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Self-match based on polling scheme for passive optical network monitoring

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A R T I C L E I N F O

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A B S T R A C T

We propose a self-match based on polling scheme for passive optical network monitoring. Each end-user is equipped with an optical matcher that exploits only the specific length patchcord and two different fiber Bragg gratings with 100% reflectivity. The simple and low-cost scheme can greatly simplify the final recognition processing of the network link status and reduce the sensitivity of the photodetector. We analyze the time-domain relation between reflected pulses and establish the calculation model to evaluate the false alarm rate. The feasibility of the proposed scheme and the validity of the time-domain relation analysis are experimentally demonstrated.

1. Introduction

Optical access network (OAN) is capable of delivering high-capacity data, consuming less energy and saving capital expenditure (CapEx), which can remove the bottleneck of the telecommunication development [1,2]. Passive optical networks (PONs) are considered one of the most promising candidates for OANs due to the high transmission rate and low-cost infrastructure [3,4]. With the rapid development of PONs, management and maintenance issues are emerging. As an effective solution, PON monitoring can reduce provisioning time, improve quality of service (QoS), attract more clients and reduce maintenance costs [5,6]. Therefore, a simple but effective monitoring scheme is essential for continuously developing PONs.

Optical time domain reflectometry (OTDR) is widely used in the point-to-point (P2P) fiber link test, which can provide a plot of distance versus signal level in a fiber. However, it may be ineffective in point-to-multipoint (P2MP) networks because all returned signals coming from different branches add up together [6,7]. Some modified OTDR techniques, such as reference reflector and tunable OTDR (i.e., RR-OTDR and T-OTDR), are limited by the network size and expensive OTDR equipment, respectively [8]. Note that the PON market is highly sensitive to cost. Thus, the PON monitoring system must be cost-effective, especially at the user terminals because the components cannot be shared. Some PON monitoring schemes aiming at improving the network size and reducing the cost have been proposed [9–12]. The periodic coding (PC) scheme uses a unique code to distinguish between different drop fibers (DFs) [13]. The optical encoder installed at each DF end is constructed by two fiber Bragg gratings (FBGs) with different reflectivity and appropriate length patchcord. The PC scheme presented in Ref. [13] is a typical technique with simple and low-cost design. However, the insertion loss can be 4.2 dB for PC encoders with two identical center reflected wavelengths due to partial reflection (i.e., 38% reflectivity) of the first FBG. In addition, the infinite-length periodic sequence with poor correlation characteristics increases the difficultly in the recognition process, i.e., localization of the encoders at the center office (CO). The reduced complexity maximum likelihood sequence estimation (RC-MLSE) algorithm used in the PC scheme is difficult to apply in practical PON systems [14]. Brillouin OTDR (BOTDR) based monitoring technique exploits the Brillouin frequency shift (BFS) to distinguish the backscattered signals from each DF. Due to the special dopant concentration for each DF, this technique requires a dramatic change in current existing PON infrastructure [15]. Obviously, it drastically increases the CapEx and is not welcomed in the cost-sensitive PON market. The monitoring technique based on the optical frequency domain reflectometer (OFDR) uses a frequency-modulated continuous-wave as the probe signal. The interference signal with a unique beat frequency created by each interferometer (IF) unit is used to distinguish each other [16]. Each IF unit including a coupler, a FBG, a mirror and the patchcord with appropriate fiber length may be complex and not conducive to reduce the cost. For the self-injection locked reflective semiconductor optical amplifier (SL-RSOA) based monitoring technique, an upstream transmitter utilizing SL-RSOA can generate both upstream data and probe signals [17]. However, this technique requires a protocol

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extension to avoid the interference between the probe data and the upstream data, which increases the complexity of the PON system.

In this paper, we propose a self-match based on polling scheme for PON monitoring. The status of all DF links is identified one by one using a specific probe signal, which is so-called polling. Undeniably, this design examines only one DF at a time, which creates a delay between consecutive probes, especially for large network users. The patchcord length of each optical matcher (OM) is separately configured to match with the pulse interval of the corresponding probe signal. As a direct consequence, only one OM at a time makes the pulse interval of the corresponding pulse signal to become zero, which is referred to as self-match. In a PON with non-equidistance, the status of each DF link needs only be identified by the presence of the corresponding overlapped pulse. Here, non-equidistance means that all optical network units (ONUs) are distributed randomly. That is, the distance between the optical line terminal (OLT) and all ONUs is different. Compared with the PC encoders, the proposed scheme incurs almost no insertion loss because two FBGs with different center reflected wavelengths in each OM are 100% reflectivity. The recognition process in the proposed scheme mainly involves amplitude detection, which is much simpler than the auto-correlation detection used in the PC scheme. In a PON with non-equidistance, the overlapped pulse is easy to distinguish from other pulses. Especially, due to the round trip of the probe signal, the loss budget may be huge in a PON with a high splitting ratio. The power loss can be compensated by the overlapped pulse to some extent, which is conductive to reduce the sensitivity of the photodetector (PD). Obviously, the proposed scheme is simpler and cheaper when compared with the above three techniques (i.e., BOTDR, OFDR and SL-RSOA based monitoring techniques).

