current 25G DML technology is close to maturity, while the 50G DML technology is still in the sampling stage and needs further technical improvement to support commercial use. Impressive progress in high-speed DMLs has been reported in recent research papers [11, 12].

OLT/ONU receiver: 25/50G APD.

The 50G-PON system uses high-bandwidth and high-sensitivity Avalanche Photo Diodes (APDs) to receive high-speed optical signals and meet the required power budget. A promising receiver technology for 50G-PON is SiGe-based APDs which have the characteristics of low noise, high bandwidth, and high sensitivity [13]. 25G/50G SiGe APDs are a prime candidate receiver device for use in 50G-PON. At present, the 25G APD technology is mature and it has been widely used in other applications. In 50G-PON, when combined with the DSP-based equalization technology, the use of 25G APDs can provide sufficiently good performance. In addition, 50G APD suppliers have begun to provide samples, which can also be considered for application in 50G-PON systems. However, the 50G APD technology still needs to be further developed and matured before commercial application.

B. *Key electrical components:*

50G EML Driver: In the downstream, to ensure high signal quality, the EML driver at the OLT transmitter must have a large enough bandwidth to generate 50 Gbit/s Non-Return-to-Zero (NRZ) optical signals. The extinction ratio (ER) of the output signals of the modulated EML-SOA must be greater than 7 dB. To realize this ER, the electrical output amplitude from the driver chip must be greater than 2 V (peak to peak). Furthermore, the power consumption of the chip must be as low as possible to enable integration into pluggable optical modules. Thanks to the rapid technical development of data center modules, the 50G EML driver technology has reached maturity and is now widely used, 50G-PON can reuse the same technology.

25G/50G Burst DML Driver: In the upstream direction, the 50G-PON Optical Network Unit (ONU) now needs to generate 25G or 50G NRZ high-speed burst signals (as the 12.5G upstream option can largely reuse already mature XGS-PON technologies). The burst start and stop time sequence must be fast, and the optical ER must be greater than 5 dB. Therefore, it is necessary to use a high drive current and drive bandwidth while supporting the burst function. Currently, the 10 Gb/s burst driver has been used in XGS-PON for a long time. The 25 Gb/s burst DML driver has been developed by the industry recently and this can meet the requirements of the asymmetric-rate 50G-PON application. 50 Gb/s DML drivers and optical transmitters are still in the sampling phase and on the way to commercial use.

25G/50G Burst-Mode (BM) TIA: In the upstream receive direction, the 50G-PON system requires the Burst-Mode Trans-Impedance Amplifier (BM-TIA) to convert the burst photocurrent from the photodetector into burst voltage signals and provide corresponding variable gain control. Currently, two types of BM-TIA are relevant to 50G-PON. One type is a linear BM-TIA, which can work well in conjunction with the DSP-based equalizer to receive both symmetric and asymmetric rate upstream signals. The second BM-TIA type is a bandwidth-limited BM-TIA that works well in conjunction with burst-mode limiting amplifiers (BM-LA) to receive asymmetric rate 25 Gbit/s signals. Currently, both 25G BM-TIAs and 50G linear BM-TIAs are in a sampling state, which is expected to be mature and commercialized in the near term.

DSP: Compared with 10G PON, 50G-PON increases the line rate by five times, and the dispersion penalty imparted on high-baud-rate signals increases sharply. Link performance is limited by this high dispersion penalty and the decreasing receiver sensitivity. Link performance gains through optical component improvements alone are very hard to realize practically. Therefore, DSP equalization technology is introduced into commercial PON systems for the first time in 50G-PON. The DSP algorithms can eliminate the impact of component bandwidth limitations and dispersion in high-speed signal transmission and so improve the link power budget.

In the upstream direction of a 50G-PON system, there are three line rates: 12.5 Gbit/s, 25 Gbit/s, and 50 Gbit/s. The impairment of each upstream signal from different ONUs with different line rates varies greatly. Therefore, fully exploiting the potential of DSP technology and implementing dynamic and flexible DSP equalization technology can achieve the best performance in the 50G-PON system.

