An Operator's Approach on the Coexistence in Future Optical Access Networks (Invited)

Fabienne Saliou, Philippe Chanclou, Gaël Simon, Jérémy Potet, Georges Gaillard, Stéphane Le Huérou

Orange, 2 avenue Pierre Marzin, 22307 Lannion

Author e-mail address: fabienne.saliou@orange.com

Abstract: Main challenges of coexistence of future access transmissions are detailed. Important tradeoffs are identified: wavelength plan for triple PON coexistence, optics for high optical budget, considering OOB and SRS penalties. Multiplicity of technical implementations for PtP and PON transceivers are against future interoperability.

1. Introduction

Fibre to the Home/Building/x (FTTx) deployments are ongoing worldwide since mid-2000's, reaching 726 million of fibre-based households in 2020 and it will continue its expansion to reach about 1.2 billion in 2027 [1]. In the meantime, technologies for fibre access networks keep on progressing, from Gigabit capable PON (G-PON) to 10 Gbit/s symmetrical PON (XGS-PON) [2], providing an average broadband speed from 121 Mbit/s in 2020 to evolute to an estimate of 844 Mbit/s in 2027[1]. With more than 80 % of FTTH expenses being in the passive fibre plant installation, it is crucial to maintain already deployed Optical Distribution Networks (ODNs) when upgrading to future PON systems.

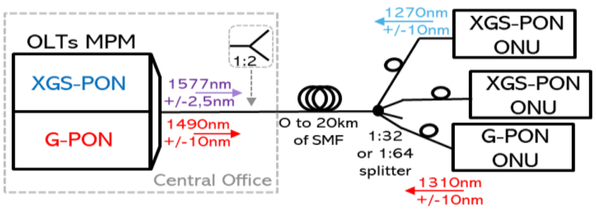


Figure 1: Coexistence of G-PON and XGS-PON with an MPM

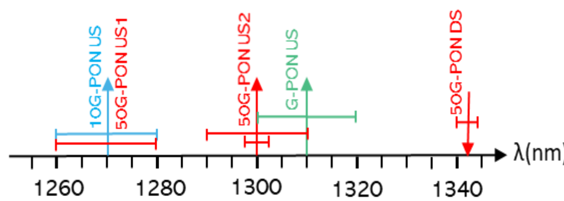


Figure 2: ITU-T's Wavelength plan for PONs (in O-Band)

Coexistence of G-PON and XGS-PON technologies on the same ODN have been made possible by wavelength overlay, choosing in the ITU-T distinct spectral bands for each DownStream (DS) and UpStream (US) carriers of each technology, as shown on Figure 1 and 2. However, an additional spectral filter needs to be introduced to provide this coexistence on the same ODN. It can be realized either as a separate passive Coexistence element (CEx) or as filters integrated in a Bidirectional Optical Sub-Assemblies (BOSA) in a Multiple PON Module (MPM) transceiver. The latter is the most popular when deploying XGS-PON. This leads to an extra loss of 1 dB that is considered in the optical budget classes N1 [14-29 dB] and E1 [18-33 dB]. However, despite these spectral and insertion losses precaution being covered by the standards, coexistence issues were pointed out between GPON and XGS-PON. The first one is due to Stimulated Raman Scattering interactions between the GPON and the XGS-PON, leading to a possible power depletion on the GPON [3]. A second issue in a coexistence scenario is that ONUs with high Out-Of-Band (OOB) crosstalk levels may cause crosstalk induced errors in upstream reception at the OLT of another PON system. ITU-T has proposed to reduce this risk by the definition of an OOB Power Spectral Density (PSD) mask, to be edited in a revised version of G.9807.1 (Annex B.A). In addition, other means to facilitate coexistence are described in [4].

