

Embedded OTDR Monitoring of the Fiber Plant behind the PON Power Splitter

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We present a laboratory prototype which verifies a novel embedded optical time-domain reflectometry (OTDR) approach. It integrates inexpensive fiber monitoring functionality into an optical network unit (ONU) transceiver module of passive optical networks (PONs). The prototype includes a laser module, an analog front-end, a reconfigurable digital control platform with back-end data processing and a graphic user interface. The prototype demonstrates accurate OTDR measurements of two cascaded sections of optical fibers behind a power splitter representing a PON drop fiber section. Experiments show backscattering curves and Fresnel reflections where signal-to-noise ratio was improved by signal processing.

Introduction

For tomorrow's broadband optical access networks, the point-to-multipoint (P2MP) network architecture has best cost to performance ratio and its deployment is gaining momentum fast. A time division multiplexing (TDM) P2MP network contains optical power splitters between an optical line termination (OLT) and optical network units (ONUs) (Fig. 1). Time slots are allocated for the upstream traffic from each ONU to the OLT, during which the ONU transmits upstream data in bursts, rather than continuously. The burst-mode ONU data transmitter comprises an optical laser module and a laser driver. The large scale of modern PONs makes cost-efficient fiber monitoring from the ONU side desirable, to reduce the operation and maintenance costs. By integrating OTDR (optical time-domain reflectometry) functionality into optical transceiver modules, the embedded OTDR becomes an integral part of the network, which can be accessed by the PON management plane to monitor and test the quality of the physical layer.

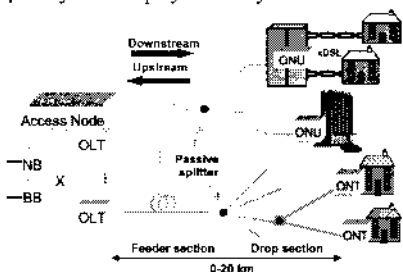


Fig. 1. Fiber network with TDM P2MP topology

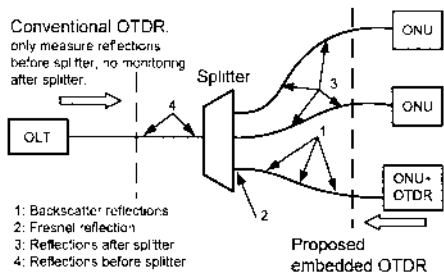


Fig. 2. Proposed embedded OTDR can monitor fiber drops without ambiguities

Conventional PON fiber monitoring is performed by OTDR measurements at the OLT side (Fig. 2). However, this suffers from reduced sensitivity due to high splitting losses and from ambiguous results due to the superposition in time of multiple OTDR traces originating from different ONU 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. As the high split ratio of P2MP networks makes the cost of the ONU a dominant decision criterion, a recent concept for low-cost ONU-embedded OTDR reuses the existing ONU data laser diode (LD) and laser driver [1]. This reduces the cost to a certain extent as no dedicated OTDR laser and driver are required, but an additional coupler and photo detector are still needed.

This paper presents a novel technique called FiberMon for embedding OTDR into existing data transmitters, suitable for monitoring the fiber plant of a wide range of TDM optical networks in the background, during network operation. The OTDR hardware is purely electronic, integrated inside the burst-mode optical transmitters (BM-Tx), and does not require extra (electro-)optical components. An original FiberMon prototype was built containing an optical front-end, a reconfigurable digital platform and graphic user interface (GUI). Experimental results prove the functionality and the feasibility of embedded OTDR. The FiberMon technique is developed with PON (passive optical network) specifications in mind [2], but is in fact quite generic.

