Numerical Simulations of in Service Monitoring Technique for Passive Optical Networks Using Time Domain Reflectometer with Fiber Bragg Gratings

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We present numerical simulations of a monitoring technique for passive optical networks. The proposed technique is based on using an optical time domain reflectometer with fiber Bragg gratings which collaborate with the information provided by the Rayleigh backscattered power to distinguish between the different branches in the network. This will allow us to determine the position of any problem or losses in the network easily. We also include splitters in the simulated traces of passive optical networks. These simulations provide an important software tool for telecom companies to achieve low cost and efficient monitoring techniques in fiber to the home networks.

Introduction

Passive optical networks (PONs) are among the most promising solutions for fiber to the home due to the significant cost reduction on active components/devices and fibers sharing [1,2]. Since these networks can accommodate a large number of subscribers, when any fault occurs at one point in an optical fiber line, the access network will be out of service behind the break point. Faults affect the whole services transmission. This makes monitoring and maintenance techniques so important to guarantee quality of service through the PON.

One way to monitor optical networks is by using optical time domain reflectometer (OTDR). This technique is used for fault detection and localization in optical fiber links. In PONs, OTDR is used as a troubleshooting device which allows us to determine faults, splices, and bends in fiber optic cables. OTDRs take advantage of the scattering of light in the optical fiber to make their measurements by emitting a high-power pulse that hits the fiber, some power is scattered back. This scattered light is measured, converted to an OTDR trace (backscattered power as function of the distance). These traces are used to localize the network faults which can be a fiber breakage, losses from a splice, or reflections from a connector. The more quickly troublesome issues are identified and addressed, the lesser the fiber optic network will suffer from data transfer problems. Normally, an OTDR measurement can take between ten seconds and three minutes.

Several numerical methods have been developed to simulate the time traces of OTDR [1]. Although these models could generate an OTDR trace, they do not include the effect of the splitters but instead they only consider the simulation before and after the splitter.

In this paper, We present a mathematical model for the numerical simulations of the OTDR, In these simulations, we take into account the existence of the splices, the connectors, and the splitters in the network. We use fiber Bragg gratings (FBGs) as reflective elements with a certain reflection ratio in each branch to distinguish between the different branches. This software tool allows us to simulate the OTDR traces of PONs, which include splitters allowing the analysis of an OTDR monitoring of PONs from the central office. This feature is not found in any other existing state-of-the-art OTDR simulator [3]. This will help to analyze the feasibility of remote monitoring of the PON and if feasible, to reduce the cost and the time which are normally required to perform an OTDR tracing from the user site.

Rayleigh backscattering module

OTDRs launch pulses of light into a fiber under test and then measure the intensity of the backscattered light as a function of time. The differential width of this pulse is given by

$$dz = dt * v_g \tag{1}$$

where $v_g$is the group velocity of the laser pulse and dt is the pulse duration. Let us consider P_o is the peak power of the pulse, then the total backscattered power near the OTDR's front-panel connector is given by:

$$dP_{bs} = 0.5 * P_o * \alpha_s * S * dz \tag{2}$$

In equation (2), S is the backscatter factor, α_s is the attenuation in 1/km due to Rayleigh scattering. P_o is the pulse peak power. The total backscatter near the OTDR's front panel from the pulse can be rewritten as:

$$P_{bs} = 0.5 * P_o * \alpha_s * S * \int_0^D e^{-\alpha z} dz \tag{3}$$

where α is the total attenuation constant in 1/km for the fiber and D is the physical pulse width. In modern telecommunications fiber, α and α_s are nearly the same [1]. Solving equation (3), we have:

$$P_{bs} = 0.5 * P_o * \alpha_s * S * [\frac{1 - e^{-D*\alpha}}{\alpha}] \tag{4}$$

Expanding the exponent term in equation (4) and keeping only the first- and second-order terms, we get:

$$P_{bs} = 0.5 * P_o * \alpha_s * S * W(1 - W * \alpha) \tag{5}$$

In equation (5), W represents the pulse width in km. If the length of the laser pulse is small compared to the fiber's attenuation constant, then the quantity $(1 - W * \alpha)$ is approximately 1, and equation can be simplified to:

$$P_{bs} = 0.5 * P_o * \alpha_s * S * W \tag{6}$$

This equation will form the basis for our matlab simulation model. In this equation, we see that the backscattered power is directly proportional to the scattering coefficient, the pulse width and the laser power. The backscatter coefficient, S, depends on the type of fiber being tested, and is proportional to the square of the ratio of the fiber's numerical aperture to its core index.

Numerical results

We build a complete model in Matlab to simulate the backscattered power in PONs. In this model, we take into account the fiber segments, the nonreflective events, the reflective events, the splitters and branches. Moreover, we use fiber Bragg gratings as a reflective component at the end of each branch of the splitter. In the fiber segments, we calculate the losses due the attenuation. Optical Fibers are typically joined using mechanical splices, connectors, or fusion splices. Fusion splices are formed by aligning the fibers and then locally melting their ends with a hot electric arc discharge.

