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Fault localization using dual pulse widths for PON monitoring system

Xuan Zhang [a,*], Hao Guo [b], Xinhong Jia [a], Qinghua Liao [c]

[a] *College of Physics and Electronic Engineering, Sichuan Normal University, Chengdu, Sichuan 610101, China*
[b] *State Key Laboratory of Electronic Thin Films and Integrated Devices, College of Optoelectronic Information, University of Electronic Science and Technology of China, Chengdu, Sichuan 610054, China*
[c] *College of Science, Nanchang University, Nanchang, Jiangxi 330031, China*

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ABSTRACT

We propose a novel method using dual pulse widths to locate the fiber break, which can share the pulse detecting source with the previous proposed passive optical network (PON) monitoring systems. The rectangular detecting pulses with two different pulse widths are sequentially injected into the faulty fiber link to generate corresponding parameters for the established model equations. We also investigate the corresponding variables (i.e., different combinations of dual pulse widths, pulse repetition frequency and accuracy of the power meter) that may affect the performance of the proposed method. The experimental results show that the fiber breakpoint can be located with little error. The simple and low-cost method provides a fault localization functionality for the PON monitoring systems.

1. Introduction

Passive optical network (PON)-based approach has emerged as an important technology that enable the network operators to deliver many emerging services such as IP telephony, video on-demand (VoD), interactive game, or two-way videoconference. With the rapid growth of data services, the monitoring and management of customer access networks have become increasingly important [1]. For instance, fiber-to-the-home (FTTH) based PONs seems to be the ultimate winning solution for the first/last-mile bottleneck. However, many FTTH management problems are usually caused by the fact that valid network status information can not be obtained by the central office (CO) manager. Consequently, the quality of service (QoS) of the network is directly affected and the maintenance costs of the network increase significantly [2].

The traditional maintenance method usually requires a truck-roll tour and outside intervention of technicians when a fault occurs. For this method, each branch fiber must be separately checked from its end by means of upstream power meter and/or optical time domain reflectometer (OTDR) transmission in order to identify the faulty one. As a direct consequence, it consumes huge amounts of labor power and financial resources. To solve these problems, many PON monitoring techniques with simple design and effective monitoring have been proposed to deliver high QoS for the end-users. Optical coding based monitoring technique uses passive encoders that generate a unique code to distinguish between different PON branches. A decoding module is placed at the CO to decode the codes returned from different branches [3]. The status of each branch is identified by the reduced-complexity maximum-likelihood sequence estimation (RC-MLSE) algorithm [4]. Monitoring technique based on remote coding scheme uses the optimal arrangement of coding gratings to allocate a dedicated frequency response for each drop fiber (DF). At the remote node (RN), a cascaded encoder simultaneously realize optical splitting and coding. Each DF link status is identified by the unique wavelength combination [5]. Optical frequency hopping/periodic code (OFH/PC)-based PON monitoring for high capacity end-users simultaneously generate optical codes in the frequency and time domain. The optical encoders consist of multiple fiber Bragg gratings (FBGs) with 100% reflectivity and different center reflected wavelengths [6]. The RC-MLSE algorithm is also used to identify the status of each DF. The experimental results show that all these PON monitoring techniques can effectively detect fiber break in a PON. However, two objectives should be included in the PON troubleshooting [1]. The first and second objectives are fault detection and fault localization, respectively. The fault localization provides the exact location of a fault within the faulty branch, which helps to reduce the operational expenditure (OpEx). Unfortunately, PON monitoring systems based on the above techniques can only achieve the first objective but not the second one.

* Corresponding author.
E-mail address: xuanzhang@sicnu.edu.cn (X. Zhang).

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OTDR is an efficient way to characterize a point-to-point (P2P) fiber link, which can provide accurate localization of a failure. Specifically, an OTDR sends short pulses of light into a fiber from one end of the fiber cable, with the OTDR port to receive the returning information. As the optical pulse is transmitted through the fiber, part of the scattered reflection will return to the OTDR and be measured. However, it is ineffective in point-to-multipoint (P2MP) networks because the back-reflected and backscattered light signals from different branches add up together. To solve this problem, two typical OTDR-based techniques, such as reference reflector (RR-OTDR) and tunable OTDR (T-OTDR), have been presented. However, the RR-OTDR and T-OTDR techniques are limited by the network topology and capacity, respectively [7,8]. Additionally, some non-OTDR-based techniques for fault localization have also been presented. For instance, Bi-directional transmission reflection analysis (BD-TRA) technique using broadband light source is able to detect, identify and localize both reflective and non-reflective events in a ring-based long-reach PON [9]. Chaos detection with a high spatial resolution is used to locate faults in a wavelength-division-multiplex ing PON (WDM-PON), which utilizes a multiple-longitudinal-mode Fabry-Pérot semi-conductor laser with direct modulation generated by a Colpitts oscillator [10]. Obviously, these fault localization techniques cannot be used in the above-proposed PON monitoring systems due to the difference of the detecting source. To the best of our knowledge, research on fault localization for the PON monitoring systems with pulse detecting source has not been reported.