The FiberMon Embedded OTDR Concept

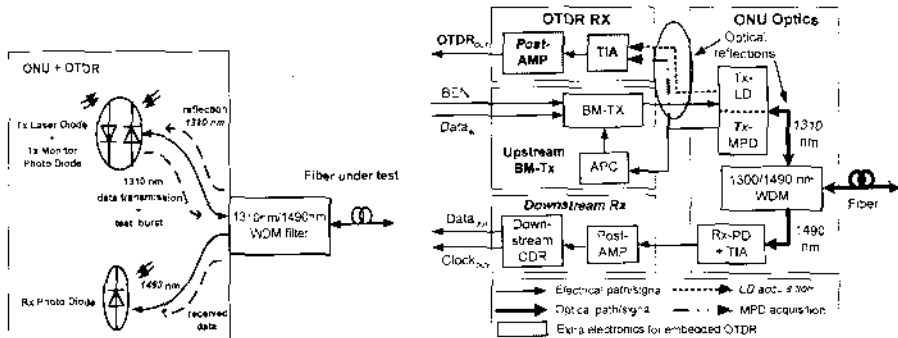


Fig. 3. The optical architecture of an ONU

Fig. 4. A PON ONU transceiver with embedded OTDR

Fig.3 shows the ONU optics, with the 1310nm reflection to be used for OTDR. Reflection-tolerant Fabry-Pérot (FP) lasers with integrated monitor photo diode (MPD), and vertical-cavity surface-emitting lasers (VCSELs), are cost-effective in a PON ONU, as the expensive integrated optical isolator can be omitted. During data transmission the LD emits light bursts and the MPD monitors the emitted optical power, serving the automatic power control (APC) loop. During the idle time window between two bursts, the LD can transmit an OTDR test signal after which the LD and/or MPD act(s) as an OTDR photo detector to receive the optical reflections. Fig. 4 shows a PON ONU transceiver with embedded OTDR unit. It consists of ONU optics, upstream 1310 nm BM-Tx, downstream 1490 nm receiver (Rx) and 1310 nm OTDR Rx. This OTDR hardware doesn't need any additional OTDR optics and only requires a limited amount of extra electronics. If there are no suitable idle time windows, FiberMon can perform OTDR measurements in the background by processing the optical echo signals caused by the data bursts themselves. LD and/or MPD then receive(s) the optical reflections immediately after emission of a data burst. Mathematical analysis and simulation have proven that the response of a pulse with arbitrary width can be converted into the standard step response, when the OTDR front-end is sufficiently linear [3]. In this way, fully non-intrusive OTDR can be performed that does not interfere with the ongoing traffic nor penalize the network performance.

