Carrier Lab Trial of a Real Time 50G-PON Prototype

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Abstract *The design and performance of a first real-time 50G-PON prototype with 50Gbps downstream and 25Gbps upstream line rate is described. Results from trials in a network carrier lab show ~40Gbps downstream service capacity with ~80µs latency for a 10km fibre link.*

Introduction

Fibre access networks have been deployed on a massive scale using passive optical network (PON) technology. To date, GPON [1] has been the most widely deployed PON technology with several hundreds of millions of subscribers to date. From around 2016, network operators have been upgrading their Gigabit class PON networks to 10Gbps. For those deploying ITU-T PON, this means XG(S)-PON offering 10Gbps downstream (DS) rate, and 10Gbps or 2.5Gbps upstream (US) rate [2, 3]. With the success of these early 10G-PON deployments in mind, in 2016, the ITU-T began studying options for upgrading PON deployments to line-rates greater than 10Gbps. Following an initial feasibility study period, it was agreed in 2018 to start a project on Higher Speed PON operating at 50Gbps line rate [4]. In April of 2021 the series of recommendations for 50G-PON were consented in the ITU-T.

50G-PON is a TDM/TDMA based PON system using NRZ modulation and high gain FEC to enable operation over installed access fibre infrastructure. The system uses the O-band to benefit from low fibre chromatic dispersion (CD). 50G-PON is the first PON system to be specified assuming that Rx-side DSP will be used. At the cost sensitive ONU, use of mature 25Gbps APD devices is assumed. Bandwidth limitations may be overcome using DSP based equalisation (EQ). Furthermore, fibre CD induced ISI may also be compensated by the DSP. For the DS 50Gbps signal at 1342±2nm an accumulated CD= 77.1ps/nm must be tolerated.

To date, there have been several studies on the physical layer aspects 50G-PON with a particular emphasis on the use of limited bandwidth Rx and DSP at 50Gbps NRZ. For example, [5] showed how both Rx-side EQ and advanced FEC can be used to support 50G-PON DS transmission. The only report to date of a real-time 50G-PON link is in [6]. In this paper, the authors demonstrated a real-time DSP and implemented a simplified PON MAC function. This proof of concept, bench-top demonstration was performed over a two fibre link whereas single fibre operation is required for PON systems.

With the 50G-PON standard nearing final publication, network operators and system vendors are motivated to build prototype systems to begin planning for future products and network deployments. With this in mind, a first real-time 50G-PON prototype has been built in a commercial PON chassis and tested in a carrier lab trial. This early prototype demonstrates unique features of 50G-PON such as the EQ of bandwidth limited TRx components.

This paper describes the design of the real-time 50G-PON prototype and the main performance parameters. Furthermore, first results from carrier lab trials are reported. To the best of our knowledge, this is the first such real-time 50G-PON prototype system.

50G-PON Prototype

The 50G-PON prototype works with a DS rate of 50Gbps and US rate of 25Gbps. Figure 1 shows the 50G-PON prototype functional blocks. Both OLT and ONUs consist of three main functions: OLT/ONU PON MAC, DSP (in FPGA) and Tx/Rx optics assembled in bidirectional module (BOSA). In the DS direction, the OLT uses a 1332nm, 25Gbps EML with ~19GHz 3dB bandwidth and the ONU uses 25Gbps APD. 50Gbps NRZ transmission DS is achieved by exploiting DSP. In the US direction, the ONU also uses a 25Gbps EML as the Tx (1272nm) but the OLT uses a 10Gbps burst-mode (BM) APD Rx + DSP to realise 25Gbps NRZ reception.

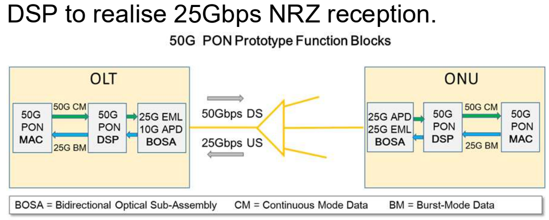

Figure 1: 50G-PON prototype functional blocks

Figure 2 expands on the details of the functions to realise the 50Gbps DS link based on 25G-class TRx. All functions shown in blue are implemented in the DSP block. At the OLT Tx side, the 50G-PON MAC provides the conventional point-to-multipoint access control functions as for previous generations of PONs. The DSP block mainly implements low-density parity-check (LDPC) encoding and Tx pre-EQ from the DAC to drive the 25Gbps EML and give a 50Gbps NRZ optical output. At the ONU Rx, besides the ADC function, clock recovery (CR), digital EQ and LDPC FEC decoding are all implemented in the DSP block.

