50Gb/s TDM PON Digital Signal Processing Challenges: Mining current G-PON Field Data to Assist Higher Speed PON

Gaël SIMON[(1)], Fabienne SALIOU[(1)], Philippe CHANCLOU[(1)],
Luiz ANET NETO[(1)], Hamza HALLAK ELWAN[(1)]

[(1)] Orange Labs, 2 avenue Pierre Marzin - 22300 LANNION - France, gael.simon@orange.com

Abstract ITU-T's HS-PON will be the first PON generation to involve digital signal processing. We propose in this paper to benefit from the G-PON abundant field data related to the optical transmission channel in order to help meeting HS-PON challenges.

Introduction

The success of Passive Optical Networks (PONs) technologies is today undeniable. While a mass deployment is globally ongoing, standardization bodies are already working on the post 10Gb/s PON[1], which is referred to as Higher Speed PON (HS-PON). International Telecom Union (ITU-T) selected the Non-Return to Zero (NRZ) modulation format to meet the 50Gb/s (downstream) Time Division Multiplexing (TDM), and success GPON and XGS-PON[3]. In order to meet its predecessors' success, HS-PON needs to conserve certain key-features. One of them is interoperability, which is a key to mass, simple and low cost deployment. Interoperability is a characteristic of a given hardware equipment composing the PON system which allows it to work with other hardware without restrictions and according to a set of standards.

Physical layer interoperability challenges

In the case of PONs, interoperability implies that the Optical Distribution Network (ODN), which will be conserved for next PON generations, can be shared among an Optical Line Terminal (OLT) from "vendor A" and tens of Optical Network Units (ONUs) from vendors A, B, C, … (see Fig. 1, left). As PON networks are widely deployed and experience several years of existence, it also implies that multi-generation hardware interoperability is supported, even from the same vendor. Thanks to an important amount of work from the community, interoperability goal was achieved for previous PON generation and should be achieved in the same way for HS-PON [4].

However, the important baud rate of HS-PON stresses the physical layer constraints of the transmission: since the first discussions[1], Digital Signal Processing (DSP) was proposed to improve the NRZ transmission performance experiencing Inter Symbol Interference (ISI) caused by the bandwidth limitation of the transmitter and receiver (Tx and Rx), and by the fiber chromatic dispersion (CD). CD is a well-known phenomenon[5,6,7,8] managed in legacy PON, which affects the transmission channel, see Fig. 1 right. Its effects linearly increase with the propagation distance and quadratically with the baud rate. Various solutions[9,10,11] were proposed to mitigate ISI, namely Feed Forward Equalization (FFE), Decision Forward Equalization (DFE), Maximum Likelihood Sequence Estimation (MLSE), Neural Networks, etc. Those solutions, to be embedded in the OLT and/or ONU, could be configured to compensate the limitations of the associated transmitter and receiver as well as those of the channel. The DSP elements must be compliant with multi-vendor and multi-generation interoperability and they must also match all possible combination of bandwidth-limited transmitter and receiver on the transmission channel. Pre-distortion and/or post-compensation are considered to meet the challenges of DSP for HS-PON, but the deployed solution should meet the low cost constraints of PON[12]. Thus, in downstream (DS), pre-compensation seems a legitimate solution, allowing a single OLT embedded DSP

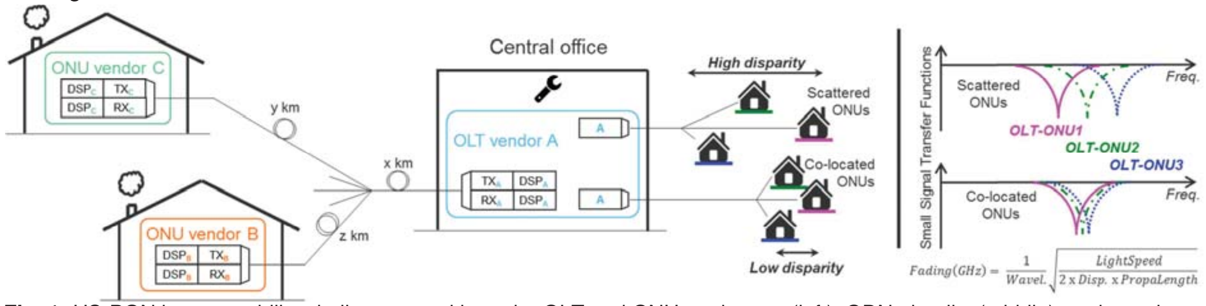

Fig. 1: HS-PON interoperability challenges: multi-vendor OLT and ONU equipment (left), ODN plurality (middle), and a variety of optical propagation channels on the same ODN tree (right) (the Tx/Rx bandwidth limitations are not represented)

and avoiding multiple ONU embedded DSP (or at least simplifying it). But the feasibility of such DS solution is still to demonstrate considering the variety of optical paths.

