An experimental set-up for the feasibility study of embedded optical fiber monitoring

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This paper introduces a new embedded optical fiber monitoring (OFM) technique to characterize the channel response of a passive optical network (PON). Embedded OFM aims to integrate a cost-effective monitoring unit inside the transceiver module of optical networks. As a feasibility study for this purpose, an original experimental lab set-up was developed that consists of a front-end with an optical transceiver module, a configurable digital control platform and a back-end data processing unit. The first optical time-domain reflectometry (OTDR) curve of the lab experiment with 15 km G652 single-mode optical fiber was obtained by the use of our embedded OFM method. This proves the new OFM concept and the correct functioning of the experimental set-up.

Introduction

Classic optical time-domain reflectometry (OTDR) is a valuable technique for characterizing losses and locating faults in fiber communication links [1][2]. This is suitable for traditional long haul and metro fiber-optic networks. However, the fiber-to-the-home (FTTH) architecture, which uses a passive optical network (PON) technology, has optical splitters between an optical line termination (OLT) and optical network units (ONUs). Fiber monitoring is usually done by performing OTDR measurements at the OLT side. Today this requires extra equipment that is connected to the line under test, which is quite expensive. Therefore, an integrated approach is needed that provides the measurement capability in every network element that is connected to a fiber link. For PONs, measurements from both the ONU and the OLT side are required, as it is impossible to distinguish reflections from the different fiber branches behind the optical splitter. The solution should be cost-effective, as each ONU should be expanded with the monitoring hardware. Classic OTDR may gather the required information, but imposes severe limitations. Moving OTDR functionality into optical transceiver modules, the OTDR measurement will become an integral part of the transmission equipment and of the management systems in future optical access networks. This is called embedded OTDR.

Some commercial embedded OTDR modules [3] are already under development for the emerging market. To simplify the structure of the optical module and reduce the cost of OTDR unit even further, a novel approach for an embedded OTDR is proposed in this paper. An original experimental set-up was built and the first OTDR curve with 15 km G652 single-mode optical fiber was obtained. This proves that it is possible to monitor a complete PON system cost-effectively and that the experiment set-up is functionally correct.

Measurement concept

The OTDR measurements at the OLT side of the network suffer from reduced sensitivity due to high splitting losses and from ambiguous results due to the superposition of many OTDR traces originating from different PON drop sections. To monitor the fiber status and locate a fault in the drop section more accurately, the better choice is to integrate an OTDR unit in the ONU. In this paper, comparisons are made among the traditional OTDR, the current embedded OTDR and our proposed novel embedded OTDR from the ONU side.

Actually, to perform a traditional OTDR measurement from the ONU side of the PON system, a complete set of an optical transceiver module with an extra laser diode (LD) and an extra photo diode (PD) is needed, which is independent from the optical transceiver module of the date link with different wavelengths. Out of consideration for the cost issue, it is not an optimum solution for the integration in every ONU. Figure 1 shows one of the current embedded OTDR solutions for a commercial embedded OTDR product [3]. Comparing with the traditional OTDR solution, this embedded OTDR solution is improved and a dedicated OTDR LD is saved. However, in addition to the ONU data link optical module, a separate OTDR PD is still needed and one extra 10% -tap coupler is required too, which is used to measure the optical reflections from the data transmission fiber link.