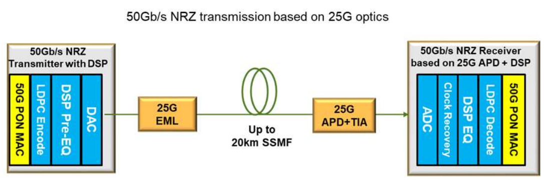

Figure 2: 50Gbps NRZ transmission based on 25G-class optics for 50G-PON downstream

In the US direction at 25Gbps, the functional blocks are similar to the DS. The major differences are: (i) there is no need for pre-EQ as the Tx is 25Gbps capable and (ii) the US signal is burst-mode, so a BM-CDR is necessary in the DSP at the OLT Rx.

The LDPC code-word implemented in the prototype is [17280, 14208] with code-rate = 0.822 – only slightly different from the default code-word ultimately agreed for 50G-PON in the ITU. The tolerable input BER can be up to 1.2×10^{-2} to achieve an output BER= 10^{-12}.

Key Performance Results

Test results from the prototype units described above demonstrate the key performance characteristics achieved. Being a prototype, we don't expect full compliance to ITU standards at this time, especially as, the ITU standards had not yet been completed when the prototype was developed.

Fig. 3 shows the physical layer test configuration with the 50G-PON line card in a commercial PON chassis connected to two 1U height ONU units. The ODN consists of a fibre span, a VOA and a 2:8 power splitter. Unused ports of the splitter are used to monitor the optical signals. An Ethernet traffic tester is connected to the uplinks on the OLT and the user network ports of the ONUs.

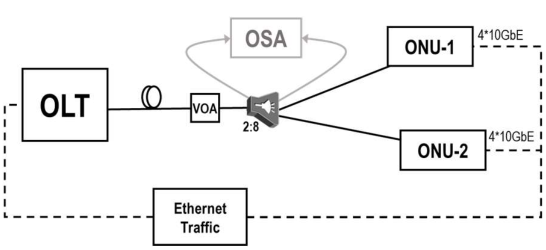

Fig. 3: Physical layer test configuration

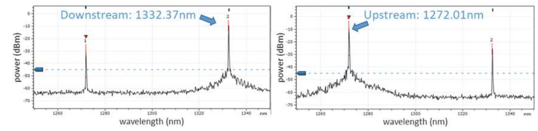

Fig. 4 Optical spectra for (a) DS signal and (b) US signal.

Fig. 4 shows the spectra recorded on the Optical Spectrum Analyser (OSA). The Rx sensitivity of the ONU is measured using a variable optical attenuator to adjust the power into the ONU. Fig. 5 shows such a measurement for ONU-1. With symbol-spaced feed forward equalization (FFE) DSP, a sensitivity of -20.1dBm was measured in back-to-back for a BER = 1.2×10^{-2}. For the G.652 fibre and Tx wavelength used here, there was no significant degradation observed after 20km fibre transmission.

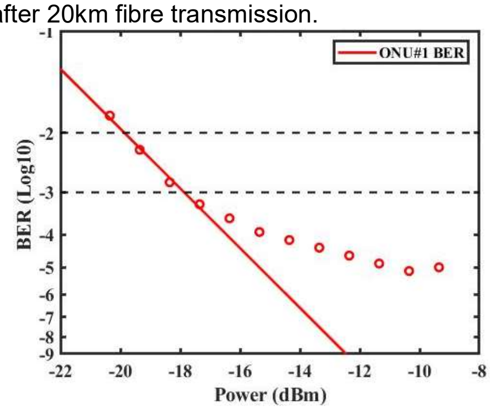

Fig. 5 BER vs received power at the ONU.

Considering the +2dBm launch power from the OLT EML Tx, the link budget demonstrated is ~22dB. With a specifically developed 1342nm Tx for 50G-PON based on an EML+SOA, optical power in excess of +10dBm is feasible [7]. It is also expected that the extinction ratio of the OLT signal can be improved as it is currently limited by the driver. Furthermore, the Rx sensitivity will be improved in an ASIC implementation with stronger DSP e.g. with more FFE taps or MLSE. Thus, the required link budgets in excess of 30dB are fully achievable and so enable backward compatibility with deployed ODNs.

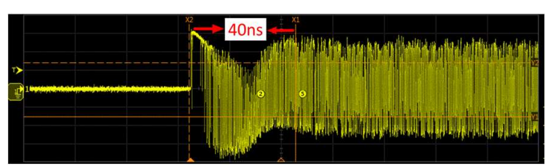

Fig. 6: 25Gbps Burst-mode upstream signal reception

In the US direction, the key technical challenge is the BM reception. Each US burst includes an overhead at the beginning for BM-TIA and BM-CDR settling. Fig. 6 shows a BM-TIA settling time of ~40ns for the prototype. The BM-CDR function is implemented in the DSP and achieves a similar settling time as for XGS-PON.

