Advanced Monitoring System for Next-Generation Passive Optical Networks

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The aim of Passive optical network (PON) monitoring is to provide automated test and diagnostic capability without compromising the available bandwidth for services. Here we propose to study and develop a new advanced PON monitoring solution that will allow detecting, quantifying and localizing fault-induced losses within the optical network. The proposed method is based on a Transmission-Reflection Analysis (TRA) localization technique used in combination with a detection/quantification method based on Optical Frequency Domain Reflectometry (OFDR) technique. Preliminary theoretical and experimental studies show that this solution provides excellent performance with good scalability and affordable cost.

Introduction

Due to the rapid evolution of bandwidth-hungry services, our everyday life is now familiar with advanced applications that consume large-volume data, e.g. high-definition television (HDTV) and Video-on-demand (VoD). Compared with traditional access networks media such as coaxial and twisted pair cables, optical fibers provide a huge bandwidth over extremely long transmission distance. Fiber-based Passive Optical Network (PON) technology is thus currently receiving more and more attention. A typical PON consists of a tree-like structure composed of an optical line terminal (OLT) at central office, a number of optical network terminals (ONTs) at customer premises and the optical distribution network (ODN) in between.

As the development of PON system, making a PON system operational with a high reliability, stability and cost efficiency is very challenging. Figure 1 shows the capacity trend of PON systems. According to this figure, in less than 10 years' time, the bandwidth of next-generation PON systems can be up to 250 Gbit/s in both downstream/upstream directions [1]. Thus, a single failure can generate a loss of huge amount of data. In order to minimize the interruption time and to improve the reliability of the network, monitoring of the access network becomes therefore extremely important. In general, the objective of a PON monitoring system is to provide real-time information on fiber/device fault detection, quantification and localization**.**

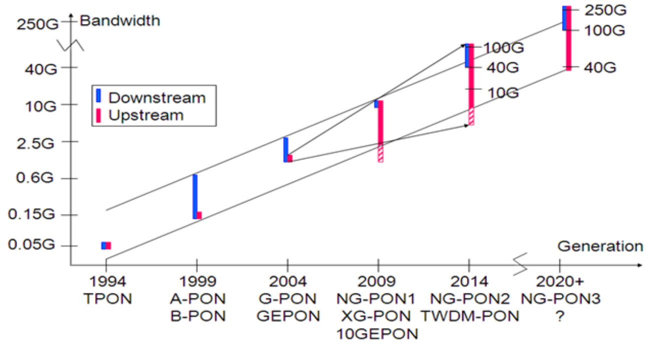

Figure 1: Capacity trend for PON systems [1]

There are currently several PON monitoring methods available on the market, all with different limitations, therefore, more efficient PON monitoring solutions are still needed and are currently subject to intensive research activities. In the frame of this project, we propose to develop a solution that will improve the monitoring system and address the limitations of the existing techniques in order to meet the challenge raised by next-generation PON systems. The method is based on a Transmission-Reflection Analysis (TRA) localization technique in combination with a detection/quantification method using Optical Frequency Domain Reflectometry (OFDR). In this paper, we mainly focus on the TRA fault localization technique.

Approach description

As already specified, a PON monitoring system should be able to detect, quantify and localize faults within the network. In the frame of the project, we propose to investigate one technique for the detection and quantification functionalities: the Optical Frequency Domain Reflectometry (OFDR) technique. The localization process will be realized by implementing the Transmission-Reflection Analysis (TRA) technique, only used so far for sensing applications. As figure 2 shows, since the detection / quantification method (OFDR) will give an alarm, the corresponding TRA unit will be started in order to localize the fault. The final solution should provide a large enough dynamic range (related to the maximum fiber length that can be characterized within the network, i.e. 25 kilometers) and a spatial resolution suitable for the application (i.e. 5 meters).

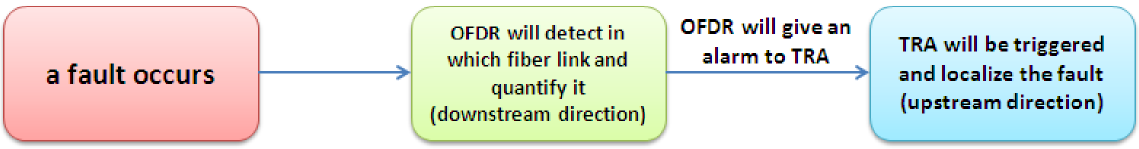

Figure 2: flow chart of the final monitoring method

TRA fault localization method

- Principle of TRA method

TRA is a novel, simple, efficient and inexpensive monitoring technique, which is usually used for fiber sensing applications [3], normally over a single fiber (not on a tree-like structure). Generally speaking, it is based on the unique relationships between transmitted power (P_T) and the measured backscattered power (P_B) for a given loss location. The transmitted power is the power transmitted through the fiber link when a continuous optical wave (CW) is launched. By backscattered power, we mean the power that is reflected all along the fiber link. P_B is due to Rayleigh backscattering, which is a scattering phenomenon that results from the presence of inhomogeneity in the fiber material. Once P_T is known, the measurement of P_B allows localizing the faults.

In the presence of a loss in a fiber, P_T is insensitive to its location. The dependence of P_B on the loss location can be understood as follows: the Rayleigh backscattering power decreases after a fault and the measurement of P_B is the integrated backscattering power along the whole fiber link since a CW light is launched in the fiber. Consequently, if a loss is located at the beginning of the link, P_B will be significantly decreased. If the loss is located near the end of the link, P_B will be less affected.