ODN characteristics also increase the possible combinations. PON's reach is generally specified for 0 to 20km, and the CD varies from 1 to 3.9ps/nm.km in the downstream wavelength range selected for HS-PON (1342+/-2nm)[1]. Then, the dispersive range of the system can go from 0ps/nm.km (no CD induced ISI) to 78ps/nm.km (CD brings ISI). Chirp can also worsen signal quality, mainly when a directly modulated laser is used in order for example to reduce transceiver expenses compared to external modulation. DSP can partially compensate ISI generated by Tx/Rx bandwidth limitations and CD. However, the DSP optimal configuration depends on the dispersive range[9,10,13], thus, on the propagation distance.

Proposition

PON generations might succeed each other, but the ODNs currently deployed will remain the same as the passive infrastructure is by far the major source of expenses in PON deployment. We propose to benefit from today's massively deployed ODNs characteristics, mainly OLT-ONU distance of GPON, to help solving the previously presented DSP interoperability issues related to the optical communication channel in both established communication and ranging phases of OLT-ONU pairs.

We propose to consider three scenarios:

- Unified equalization: DSP configuration is pre-adjusted to a set of parameters, meeting all possible transmission channel combinations but without prior knowledge of the Tx, Rx, or optical channel characteristics [14].

- Adaptive equalization: as each transmission channel is different because of the Tx, Rx (vendors variety) and optical channel combinations, DSP parameters are reconfigured for each OLT-ONU pair. The feasibility of such solution, combined with the TDM/TDMA nature of PON, requires a microsecond to nanosecond DSP reconfiguration capacity. Also, the propagation channel characteristics, including the reach, are supposed unknown. Then, the ranging phase of a new ONU connected to the ODN may require a "pre-ranging" phase to share knowledge of the transmission channel. For example, a low rate transmission channel between OLT and ONU can be used to exchange the Tx/Rx capabilities, but also to probe the length of the optical channel in order to estimate the range of CD.

- Per ODN equalization: we also propose to explore the data from the exploitation field to explore the distribution of ONUs along the considered ODN. Indeed, a maximum of 64 ONUs is generally allowed per OLT port. If the ONUs are co-located (see Fig. 1, right) the low disparity of the OLT-ONU distance for all ONUs of the ODN could significantly simplify the variety of CD range. Thus, it reduces the combinations of DSP parameters, and allows a "locally unified equalization" matching the parameters of the ODN considered. As for adaptive equalization, knowledge of the OLT-ONU distance over the tree (or at least its mean) is still required.

Methodology and results

Operators collect lots of data from their networks (alarms, traffic flows characteristics, current configuration,…) on a daily basis. In our case, the exploited data are extracted from 3.3 million GPON ONUS from all over France. Data are collected from 3500 OLTs, connecting 123 000 ODNs (PON trees). It represents more than 95% of todays Orange's subscribers in France. Three metrics are used:

- M: mean OLT-ONU distance of all ONUs in the ODN [km].

- D: disparity, being the distance difference

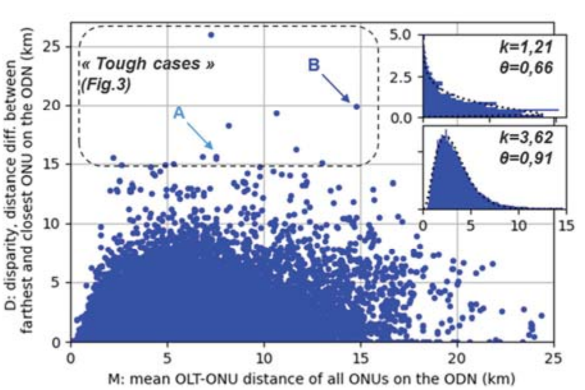

Fig. 2: ODNs characteristics (each dot represents an ODN)

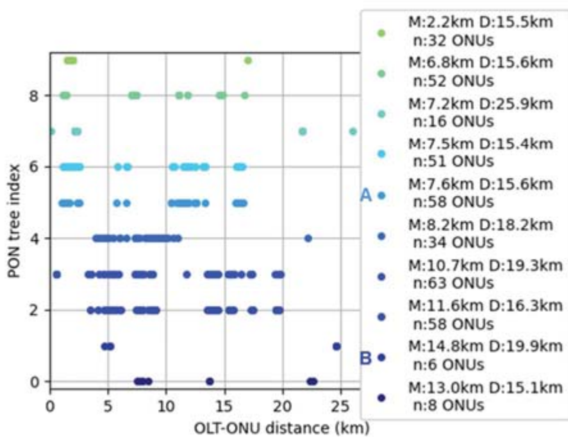

Fig. 3: OLT-ONU distance distribution for "tough cases" (a line represents an ODN, a dot represents an ONU)