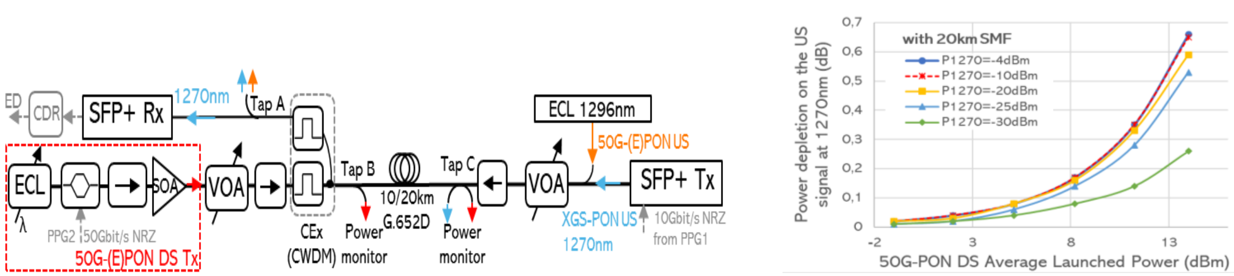
In the meantime, optical networking is the foundation for high-speed, reliable, and efficient connectivity, supporting not only new residential usages but also for enterprise, smart cities, and mobile services. For the latter, PON systems are not preferred due to their limited latency and shared bandwidth of commercially available systems that are not sufficient to support today's mobile requirements: 5G mobile backhaul and business networks links are already being upgraded to the full capacity of 10 Gbit/s Point to Point (PtP) links and even 25 Gbit/s PtP in some cases [5]. Higher bandwidth demand, along with low-latency and jitter, reliability, and security, are major drivers for next-generation PtP and PON solutions, moving from 10G to higher speeds as defined by ETSI Industry Specification Group (ISG) for the fifth generation of fixed networks "F5G" [6]. This invited paper will discuss the upcoming evolutions of technologies and their challenges with regards to co-existence possibilities.

2. Coexistence of future PtP technologies

Latest standards recommendations at IEEE and ITU-T [7] showed efforts on specifying single fibre PtP interfaces to optimize the fibre numbering. Standards are edited for up 50 Gbit/s transmission and 100 Gbit/s are currently being prepared with already products available on the market. For the first time, IEEE and ITU-T provide specifications with convergence efforts for PtP above 25 Gbit/s. However, interoperability remains utopic when operators try to combine plethora of transceivers available on the market. For example, 100G transceivers exist from different vendors with different form factors, fibre reaches, optical budgets, modulation formats, wavelength pairs, duplex/simplex, energy classes, FEC/DSP implementation, etc… A pair of PtP transceivers being deployed on distant sites, in different host equipment types (switches, routers, OLTs, Radio Access Networks equipment…), all these multiple factors induce complex operational rules to avoid pairing issues and enlarge the sparing items required. Recent initiative from the MOPA (Mobile Optical Pluggable Alliance) and some major European Operators (in a Memorandum of Understanding) tends to reduce the transceiver catalog related to O-RAN context, focusing only on the most suitable products for identified use cases. Looking for further possible evolutions, PtP technologies could also benefit from the PON Optical Network Unit (ONU) Management and Control Interface (OMCI), adopting it for enhanced operation and maintenance tools such as inline remote monitoring, PON-ID, dying gasp, etc… PtP and PON cards are deployed in the same OLT shelves today so this would be a step forward for convergence of PtP and PONs and allow simplifications for OLT softwarization and virtualization.

3. Coexistence of future PON technologies

50G-PON has been edited by the ITU-T in 2021and is considered as the main successor of XGS-PON and G-PON for Higher Speed PONs [8]. Current wavelength plan of PON technologies prevents operators from choosing triple coexistence of G-PON, XG(S)-PON and 50G-PON on current ODNs. Indeed, the US wavelength options (US1: 1270 +/- 10nm; US2: 1300 +/- 10 nm; or US1 narrow :1300 +/- 2nm) are overlapping either with the GPON one (1310 +/- 10 nm) or with the XGS-PON one (1270 +/- 10 nm), as shown on Figure 2. To deploy 50G-PON and maintain XGS-PON on the same ODN, operators would have to remove every GPON ONUs that are already deployed on their ODNs; or 50G-PON could coexist with G-PON if no XGS-PON is deployed on the ODN, but this scenario is less attractive as XGS-PON is already deployed with considerable volumes. Today, G-PON ONUs average selling prices are 4 times lower than XGS-PON ones, and it is forecasted to be still at least twice cheaper in 2027 according to [9]. In the meantime, considerable volumes of 50G-PON are not expected in that period, GPON and XGS-PON still have a long life in FTTH networks. Consequently, operators could find more interest in a smooth migration towards higher speed PONs, taking the opportunity to deploy a few 50G-PON for very specific demanding use cases. In addition to this economical perspective, operators are facing real expectations to reduce their energy and environmental footprints, thus reducing their power consumption and carbon emissions, increasing the energy mix and life cycle of network technologies [10]. Thanks to the PON architecture, the impact of the OLT MPM transceiver is more limited than the many connected ONUs (fiber gateways). So, we need to preserve the life cycle of previous ONUs at the same time as we propose new generation of optical gateways. A total technology swap of current G- or XG(S)-PON, to be replaced by 50G-PON, is not the best trend to meet the green deal engagements of the next decade. It is then crucial to allow triple coexistence of PON technologies. We propose a technical study of this possibility in [11] showing that for a small sample of 4180 G-PON field ONUs, the US wavelength distribution was limited to the upper band above 1305nm and proposing a new wavelength plan to allow triple co-existence with a MPM module definition. The wavelength window open for triple co-existence is then between 1290nm and 1305nm, and there is a tradeoff to find to define the affordable range for 50G-PON US wavelength. Looking at Wavelength Division Multiplexing (WDM) technologies, Thermo-Electric Cooler (TEC)-free sources are available only for Coarse-WDM transceivers and narrower spectral ranges impose the use of temperature controllers. Therefore, a tradeoff still needs to be found in this spectral window to enable affordable triple coexistence of PON technologies.