Some simulations have already been undertaken to test the localization capability of the method. Figure 3 shows the simulated relationships between the transmitted and backscattered signals when different fault-induced losses are introduced at several given locations. The attenuation coefficient and the scattering coefficient of the fiber we use were 0.23dB/km and 0.2dB/km respectively, the power of the light source was 10 dBm.

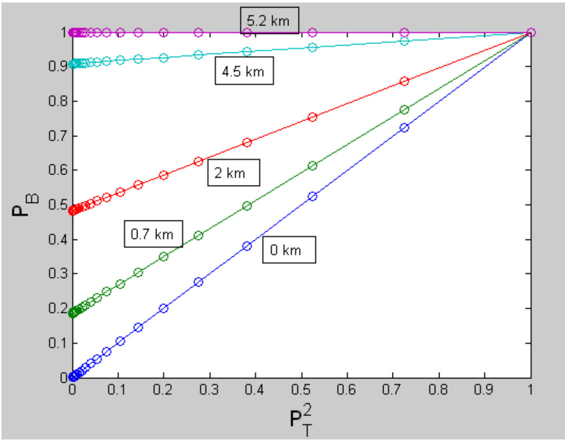

Figure 3: TRA simulation result for various loss locations

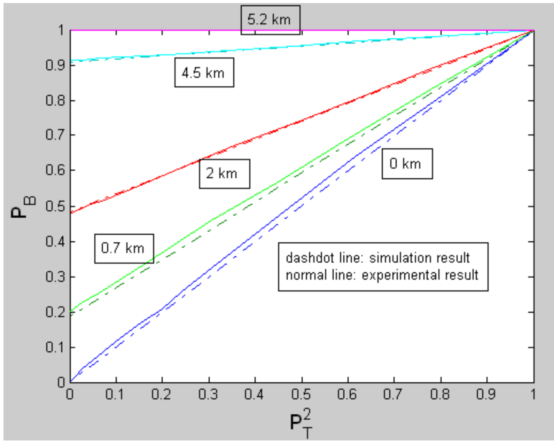

Figure 4: experimental result and simulation result for various loss locations

(in figure 3 and figure 4, P_T and P_B have been normalized by their unperturbed powers)

For a fixed fault location, all the simulated (P_T^2, P_B) points obtained for different loss values are on a straight line with a specific slope that depends on the fault location. The slope can be described in equation (1), in which, α is attenuation coefficient, L is fiber length and l1 is the fault location.

$$\frac{\partial P_B}{\partial P_T^2} = \frac{e^{-2\alpha l1} - e^{-2\alpha L}}{1 - e^{-2\alpha L}} \tag{1}$$

As we can see from equation 1, the slope uniquely depends on the loss location l1. By some mathematical manipulation, we can derive the equation for l1:

$$l1 = \frac{1}{-2\alpha} \times \ln\left(\frac{P_B \cdot (1 - e^{-2\alpha L}) + P_T^2 \cdot e^{-2\alpha L} - 1}{P_T^2 - 1}\right) \tag{2}$$

Thus, the measurement of the transmitted and backscattered powers will lead to the fault location. Based on some preliminary study of the system sensitivity, we found that the resolution of the fault localization can be as small as a few meters, which outperforms the existing methods based on OTDR (15 meters [4]).

- Experimental validation

To verify the proposed optical fault localization method, the above mentioned TRA technique for a point-to-point configuration was implemented in our lab as figure 5 shows. In the experiments, we tested five different loss locations, (0 km, 0.7 km, 2 km, 4.5 km and 5.2 km). At each fault location, we repeated the measurement with different loss magnitude for more than 15 times. In order to easily compare the experimental and simulation results, we plot the data together in Figure 4. As Fig. 4 shows, the experimental result agrees well with simulations. Those small deviations, which can be found for certain loss locations, may arise from measurement fluctuations.

The above simulation and experimental results show that for a point-to-point configuration, TRA is able to localize a loss. As a next step, we propose to apply this method into PON systems in order to realize the PON monitoring functionality. TRA has never been applied for the monitoring of tree-like structure. Adapting the technique to PON monitoring consitutes a novel approach. In order to do so, we propose to implement a low-cost light source in ONTs that launches the upstream measuring signal into the fiber links. The embedded powermeters in the ONTs can be used to measure the Rayleigh backscattered power.

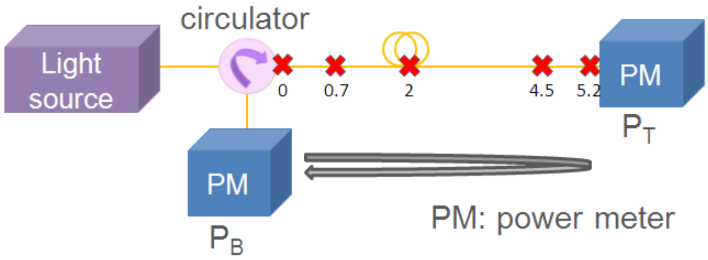

Figure 5: Experimental set up of TRA based on a single fiber

Discussion

In the proposed solution, the combination of two techniques, i.e. OFDR and TRA methods, helps to achieve the three key functionalities of a PON monitoring system: fault detection, fault quantification, and fault localization. The use of TRA method as the fault localization process not only makes the monitoring system much simpler, but also saves a lot of measuring time, which is crucial to further improve the efficiency of the next-generation PON. Moreover, compared with Optical Time Domain Reflectometry(OTDR) based monitoring method, TRA launches monitoring signal from ONT instead of OLT. This important modification makes fault localization in branches (fiber branches after the splitter) possible. Besides, preliminary experimental results also show that using TRA technique can greatly increase the resolution of fault localization process. It is also worth to point out that since all the required equipments (OFDR unit, IF unit, TRA light source) will be installed either in central office or in the ONT, the ODN part of the PON system is kept passive.

References

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