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Precise fault location in TDM-PON by utilizing the delay signature of the chaotic laser with optical feedback

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Abstract–We propose and experimentally demonstrate a method to precise locate the fault in TDM-PON utilizing the time delay signature of the chaotic laser which generated in the form of optical feedback. A laser diode couple into TDM-PON at the side of control office and the laser is reflected by a fiber Bragg grating at the end of each branch. And then, the laser diode and whole TDM-PON constitutes a chaos laser generation system with multi-feedback. Each branch corresponds to a time delay signature (peak) in auto-correlation with the contribution of each optical feedback, and the signatures' position represent all reflectors. In the monitoring of TDM-PON, the disappeared peak represents the fault branch, and emerged peak corresponds to the fault position. Since the broad bandwidth of the chaotic laser, the spatial resolution can reach the level of millimeter and each branch adds tiny fiber to distinguish with other's length. The experiment results prove the concept and the spatial resolution of the location is 8 mm.

1. Introduction

Chaotic laser has been extensive studied [1, 2] since its developed attractive application fields, such as high resolution ranging, fast random number generation, chaos-based secure communications. In the approaches of chaos generation, the laser diode (LD) with optical feedback has been wildly used because of the simplest structure which consists of only one LD and one reflector. But in this method, the output chaotic laser contain the external feedback time delay signature (TDS) [3-5], which is recognized as a nuisance in chaotic laser applications. Many researchers have developed new optical feedback mechanisms to suppress or conceal the TDS [3, 6-11] in recently years.

However, we find the TDS can be utilized in the time-division multiplexing-passive optical network (TDM-PON), which can realize the distinction of the fault branch and the precise location of the fault position simultaneously. Any fault in TDM-PON will lead to service interruption and tremendous data loss because of the fast data rate and large capacity in TDM-PON. And this force researchers developed many techniques to achieve the monitoring in TDM-PON [12-14].

The most directly approach is to initiative select each branch fiber to scan with function of optical time domain reflectometer (OTDR). The selection is realized by control a switch or selector which sited at the splitter, or test the branch fiber one by one from the optical network units' (ONUs) side. Another approach is add some unique feature to identify each branch, mainly performed in the aspect of fiber length, wavelength and code. And locate the fault by an OTDR. The other approach is analyzing from radio-frequency (RF) spectrum, where different frequency corresponds to different branch.

The monitoring of TDM-PON requires to consider the cost of the operational expenditure (OPEX) and the scalability of the test equipment. In the techniques discussed above:

(a) Branch scanning technique need active components or behavior to realize, that will increase operation and maintenance cost;

(b) Unique feature technique require to customize amount fiber Bragg gratings (FBGs) with different wavelength, and the range of the wavelength of test laser will limit the scalability of the branch feature; unique fiber length between two close branch must have an interval greater than the resolution of the OTDR, which can reach meters or more when detect in a long range;

(c) Analyzing from the frequency have a complex structure and expensive spectrum analyzer, let alone the cost of other components.

Moreover, the techniques realize the function of location with the help of OTDR, and the principle of OTDR process a tradeoff between spatial resolution and measurement range [15]. Although we presented a precise located method with chaotic laser [15], it did not apply to the TDM-PON since the indistinguishable branch and the great attention of power splitter. To decrease the OPEX, researchers keep exploring new effective technique with simple structure for low cost and high spatial resolution for saving location time. In this paper, we improve the technique of the monitoring to some extent, and provide a new method to distinction and precise location in TDM-PON.