Once the fibers are fused, they essentially become one fiber, with a small localized loss in the area of the splice due to optical and/or mechanical tolerances. So there are small losses due to the splices which represent the nonreflective events in our simulations. Reflective events occur whenever light encounters a mismatch in the index of refraction of the material(s) through which it is traveling. In connectors for example, there are always microscopic air gaps between the ends of the connector ferrules. Because of these gaps, the light goes from the fiber with refractive index of approximately 1.5 to air, which has a refractive index of 1, and back to fiber. Because of this rapid change in index, some of the light is reflected. Splitters are devices used to broadcast an optical signal from one fiber to many fibers. Optical signals on any of the input ports are branched to all the output ports. If the splitter has only one input port it is called a 1-by-N splitter. The total loss from the input port to any output port of such an 1-by-N splitter is given by $Splitter_{loss} = 3.4 * [\ln(N)/\ln(2)]$. Splitters pose several problems to the OTDR operator. If the OTDR is connected to the N side of a 1-by-N splitter, then the waveform shows a large loss at the splitter. This large loss limits the OTDR's ability to test far beyond the splitter as it affects the OTDR's dynamic range.

We use our model on a part of the PON, which consists of long fiber segment with length of 100 Km which is connected to the central office (CO) in first side while the second side

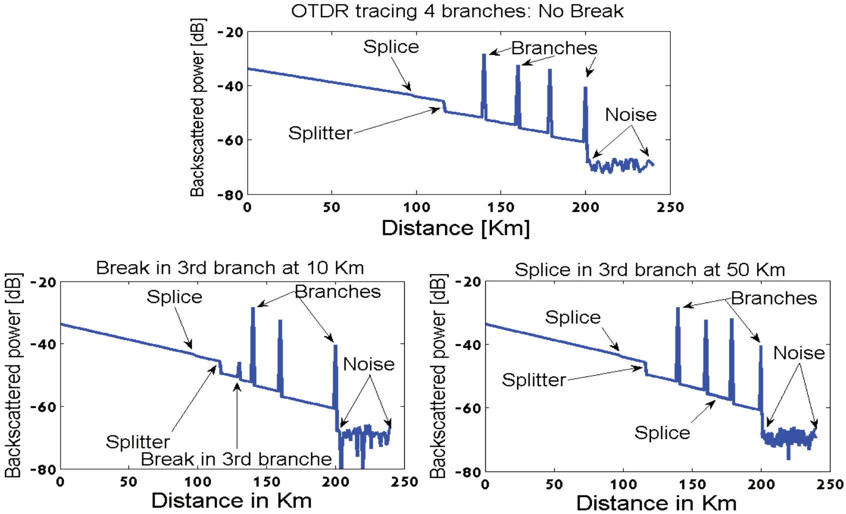

Figure 1: OTDR tracing for 4 branches (a) No break. (b) With break in 3rd branch. (c) With splice in 3rd branch.

is connected using splice to another short fiber segment of length of 15 Km. A splitter is used at the second end of the short fiber segment to split the power between four different branches which have the following lengths: 20, 40, 60, and 80 Km. We use FBGs at the end of each branch. In Fig. 1(a), we show the time trace generated by our code, where we can see the attenuation effect on the backscttered power in the fiber segments. Small loss is distinguished at the splice position while bigger loss is shown at the position of the splitter. Big reflection appears at the end of each branch due to the effect of FBGs.

Next, we introduce a break in the third branch located 10 km behind the splitter. This yields the OTDR trace shown in Fig. 1(b). As we can see, the reflection peak of the third branch has now disappeared and we have got an extra reflection at the break position. Remember that it is very important to perform an OTDR tracing at the time of installing the network, to properly document it. This will serve as a reference which will be compared with the tracing of the network when an event occurs and this will allow us to determine in which branch we have problem.

Finally, we introduce a loss in the third branch at 50 km from the splitter. This loss could be caused by a splice loss or by a fiber bend. The result of this simulation is shown in Fig. 1(c). We can notice the loss at the position where we introduced it, which shows that our code can be used to simulate a break or loss occurring in the PON. More details of using numerical simulations to determine the problems in PONs can be found in [4].

Conclusions

In this contribution, we have presented a comprehensive mathematical formalism to simulate the OTDR traces in PONs which include splitters. We have shown how the breaks, splitters and splices affect the OTDR trace. These simulations can facilitate OTDR related research in optical telecommunication networks, by reducing the number of necessary OTDR measurements. For telecom companies, these simulations provide a monitoring tool which helps in the monitoring and the maintenance of their PONs in more efficient and low-cost way.

Acknowledgment

This work was supported by the Agency for Innovation by Science and Technology (IWT) under contract 095115 (EP2CON) and by TE Connectivity. The authors acknowledge the Research Foundation Flanders (FWO) and the Interuniversity Attraction Poles IAP P7-35 photonics@be. M. K acknowledges Damascus University for financial support.

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