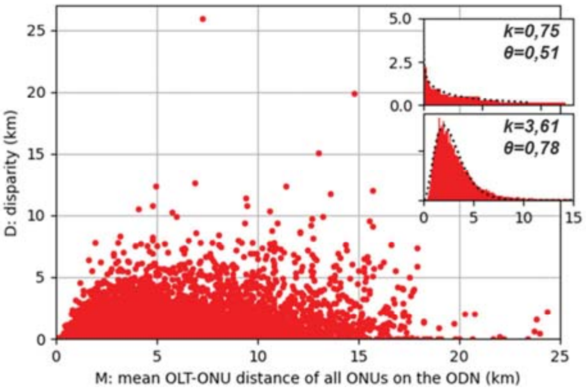

Fig. 4: ODNs characteristics (ONUs per ODN ≤ 16)

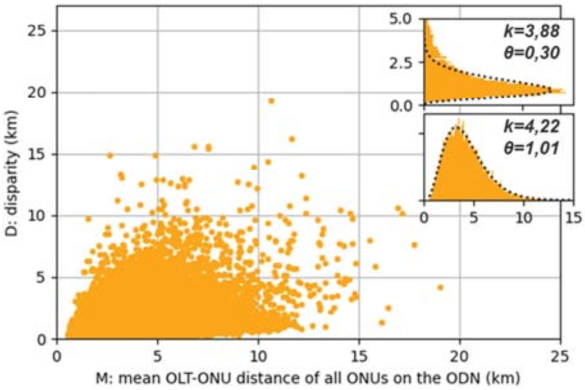

Fig. 5: ODNs characteristics (ONUs per ODN ≥ 48)

between the farthest and the closest ONU to the OLT, on the same ODN [km].

- n : number of ONUs per ODN.

We assumed that, given the high number of ONUs considered, the measurement errors intrasic to PON round trip delay precision where globally self-compensating.

Each of the 123 000 ODNs is represented on Fig. 2 by a dot of coordinates M (mean OLT-ONU distance) and D (disparity). ”M” and ”D” distributions are presented in the top right corner of Fig. 2. A Gamma distribution model of parameters [k, θ] (displayed on Fig. 2) is used to modelize the field data.

”M” is globally low, with an average of 3.6 km, compared to the maximum affordable 20 km distance. Today’s disparity D on Fig. 2 is also low in the majority of the cases. D even equals 0m as long as the ODN hosts only a single ONU. However, on this sample, 10 ODN, referred as ”tough cases” on Fig. 2, exhibit a disparity higher than 15km.

Fig. 3 depicts the OLT-ONU distance for the 10 “tough cases” (D>15km), where each line/color is an ODN and each dot an ONU. It shows that the disparity can be important whether the tree is full (case “A” on Fig. 2&3, 58 ONUs) or almost empty (case “B”, 6 ONUs).

Fig. 4 and Fig. 5 are variants of Fig. 2: Fig. 4 represents D vs M when “n”, the number of ONUs in the ODN, is lower than 16 and in Fig. 5 when ”n” is higher than 48. As expected, in Fig. 4 the majority of the ODNs are close to the bottom line: disparity is low, even if some ODNs demonstrate an important disparity with few ONUs. Fig. 5 shows what should probably look like a more realistic D vs M graph in a near future when the optical fiber will be the reference broadband technology, and ODNs will be more filled.

Discussion and conclusion

The previously presented figures are today’s deployment data in a real PON network. We can assume several evolutions from those:

The mean OLT-ONU distance of all ONUs on the ODN (M) will probably increase. Today’s deployment mainly concern urban and short reach areas. Many long reach rural areas need to be connected in France.

For the same reason, the disparity (D) can only increase. Such an important disparity of OLT-ONU distance over the same ODN substantially complicates the work on interoperability for HS-PON, regarding the high number of transmission channels combinations, even on the same ODN. Proposing another technological solution for the “tough cases” may seem seducing (e.g. several point to point sharing the PON ODN), but it would become an operational nightmare in terms of deployment, maintenance and provisioning through the information system when mixed with PtMP.

From the three equalization scenarios proposed (unified, adaptive, and “per ODN”), the “per ODN” equalization does not seem superior to adaptive equalization, according to the variety of OLT-ONU distance and then CD range that could be encountered in a single ODN. The feasibility of unified equalization, with DSP parameters pre-adjusted to meet all possible transmission channel combinations, is still to be demonstrated with PON cost constraints at 50Gb/s. On the other side, adaptive equalization as proposed in this paper requires a solution for the equipment to be aware of the transmission channel characteristics (Tx/Rx bandwidth and CD range), which is not under study in standardization bodies yet. At the end of the day, it will be mandatory for HS-PON to be interoperable to be successful.

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