2. Principle of the Monitoring with TDS

The TDM-PON contains of an optical line terminal (OLT), feeder fiber, power splitter (PS) and some ONUs. According to ITU-T L.66 (2007) Recommendation, the wavelength of maintenance laser is limited in the U-band (1625-1675 nm). As shown in Fig. 1, we utilize a distributed feedback laser diode (DFB-LD) in U-band to realize the monitoring of the TDM-PON. Test laser transmits into feeder fiber through a wavelength division multiplexor (WDM) and split to every branch by PS. Before each ONU, we insert a FBG which can reflect the laser of DFB-LD but do not influence the laser of the communications. Therefore, the DFB-LD and FBGs constitute a chaos generation system with multi-feedback, and the auto-correlation function (ACF) of the output of DFB-LD includes TDSs which correspond to each FBG's position. Due to the short distance between FBG and ONU in each branch, we can ignore the distance and regard the TDSs in ACF as ONUs' position. And then find the relationship between TDSs and branches in ACF, which will be the reference curve for the following monitoring.

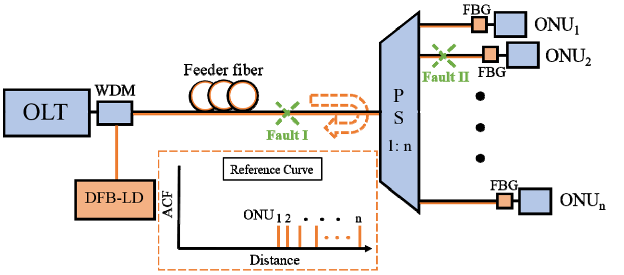

Fig. 1. Schematic of the TDM-PON's monitoring utilizing TDS of chaotic laser which generated by multi-optical feedback. The inset one is ACF of the chaotic laser. OLT: optical line terminal; WDM: wavelength division multiplexor; PS: power splitter; DFB-LD: distributed feedback laser diode; FBG: fiber Bragg grating; ONU: optical network unit; ACF: auto-correlation function.

In the operation of monitoring, calculate the ACF repeatedly and compare every results with the reference ACF curve. When the fault occurs in feeder fiber (Fault I in Fig. 1), the reflection at the fault point instead of all FBGs to affect the DFB-LD to generate chaos. So there is only one TDS in ACF curve at the position of the fault, as shown in Fig. 2(a). When a fault occur in one branch (Fault II in Fig. 1), one TDS in ACF will disappear comparing with the reference curve and the emerging TDS response to the fault position. In Fig. 2(b) we illustrate the result when the branch of ONU2 is broken.

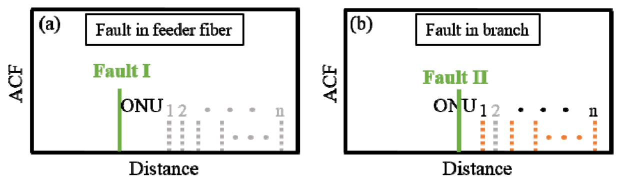

Fig. 2. Monitoring results when the fault occur in feeder fiber (a) and branch (b).

It should be point out that the spatial resolution of this technique is determined by the full-width-at-half-maximum (FWHM) of the correlation peak in ACF curve. It can reach several millimeters since the broad bandwidth of the chaotic laser [16].

3. Experiment

3.1. Setup

The setup of our experiment is shown in Fig. 3. To demonstrate a proof test, we simplify the construction of the TDM-PON since some components play no role in our monitoring techniques. The DFB-LD emits laser to a coupler with the split ratio of 99:1. A photo detector (PD) receives the 1% part and acquires by an oscilloscope (OSC). Another part with 99% laser injects into the feeder fiber and pass through a variable optical attenuator (VOA) to connect to PS. A fiber mirror is sited at the end of every branches to provide optical feedback with the adjustment of VOA to make the DFB-LD generates chaotic laser.

In our experiment, the wavelength of DFB-LD is at 1550 nm. We use three 50:50 couplers to construct PS with 4 branches and choose a 6-km single-mode fiber. The chaotic laser is detected by a PD with 12-GHz bandwidth (Newport 1544B) and recorded by a real-time oscilloscope with bandwidth of 36 GHz (LeCory, LabMaster 10-36Zi). The correlation calculation of chaotic laser is performed by a computer.