Thanks to the rapid development of data center networks, DSP-related technologies have been greatly developed. Four-level Pulse Amplitude Modulation (PAM4)-based 50 Gbit/s and 100 Gbit/s DSP technologies have been put into volume commercial use. The DSP technology applied to 50G-PON can reuse the PAM4 DSP technology and related industry chain to a large extent. The corresponding DSP chips are currently sampling and are expected to mature for 50G-PON systems shortly.

An overview of the industry progress of the key components for 50G-PON is briefly summarized in Table I.

Key components of 50G-PON		Asymmetric (50G/25G)	Symmetric (50G/50G)
Electrical part	PHY (oDSP)	Sampling	Sampling
	50G EML-Driver	Ready	Ready
	50G CM-TIA	Ready	Ready
	BM-DML Driver	Ready	Sampling
	BM-TIA	Ready	Sampling
Optical part	50G EML+SOA	Sampling	Sampling
	25G/50G DML	Ready	Sampling
	25G/50G APD	Ready	Ready

TABLE I. SUMMARY OF KEY COMPONENTS OF 50G-PON

III. 50G-PON CONVERGENCE UPGRADE SCHEME

The two different PON system technologies as defined by the respective standards bodies, the IEEE and ITU-T, can both coexist with 50G-PON in the same ODN network. Thus, supporting the smooth evolution of operators' optical access networks based on PON technology in large-scale deployment. This feature is of particular interest to operators who are using both XG(S)-PON and 10 Gbit/s Ethernet Passive Network (10G-EPON) technologies in their access networks. These operators can use 50G-PON as a unifying technology, to serve as the next PON evolution step for both XG(S)-PON and 10G-EPON. This greatly simplifies the planning, construction, and operation of their optical access networks and ultimately reduces costs. To some extent, this approach also avoids PON supply chain fragmentation. The complexity and general cost base can be greatly reduced when investing in the development and application of a single 50G-PON based evolution step.

The fundamental method of 50G-PON and legacy PON technology coexistence is wavelength division multiplexing (WDM). The key feature is that 50G-PON and legacy PON use different upstream and downstream wavelengths in coexistence. IEEE PON and ITU-T PON have differences in

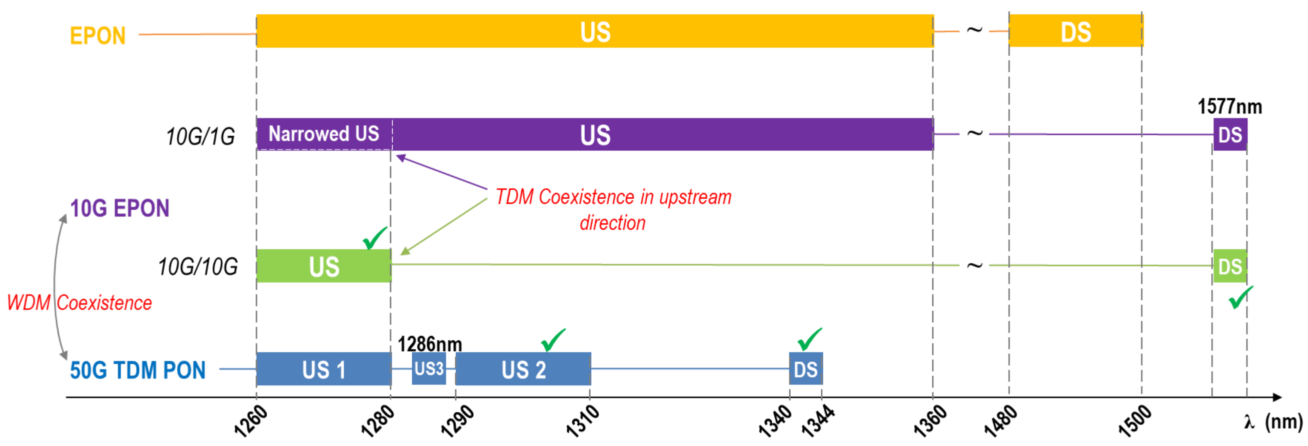

Fig. 3. Wavelength bands for EPON, 10G-EPON, and 50G-PON

some key physical layer aspects. Therefore, when the two PON technologies are evolved to 50G-PON in practical terms, the general networking architectures are similar, but the detailed inter-generational coexistence capabilities and optical interface index requirements are different.