Carrier Lab Trial

Figure 7 shows the detailed carrier lab trial set-up for the 50G-PON system. In the ODN part, a 1:4 splitter (IL≈6.8dB) and a 1:8 splitter (IL≈10.4dB) are cascaded. The cascaded optical splitters are connected to the OLT and ONUs through 10km of G.652 single-mode fibre (IL≈3.5dB). Therefore, including the insertion loss of the two connectors (~ 0.4dB each), the total ODN loss is about 21.5dB. This laboratory ODN configuration is very similar to a deployed 10G EPON network ODN (1:32 split, 5~10km optical fibre distance). One key difference is that, in a real network deployment, the 10km optical fibre may be composed of more connectors, which would typically bring additional insertion loss.

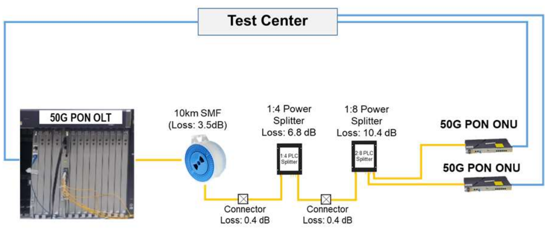

Figure 7: Carrier lab trial test configuration

The Test Centre is connected to the uplink interface of the OLT equipment in a commercial 50G-PON chassis, and the user-side UNI interfaces of two 50G-PON ONUs (ONU1 and ONU2). The Test Centre is configured with multiple 10Gbps test data streams in the DS (OLT to ONU1/2) and US directions (ONU1/2 to OLT). The first test case demonstrated the successful discovery and registration of ONU1 and ONU2 equipment by the OLT.

Further testing focussed on the key performance parameters of service rate (i.e. useful traffic capacity) and latency. These test results show that, in actual operation, the 50G-PON prototype system realised the following performance:

1) A 39.948Gbps downlink service throughput and a 15.986Gbps uplink service throughput.

2) Forwarding delays of ONU1 and ONU2 in the DS direction are respectively 80.753μs and 79.755μs, as shown in Figure 8.

In the DS, LDPC is the primary overhead factor at 17.8% so a throughput of 40.908Gbps is the best that could be expected. Additionally, some small loss of capacity can be attributed to the PON framing (XGEM). We also configured a 2% throughput margin during the test compared with the maximum capability.

In the US, besides the LDPC overhead, there is extra burst overhead for US transmission (Fig. 6). Considering purely the LDPC overhead, a best case of 20.454Gbps throughput could be expected for a single connected ONU. The guard time needed for two ONUs, and hardware limitations in the prototype, result in an efficiency reduction vs the ideal case.

The link latency consists of fibre propagation, DSP processing, PON MAC processing and packet forwarding. The fibre contributes ~50μs, LDPC and DSP processing ~5μs, PON MAC processing also ~5μs and the remaining ~20μs comes from packet processing and forwarding.

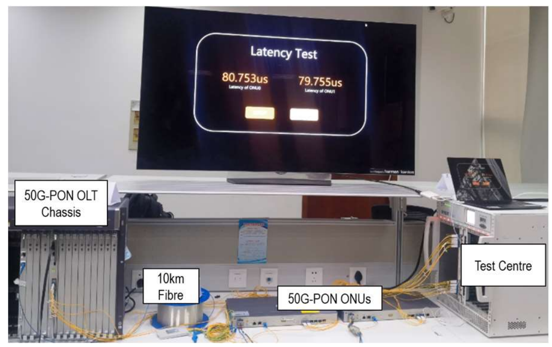

Figure 8: Latency measurement in carrier lab trial

In addition to the above traffic measurements, the 50G-PON was also tested with a Video on Demand service. Guaranteed bandwidth was configured for the video traffic and UHD video played smoothly at the ONU side in the presence of Ethernet traffic filling the remaining capacity.

Conclusions

We report, to the best of our knowledge, the first real-time prototype of a 50G-PON implemented in a commercial PON equipment chassis. The prototype demonstrates all the key features of a PON system e.g. including PON protocol features such as ranging and activation. The prototype implements the current maximum standardised option of 25Gbps upstream. Carrier lab testing has shown Ethernet service rate throughput of ~40Gbps downstream and ~16Gbps upstream. Low latency ~80 μs (with 10km fibre) was also demonstrated. This prototype clearly shows significant progress towards real product implementations.

In future, with the ADC function integrated with the DSP, soft decision can be easily implemented, thereby further improving the FEC gain and increasing the Rx sensitivity. With optimised optical components, and an ASIC based DSP and PON MAC, we expect to meet all the requirements of the recently consented ITU standard for 50G-PON.

References

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