2. Self-match based polling scheme

2.1. Principle of operation

Fig. 1 illustrates the principle of the self-match based on polling scheme for centralized monitoring in a PON. The U-band (1625–1675 nm) detecting source contains a laser array and is directly modulated by a pulse generator (PG). Each probe signal consists of a unique pulse interval and two subpulses with center wavelengths of λ_1 and λ_2. The first probe signal with pulse interval of τ_1 passes through a circulator (CIR) and is coupled with the traffic data via a wavelength division multiplexer (WDM). Then, the probe and data signals are transmitted from the feeder fiber (FF) down to the network. The probe signal splits into n subsequences by the power splitter/combiner (PSC) at the remote node (RN), dispatched through the DFs to all ONUs. Each DF link is terminated by an OM that generates a corresponding reflected signal. The total received optical signal from different DF links is converted to an electrical signal by the PD located physically close to the OLT. Finally, the processing unit checks the overlapped pulse in the total received signal and identifies the corresponding DF link status. The control unit gives the detecting source a triggering signal after the processing unit completes the identification. Next, the second probe signal with the pulse interval of τ_2 is injected into the network and the processing unit identify the corresponding DF link status, and so on, until the last probe signal with the pulse interval of τ_n is injected into the network for the identification of the last DF link status.

2.2. Optical matcher design

As shown in Fig. 1, the OM installed in the front of each ONU contains a pair of FBGs and the required length patchcord. The center reflected wavelengths and reflectivity of these two FBGs are λ_1, λ_2 and 100%, respectively. The patchcord of l_k $(k = 1, 2, \ldots, n)$ is used to connect these two FBGs. Note that l_k needs to be unique to respectively match with the pulse interval of the probe signal. Due to the high reflectivity of FBGs, the insertion loss may be rarely introduced for

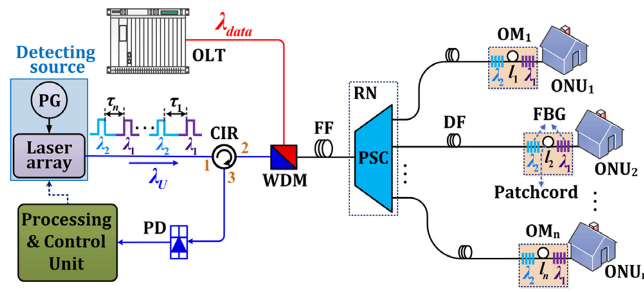

Fig. 1. Principle of the self-match based on polling scheme in a PON.

all OMs. It is also worth noting that the high number of components included in a coding device and their assembly increase the manufacturing, installation, and inventory cost. To ensure that only one completely overlapped pulse is generated by the corresponding OM at a time, the relation between the length l_k of the patchcord and the pulse interval τ_k of the probe signal must satisfy: $\tau_k = 2 l_k n_g / c$, where c is the speed of light in a vacuum and n_g is the effective group index.

Here, we also give some brief comparison and analysis between the OM and a single FBG at all DF terminations [18]. It seems more effective or cheaper to configure a single FBG at all DF terminations, however, this design may increase the overall cost of the PON monitoring system. That is, a simple structure of the DF terminal may increase the complexity of other modules of the PON monitoring system, i.e., the transmitter and receiver modules. Note that any PON monitoring system must carefully consider the cost factor because the PON market is cost-sensitive. A single FBG at all DF terminations used in the prior presented PON monitoring schemes includes two cases:

(a) All FBGs at all DF terminations are identical (i.e., the same center reflected wavelength and bandwidth), for example, RR-OTDR based monitoring technique. Note that this technique requires an OTDR. OTDR is a precision instrument that integrates transmitter and receiver; however, it is usually expensive. For the RR-OTDR based monitoring technique, dead zones created by a high Fresnel reflection in the field often mask the faults.

(b) All FBGs at all DF terminations are different (i.e., different center reflected wavelengths), for example, T-OTDR based monitoring technique. Different FBGs that cannot be shared by users are detrimental to mass production and result in high costs. In addition, the limited spectrum of very expensive T-OTDR is difficult to use in the high capacity PON monitoring.

For the proposed scheme, two FBGs with 100% reflectivity and different center reflected wavelengths are configured for all DF terminations. This design may be conductive to mass production. In addition, the simple transmitter and receiver modules can also effectively reduce the overall cost of the corresponding PON monitoring system.

Due to the simple signal characteristics created by each OM, the proposed scheme only checks the amplitude of the overlapped pulse in the final recognition process. Hence, the PON's electronic impulse response can be faster than a pre-recorded healthy response used in the most of prior works (i.e., the PC scheme). The status of all DFs can be directly identified by the threshold. For many prior works, the return signals need to be first converted into the recognizable codes and then compared with the pre-recorded healthy codes to identify the status of each DF. During this process, it may involve a lot of computing due to the complicated network recognition algorithm (i.e., RC-MLSE used in the PC scheme).

For all OMs, FBGs with the same center reflected wavelengths are located on the same side of the patchcord. When the wavelength of the first subpulse transmitted from the detecting source is λ_1 (λ_2), the FBG with the center reflected wavelength of λ_1 (λ_2) must be physically closer to the ONU. In addition, the bandwidth of all FBGs should be much