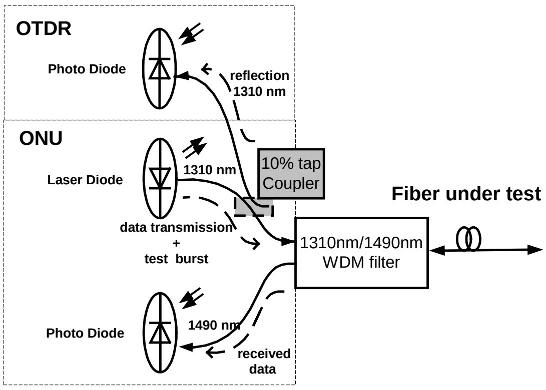

Figure 1: Current embedded OTDR for PON

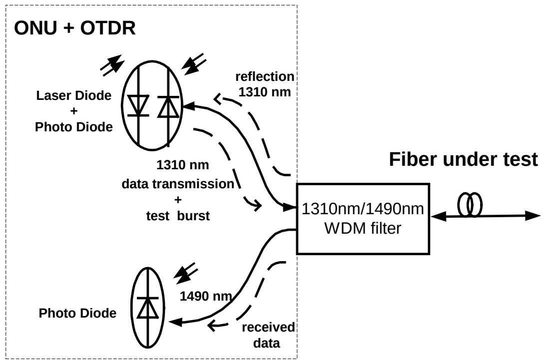

Figure 2: Proposed embedded OTDR for PON

As suggested in figure 2, the proposed (ONU+OTDR) optical transceiver module simplifies the sub-system hardware. Without any added optical component, it is a cost-effective integrated solution for the embedded OTDR. The 1310 nm LD of the upstream burst mode transmitter is mounted into a coaxial package integrated with a monitor PD and a single mode fiber pigtail. There is no optical isolator between the LD and the monitor PD of the optical module. Originally, the LD transmits data bursts and the monitor PD monitors the emitted optical power closing the automatic power control (APC) loop. During the idle window between two bursts, the LD can transmit an OTDR test burst and the monitor PD acts as an OTDR photo detector to receive reflections. In this way, an OTDR measurement can be performed using the same optical module that normally functions as an optical transmitter in the data link.

Experimental set-up

Conceptually, the reflectometry measurement is straightforward: a laser pulse is sent from the OTDR LD up to the test fiber, and the fault reflects it back to the OTDR PD. The return delay time is indicative of the distance to the fiber break. The optical power and the shape of the received reflections will disclose more details about the status of fiber under test. In order to realize the measurement concept and verify the feasibility, an original experimental lab set-up was built. The set-up (figure 3) consists of a front-end with an optical transceiver module, a configurable digital control platform and a back-end data processing unit.

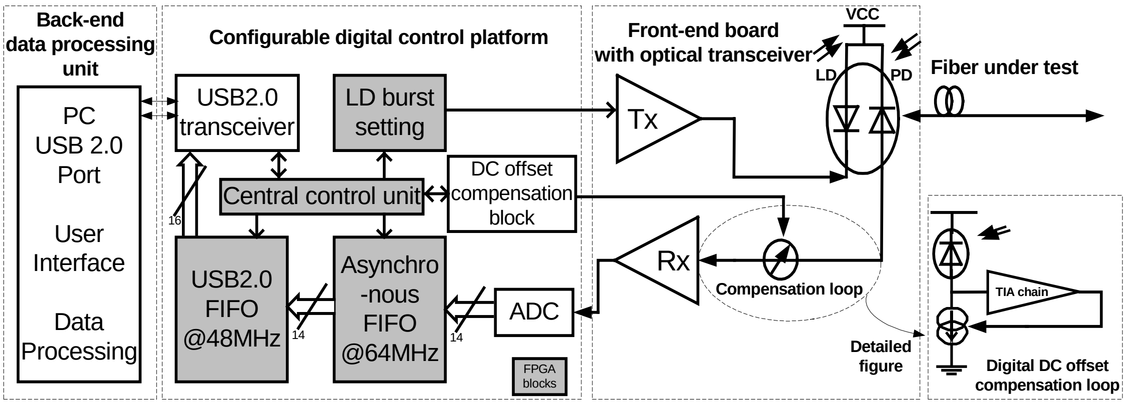

Figure 3: Proposed embedded OTDR experimental set-up

A 1310 nm InGaAsP/InP FP laser diode module was selected for the OTDR measurement, which is mounted into a coaxial package integrated with a monitor PD and a single-mode fiber pigtail. A 15 km G652 single-mode optical fiber is coupled to the optical transceiver module as the DUT (device under test). Next to the optical transceiver module, the front-end consists of a laser driver and a DC-coupled TIA-receiver. The OTDR receiver linearly amplifies the weak reflection signal such that it can be digitized with sufficient resolution by an analog-to-digital converter. The DC coupled front-end receiver in the set-up consists of a TIA and an amplifier stage. During receive mode, the weak reflection signal is amplified and filtered out from the wide-band noise floor by a 20MHz low-pass filter. The received analog signal is sampled by a high-speed low SNR (Signal-to-Noise Ratio) AD converter which runs at a sampling rate of 64 MHz. The samples are processed by FPGA and transferred to a computer through USB 2.0.