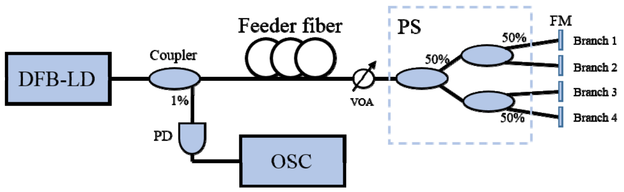

Fig. 3. The setup of the experiment

The properties of the chaotic laser is shown in Fig. 4. Figure 4(a) shows the output intensity of the probe laser changes from a noisy stable state (gray) into a chaotic state (blue) with larger fluctuation due to the feedback from the characteristic reflectors. The power spectrum of the chaotic is plotted in Fig. 4(b). The spectrum of the chaos (blue) rise a higher level than noise (gray), and have a wide bandwidth.

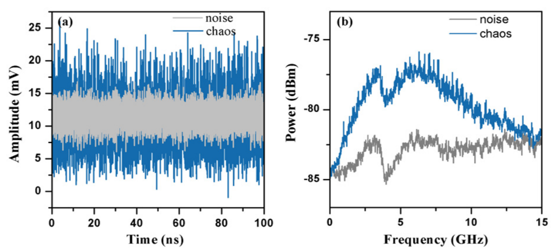

Fig. 4. The time series (a) and power spectrum (b) of the chaotic laser with (blue) and without (gray) optical feedback from each branch.

3.2. Results

We simulated the event of fault occurring in branch 2. The feedback is offered by the fault point and the marking reflectors in other branches. Figure 5 plots the corresponding ACF trace. Compared with the reference trace colored by gray, which is the ACF of the healthy PON, we can observe the second identified delay signature disappears and emerges a new peak. So the fault and the corresponding branch are identified simultaneously.

Moreover, the spatial resolution is estimated by the full-width-at-half-maximum (FWHM) of the correlation peak. The inset one plots the magnified correlation peaks of the fault. It is found that the FWHM of the correlation peak is 8 mm which determined by the broad bandwidth of the chaos.

It should be mentioned that if the fault occurs in the feeder fiber, there is only feedback from reflection of the fault point. All peaks marking branches will disappear and a new peak will emerge before these marking peaks. This correlation peak corresponds to the delay signature of the fault feedback.

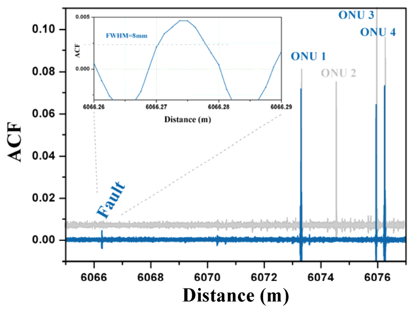

Fig. 5. Results of fault detection in branch 2, and the inset one shows the FWHM of the fault peak.

4. Discussions and Conclusion

Comparing with other techniques of the TDM-PON's monitoring, the method of utilizing the TDS of the chaotic laser has some advantages. First, the spatial resolution of the fault location is maintaining the property of the chaotic OTDR. Second, the monitoring system is just a chaotic generation system with multi-feedback, and only add a DFB-LD and some FBGs to the TDM-PON. Common DFB-LD and same FBG without customized decrease the OPEX of the monitoring in some degree by contrast to the tunable OTDR, different customized FBG or expensive instruments in other techniques. Third, the distinguished fiber length in each branch will reduce to millimeters increasing step because of the high resolution.

In conclusion, we propose and experimentally proof a technique of monitoring the fault in TDM-PON, utilizing the TDS of chaotic laser. The FBGs in every branches provide the optical feedback to the DFB-LD, and constitute a chaotic generation system with multi-feedback. According to the disappeared and emerged TDSs, we can distinguish the fault branch and fault position. The experiment results demonstrate the feasibility of our concept, and the spatial resolution can reach 8 mm. This method has combine the chaos generation and TDM-PON monitoring, and we believe the simple structure with low OPEX will attract more attentions.

Acknowledgments

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