Experimental prototype

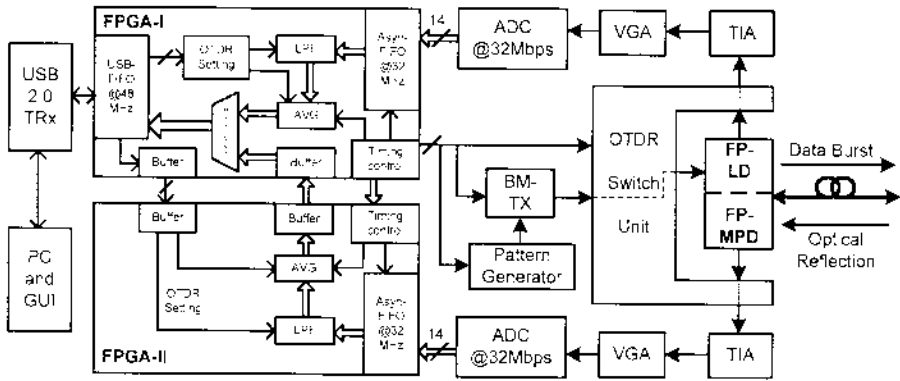


Fig. 5. Block diagram of experimental prototype

Fig. 5 shows the block diagram of the experimental prototype. The selected LD, a 1310 nm InGaAsP/InP FP laser chip, is mounted in a coaxial package with a MPD and a single-mode fiber pigtail. The OTDR switch unit (OSU) performs a fast switchover between two states: transmit mode and monitoring mode. During transmit mode, the BM-Tx connects to the forward-biased LD and modulates it with the input data signal. After transmission, the OSU shuts down the LD very quickly, and connects the OTDR analog front-end (OAF) to the LD and/or the MPD. The transient time of the OSU switchover is made short. An OTDR TIA bandwidth of 5 MHz trades-off spatial resolution and noise reduction. A variable gain amplifier (VGA) matches the input range of the analog-to-digital conversion (ADC) to the level of the received optical reflections. The ADC samples the amplified reflection signal at 32 Mbps with a 14-bit resolution, offering ample dynamic range to detect the optical events in a PON network. Performing the OTDR measurement simultaneously on both FP-LD and FP-MPD channels is interesting because it can provide a more efficient fiber monitoring with substantial averaging. For this purpose two Virtex-II FPGAs perform real-time processing, one on each channel, and provide OTDR data path connectivity between the OAF and GUI. The FPGA modules are programmed by the computer through a USB 2.0 transceiver (TRx) in a daisy chain. Both FPGAs and ADCs are synchronized to each other. FPGA-I is the master and contains a hardware counter that provides accurate timing for the OTDR measurements. FPGA-I and FPGA-II communicate bi-directionally to deliver measurement data and to set OTDR parameters. During initialization, FPGA-I receives commands and parameters from the GUI, parses them and performs the corresponding configuration of the real-time OTDR processing blocks in FPGA-I and FPGA-II. These tasks include loading low-pass filter (LPF) coefficients, setting averaging and interleaving, and defining the width of the injected pulse and the length of fiber under investigation. During operation, both FPGAs receive a large amount of reflection samples simultaneously. Asynchronous FIFOs (first-in first-out memories) in both FPGAs will store this OTDR trace momentarily. After filtering and averaging, the USB-FIFO transfers them to the computer. An updated OTDR trace is shown on the GUI, which runs on a Linux based PC platform, and the dataset is saved for further backend data processing.

Measurement results

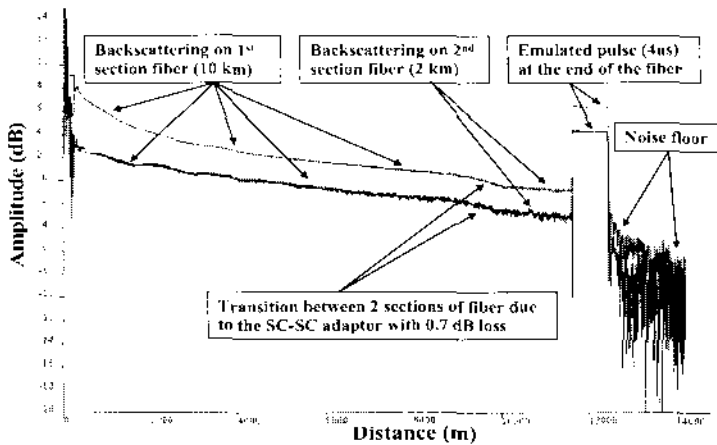


Fig. 6. Measured OTDR curves in log scale on FP-LD and FP-MPD simultaneously from the proposed experimental prototype

The prototype hardware was connected to two cascaded sections of ITU-T G652 compliant single-mode optical fiber with a similar backscatter constant and attenuation: a first section of 10 km, and a second of 2 km with a Fresnel reflector at the end. Pulses with 3 dBm peak optical power were injected repeatedly into the test fiber. In order to improve the signal-to-noise ratio (SNR), an averaging function and low-pass filtering block were activated in the FPGAs. The top OTDR trace on Fig. 6 is measured from an FP-LD with 0.12 A/W responsivity, the bottom one from a FP-MPD with 0.033 A/W responsivity. The two linear sections with 10 km and 2 km length in Fig. 6 result from Rayleigh backscattering. A transition region can be noticed with a width of 4 μ s, which indicates an SC-SC adaptor with 0.7 dB loss. At the end of the fiber, the Fresnel reflector can be clearly distinguished with a 4 μ s width emulated pulse [3]. By simultaneously measuring on both the FP-LD and the FP-MPD, a relatively stable combined optical reflection is obtained, and the polarization dependency of a FP laser module can be compensated considerably.

Conclusions

It has been shown how an original experimental prototype performs the embedded OTDR measurements. The SNR improved embedded OTDR curve with 12 km G652 single-mode optical fiber was obtained by the use of the proposed embedded method. This technique and experimental prototype will be used in the future work to perform further OTDR measurements of the PON system.

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