The configurable digital control platform comprises a high-speed AD converter, a Virtex II FPGA module, an DC offset compensation block and a USB 2.0 transceiver module. The FPGA module is programmed by the computer through a USB 2.0 transceiver and acts as a configurable central control unit afterwards. During the initialization mode, the FPGA will receive commands from the user interface, parse them and perform the corresponding front-end settings such as the LD burst or DC offset compensation. The user interface runs on the PC linux based platform. During the operation mode, FPGA will receive a large quantity of reflection samples and transfer them to the back-end processing unit. Final OTDR curve will be given out after data processing in the Matlab environment on the computer.

Since the dark current of the monitor PD can shift several nAs with the environment temperature changing, the relative big DC offset compared to the received weak reflection signal will overflow the OTDR receiver. To remove this DC offset, the digital offset compensation is a better way than compensating the DC offset manually. The digital offset compensation block was based on the 12-bit 2-wire (I^2C Compatible) serial interface DAC. The binary search algorithm was implemented with the compensation loop in figure 3, which can automatically remove the DC offset.

Measurement results

A 15 km G652 single-mode optical fiber was coupled into the optical transceiver module of the front-end. A dedicated optical pulse with 10 us width and 2 dBm peak power was injected into the test fiber. In order to improve the signal-to-noise ratio, an averaging function was implemented in the back-end processing unit and the final reflection curve was averaged out as shown in figure 4.

The reflection curve was obtained N times (N=1000 in figure 4) with repeated optical pulse injection to the test fiber. Care has to be taken that every pulse keeps the exact width and peak power. Also the time slot between every two pulses is long enough to avoid overlapping of reflection signals. In a series of N trials, the reflected signal was clearly visible above the noise. The first exponential region of the curve results from rayleigh backscattering reflection and the pulse with 10 us (640 cycles@64MHz) width results from the discrete fresnel reflection at the end of the fiber.

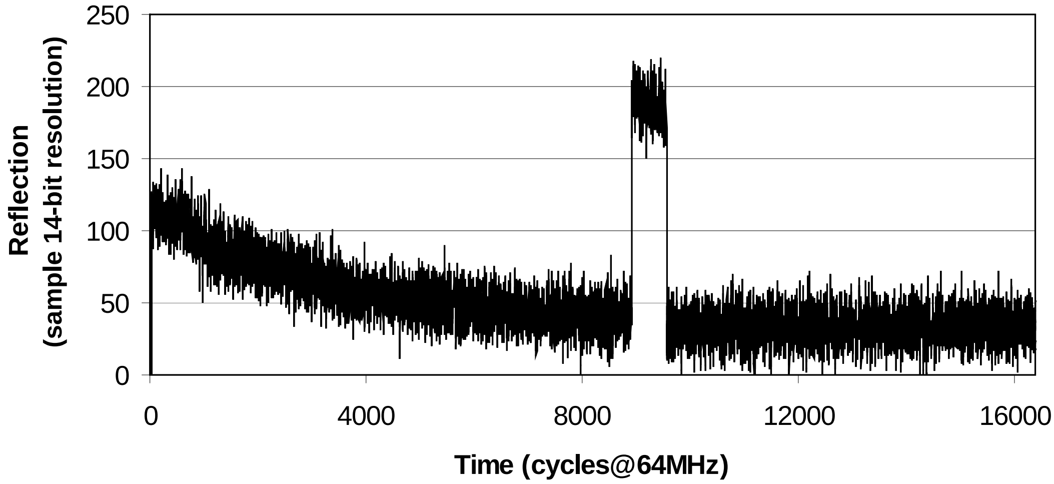

Figure 4: Embedded OTDR curve from proposed experimental set-up

Conclusion

It has been shown how an original experimental set-up performs the embedded OTDR measurements. The first embedded OTDR curve with 15 km G652 single-mode optical fiber was obtained by the use of the proposed embedded OFM method. The feasibility of this embedded OTDR method was proved. This technique and experimental set-up will be used in the future work to perform further OTDR measurements of the PON system.

References

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