In this paper, we propose a fault localization method by using dual pulse widths for PON monitoring systems with pulse detecting source. Dual pulse widths refer to two detecting pulses with different pulse widths and the same peak power, which are two independent pulses with a rectangular profile and injected into the network one by one. That is, the first rectangular detecting pulse with pulse width of T_1 launches into the network and generates the received power. Then, the same operation is repeated with the second rectangular detecting pulse with pulse width of T_2 ($T_2 \neq T_1$). Two rectangular detecting pulses with different pulse widths are used to generate the corresponding parameters for the established model equations. The breakpoint can be easily located by solving the model equations after the PON monitoring systems has identified the target fault branch fiber (or DF). For the above-mentioned PON monitoring systems, an extra OTDR is often required to achieve the fault localization. Obviously, the integration between the PON monitoring system and OTDR is very difficult. For the proposed method, all the original equipment of the PON monitoring system can be shared except an optical power meter. That is, the equipment of the PON monitoring system used for fault detection can also be used for fault localization. Note that the detecting source of PON monitoring systems in Refs. [3], [5] or [6] above used for fault detection is pulse signal. Obviously, the use of a pulse signal in this proposed method is simpler than a continuous wave (CW) signal because it does not require changes to the detecting source. Compared with the use of an expensive OTDR, the proposed method can greatly reduce the cost and may be more welcomed in the cost-sensitive PON market.

2. Principle and analysis

2.1. Operating principle

Fig. 1 illustrates the schematic diagram of two objectives of the PON troubleshooting. Suppose a break has been identified by the corresponding PON monitoring system on the target fault DF (i.e., DF_k), as shown in Fig. 1(a). That is, the first objective (i.e., fault detection) has been achieved. Here, the fault identification of DFs can use the PON monitoring systems with pulse detecting source, i.e., PON monitoring systems in Refs. [3], [5] or [6]. Specifically, as shown in Fig. 1(a), the detecting pulse signal is sent into the feeder fiber (FF) via a circulator (CIR). In the remote node (RN), n subpulses splitted by the power splitter/combiner (PSC) are assigned to different DFs. The subpulses can be encoded at the RN or the front of optical network unit (ONU). Then, each DF has a unique optical code. The monitoring signals (optical codes) are reflected by the encoder/reflector located near the ONU. Finally, in the Reception & Decision module, the presence or absence of pulse peaks are used to assess network link status according to the corresponding network recognition algorithm. If one DF fails, the PON monitoring system can give where the corresponding faulty DF is. However, the PON monitoring systems can not provide the exact location of a fault on the faulty DF. To locate the fault, the proposed method is used to achieve the second objective (i.e., fault localization). As shown in Fig. 1(b), the FF and the corresponding DF are directly connected by bypassing the PSC located at the RN. In this process, the PSC does not need to be connected and therefore is not shown in Fig. 1(b). That is, a point-to-point connection between the FF and one of the target fault DFs is used. For this connection, only one faulty DF is located at a time, but interference from other DFs can be avoided. Two rectangular pulses with different pulse widths as the detecting signal are emitted from the detecting pulse source of the PON monitoring system one by one. Due to the presence of inhomogeneity in the fiber material and the change of refractive index at the interface, the detecting signal is injected into the FF via a CIR and then generate backscattered and reflected power on the target fault DF (i.e., DF_k). The return signal is sent into a standard optical power meter via port 3 of the CIR, and the power meter replaces the Reception & Decision module in the original PON monitoring system. Then, the received power of the return signal is measured by the power meter. Note that the measured values of the power meter is not the peak but the average power in a sampling period. Finally, the physical location of the breakpoint can be calculated by substituting the measured parameters into the established model equations.

As shown in Fig. 1(b), a break on the DF_k has been detected by the PON monitoring system. A rectangular pulse with initial peak power of P_P is used as the detecting signal. The return loss and location of the break on the corresponding DF are RL and Z_b, respectively. A demarcation point between the FF and DF is Z_0, corresponding to the location of the PSC in Fig. 1(a). For any DF of the distribution drop segment, Z_0 can be seen as zero. Then, we can theoretically calculate the received peak power P_{RP} after the detecting signal traverses the fiber link. The fiber link and CIR will attenuate the power of the detecting signal due to fiber loss and insertion loss. Here, the fiber transmission coefficient associated with the fiber attenuation coefficient α can be expressed as: $T(\Delta x) = e^{-\alpha\Delta x}$, where Δx is the length of the fiber link segment, i.e., the transmission distance of the optical detecting signal in the fiber link [11]. The detecting signal is reflected at the breakpoint with a return loss of RL and generate a round trip on the fiber link. In addition, the Rayleigh backscattered power coefficient can be written as: $RAY(\Delta x) = S \cdot \alpha_s \cdot PW \cdot e^{-2\alpha\Delta x}$, where α_s is the scattering due to the Rayleigh scattering and is proportional to $1/\lambda^4$, S is the capture coefficient, and PW is the pulse width [12]. Taking the directivity DIR [dB] (i.e., power transmitted directly from port 1 to port 3) of the CIR into consideration, the total backscattered/reflected power of the initial undisturbed system (P_P) is calculated as:

$$P_{RP} = P_P \cdot \left[10^{\left(-\frac{DIR}{10}\right)} + RAY(\Delta x) + T^2(\Delta x) \cdot 10^{\left(-\frac{RL}{10}\right)}\right] \cdot 10^{\left(-\frac{IL}{10}\right)} \quad (1)$$

where IL [dB] is the insertion loss of the CIR. In Eq. (1), DIR, RL and IL in dB needs to convert to ratio using the exponential function