(a) (b)

Figure 3: (a) SRS experimental setup between 50G-PON DS and US carrier at 1270 nm and (b) Power depletion on carrier at 1270 nm when contra-propagating in 20 km SMF with a 50G-PON signal at 1344 nm

Moreover, the splitter-based specificity of PONs leads to high optical budget requirements, and it is still a remaining challenge for the first prototypes of 50G-PON. Recently, the use of specific Digital Signal Processing and/or optical amplification was demonstrated to reach more than 32 dB of optical budget at 50Gbit/s [12]. The choice of optical components and their frequency bandwidth limitation appears to be the most critical criteria to release constraints on DSP and optical amplification. The consequence of using these for the first time in PON is non negligeable with extra cost and power consumption but also with the definition of new metrics in the 50G-PON standard such as the TDEC and OMA which can be quite complex in field and certification assessments. Optical amplification also brings higher risks of OOB crosstalk due higher levels of Amplified Spontaneous Emission (ASE) transmitted.

Also, to reach the highest optical budgets, the optical launched powers in the fibre has been increased up to 14dBm from the 50G-PON OLT. The spectral spacing between the DS (1342 +/-2 nm) and US options of 50G-PON is about ~13 THz spacing which also favors the risk of SRS [13]. In figure 3, we show results of real time measurements of the power depletion occurring on the US received power according to the DS launched power in the same SMF G.652.D of 20 km length. In the case of 50G-PON DS coexistence with either XGS-PON US or 50G-PON US emitting at 1270 nm, up to 0.68 dB of power depletion is observed on the US received power, as measured on Fig3. (b). This optical power penalty is an extra challenge on reaching high optical budgets for PONs.

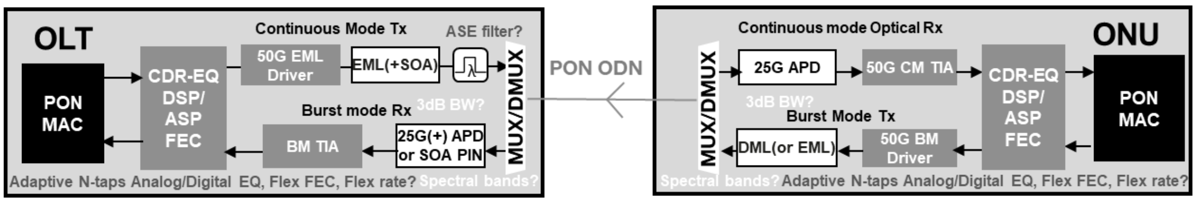


Figure 4: Example of implementation of optics for 50G(Symmetrical)-PON showing multiplicity of parameters

Finally, several tradeoffs are still to be found choosing the most cost-effective solutions to meet optical budgets as high as 33 dB and spectral options that will allow triple co-existence. In the end, the implementation choices of the transceivers are left to vendors if they meet transmission requirements defined in the standards. Figure 4 proposes a possible schematic of 50G-PON implementation, showing the multiplicity of parameters left to vendor's best practice. Interoperability will then be the last main challenge of 50G-PON to reach massive market volumes and allow coexistence of multiple ONU vendors with another OLT vendor.

4. Conclusions

An operator's view on current and future evolutions of PtP and PONs technologies towards co-existence is given in this paper. PtP market and its evolution towards "100G bidi" could benefit from a reduction of the number solutions offered today (MOPA initiative) and improvements with OMCI-like is proposed. For co-existence of PON technologies, challenges related to OOB, SRS, spectral specifications and interoperability were identified. Extension of PON market towards fibre to everywhere (Fiber To The Room, Machine, Industry…) in the future [6] will also raise other co-existence questions, maybe more related to management and orchestration interfaces, when cascading multiple PtP/PONs is considered [14].

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