The ITU-T G.9805 standard provides two mainstream coexistence mechanisms [14]. These are:

- External coexistence element (CE): Whereby 50G-PON systems and Legacy PON systems are deployed independently, and the respective wavelengths of multiple PON systems are combined by CE devices external to the OLT modules and launched into the ODN. The different PON systems have ONUs with corresponding optical filtering, to extract their respective data signals. This coexistence solution was the first proposed and has been deployed in several carrier networks.
- Multi-PON module (MPM): Whereby 50G-PON transceivers and Legacy PON transceivers are integrated along with the wavelength combining and splitting devices are all integrated into one optical module. Recently, the MPM-based GPON/XG-PON coexistence evolution scheme has gradually become the mainstream mode for operators' 10G PON deployments worldwide and has been applied at a large scale.

A. IEEE PON system migrate to 50G -PON

In IEEE 802.3, the physical layer wavelengths of Ethernet Passive Optical Network (EPON) and 10G-EPON are stipulated as shown in Figure 3. In 50-PON, three upstream (US) wavelength options are defined, i.e. upstream wavelength option 1 (US1, 1260-1280 nm), upstream wavelength option 2 (US2, 1290-1310 nm), and upstream wavelength option 3 (US3, 1284-1288 nm). The upstream wavelength bands of the EPON system and asymmetric 10G-EPON (10G/1G) are both 100 nm wide, which puts them in conflict with the wavelengths of the 50G-PON system and, hence, they cannot coexist by WDM. However, in the case of China Telecom's large-scale 10G-EPON deployment, the uplink wavelength of asymmetric 10G-EPON has been narrowed to 1260-1280nm "Narrowed US" (equivalent to the wavelength of a 10G-EPON symmetric system). In this case, the coexistence of the asymmetric 10G-EPON, symmetric 10G-EPON, and 50G-PON system can be realized by WDM, and the EPON system is taken out of service. In addition, the coexistence scheme requires US2 (1290-1310nm) or US3 (1284-1288nm) optical devices supporting N1 (29dB) Optical Path Loss (OPL) in the uplink direction of the 50G-PON system.

The coexistence architecture of the 10G-EPON asymmetric system, 10G-EPON symmetric system, and 50G-PON system based on the MPM approach is shown in Figure 4, under the premise of "Narrowed US" for the 10G-EPON asymmetric system.

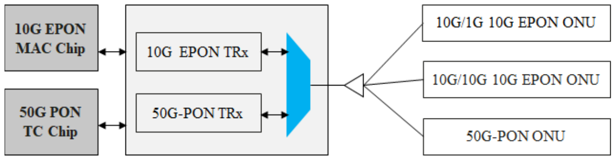

Fig. 4. Coexistence architecture of 10G-EPON and 50G-PON

B. ITU PON system migrate to 50G -PON

The wavelengths of Gigabit-capable Passive Optical Network (GPON), XG(S)-PON, and 50G-PON are shown in Figure 5. It can be seen that when 50G-PON adopts US3 (1284-1288nm) and optical devices supporting E1 OPL class OPL (33dB), the coexistence of GPON system, XG(S)-PON system, and the 50G-PON system can be realized by WDM, as shown in Figure 6a. With this three-generation coexistence, operators do not need to force the 10 million GPON OLT ports and 100 million GPON ONUs in the network to retire, which can save a lot of construction, operation, and maintenance costs for operators and avoid inconvenience for subscribers. Of course, in some GPON or XG(S)-PON Greenfield deployment areas, a two-generation coexistence scheme similar to the EPON system can also be used, as shown in Figure 6b. In this case, the uplink direction of the 50G-PON system needs to use US2 (1290-1310nm) or US3 (1284-1288nm) optical devices to avoid wavelength conflict.

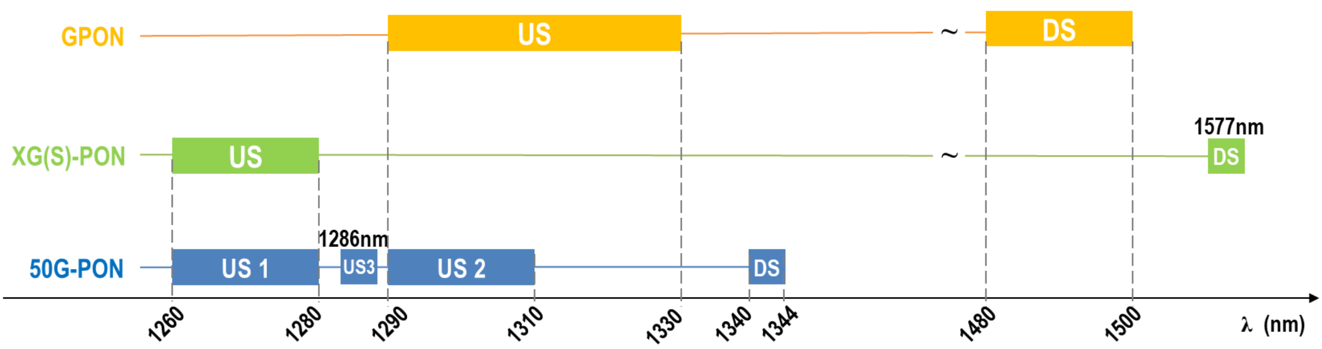

Fig. 5. Wavelength bands for GPON, XG(S)-PON, and 50G-PON

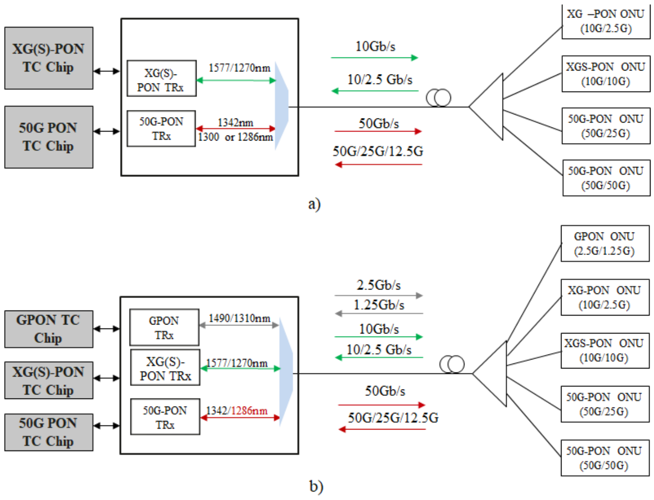

Fig. 6. Coexistence architecture of GPON, XG(S)-PON and 50G-PON

IV. 50G-PON Application Exploration

Compared with 10G PON, 50G-PON system capacity has increased by 5 times, which can meet the future demand of network capacity for future large bandwidth services such as Industrial cameras for machine vision using uncompressed video.

In-home broadband scenarios, Fiber-to-the-Room technology is emerging, Wi-Fi 6 is being applied on a large scale and, in the future, will also evolve to Wi-Fi 7. Adequate access network bandwidth is required to meet the demand for service transmission. The bandwidth required for some new services has reached 1G ~ 2.5G. Fiber to the home networks using 50G-PON technology can provide 10G access capacity for home users in the operator's network, to meet the large bandwidth applications from home users.

In industrial scenarios, the large bandwidth capability of 50G-PON can guarantee the data delivery of video services between industrial cameras and image processing programs for machine vision applications. For example, in the scenario described in the paper [15], based on XGS-PON technology, the network contains a total of 66 XGS-PON OLT ports and 396 ONU devices. If 50G-PON technology is adopted, the number of networking devices can be reduced to about one-fifth of the original number, thus greatly simplifying the network architecture and subsequent maintenance costs.

V. Summary Outlook

Operators are deploying 10G PON on a large scale to provide universal gigabit access to massive residential subscribers. 10G PON network's evolvability and upgradeability are crucial for operators to greatly protect their investments and save subscriber broadband access costs. 10G PON's future evolution has been widely accepted as 50G-PON, and the standardization is largely complete. Key physical layer devices including DSP, high-power transmitters, etc. are in the process of continuous product breakthrough, and commercialized products are expected to be available soon. Benefiting from the development of large bandwidth services such as cloud and machine vision, 50G-PON is expected to be applied to enterprise customer scenarios first, providing sufficient bandwidth for factory networks.

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