A Novel Surveillance Scheme for Passive Optical Networks Using Spectral Analysis

Zhaoxin Wang, Xiaofeng Sun, Chinlon Lin, Chun-Kit Chan and Lian-Kuan Chen
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR.
Tel: +852-2609-8385, Fax: +852-2603-5032, Email: zxpath3@ie.cuhk.edu.hk

Abstract A novel surveillance scheme for in-service fault identification in PON is proposed and experimentally demonstrated. Fiber branch failure can be monitored by analyzing the RF spectrum of the common supervisory wavelength at the central office.

Introduction

Passive Optical Networks (PON) will play an essential role in alleviating the last mile bottleneck for the next generation broadband optical access networks. With the enormous communication capacity of the fiber link, any service outage due to fiber cut will lead to tremendous loss in business. Therefore, a simple but effective in-service surveillance scheme is highly desirable for timely fault identification along the fiber link. Several methods have been proposed based on multi-wavelength OTDR [1,2], and reflection of optical amplifier’s residual ASE [3]. However, these methods required rather expensive devices such as wavelength tunable pulse source or EDFA. In [4], a RF spectrum analysis technique was proposed for in-line EDFAs monitoring. In this paper, we propose a simple monitoring scheme based on RF spectrum analysis, using low cost FP-lasers as the monitoring light sources, thus reducing the surveillance cost.

Surveillance Scheme

Fig.1 shows a PON consisting of N branches. Monitoring sources attached to each Optical Network Unit (ONU) are used to send identification tags to the central office for ONU branch labelling purpose. The identification tag is generated all optically utilizing a FP-laser, a coupler and a mirror, as depicted in the upper inset of Fig.1. The working wavelength $\lambda_m$ of the FP-laser should be chosen to be the same for all branches and lies outside the transmission wavelength band for data $\lambda_s$. A portion of the FP-laser power is coupled into the upper port of the coupler and then reflected back to the FP-laser. In this way, an external fiber cavity is formed. Consequently, the output of the monitoring source comprises a train of cavity modes (in RF domain) with a unique mode spacing corresponding to the unique cavity length. This unique cavity mode spacing serves as an identification tag $F_k$ $(k\in{1:N})$ for the respective ONU branch. For instance, if the cavity length for k-th branch is $L_k$, the generated cavity mode spacing will be $S_k=c2nL_k$, where c is the light velocity and n is the refractive index of the fiber. The cavity length $L_k$ can be adjusted by having different length of fiber for the external cavity.

The output of the monitoring source is then coupled into the fiber link through a wavelength-dependent coupler (WC) and these identification tags generated at each ONU are superimposed together onto the surveillance wavelength as they converge into the feeder fiber. At the central office, the surveillance wavelength is filtered out by another WC and fed into a monitoring receiver where the surveillance signal is spectrally analyzed in the RF domain. The individual identification tags $F_k$ $(k\in{1:N})$ can be easily differentiated by applying Fast Fourier Transform (FFT) to the obtained RF spectrum, each of which is represented by a distinctive peak in the output FFT waveform, as illustrated in Fig.2.

For a healthy system, all of the N identification tags will be present. However, when one of the ONU branches, say branch $B_i$ fails, the corresponding identification tag, $F_i$, will be significantly suppressed in amplitude, indicating the fiber cut of the branch $B_i$.

![Proposed surveillance scheme](image-url)

**Fig.1. Proposed surveillance scheme**: WC: WDM coupler

**Fig.2. Principle of proposed surveillance scheme**
The experimental setup was similar to Fig.1 except that only the surveillance part was demonstrated because the working wavelength of the FP-lasers (1.55μm waveband) in hand conflicted with the working wavelength of the lasers that can be used for data transmission. However, it is expected that in our proposed scheme, the crosstalk between the data channel and monitor channel will be negligible due to the WDM property. In each monitor source, the output power of the FP-laser was fixed at 0 dBm, followed by an 80/20 coupler. The 20% port was used as the output of the monitor source, while the 80% port was used for the lasing cavity. The mirror was obtained utilizing the 4% reflectivity of the FC connector surface, for simplicity. This PON had four branches with three monitor sources placed at branches B₁,3 respectively. Branch B₂ was left unmonitored. The corresponding mode spacings were measured to be 28.1 MHz, 23.8 MHz and 21.2 MHz, respectively, and the corresponding cavity lengths were 3.55 m, 4.20 m and 4.72 m, respectively. These cavity modes were superimposed on the surveillance wavelength while transmitting through the 20 km feeder fiber link. At the receiving end, this monitor signal was fed into an RF spectrum analyzer with 1000-MHz center frequency, and 1-MHz resolution bandwidth. Fig.3 (a) showed the composite RF spectrum in case of no fault in all of the branches. By applying FFT to it, three distinct peaks, F₁, F₂ and F₃ were obtained, as shown in Fig. 4(a). Before FFT, the DC component was filtered out numerically to make the identification tags more clear. The sub-peaks on the right side of the picture were the second-order harmonic components of the peaks. These peaks should be avoided when we allocate the identification tags. To simulate the fault identification process, Fiber branch B₂ was intentionally disconnected. The captured RF spectrum was shown in Fig. 3 (b), with the resultant RF output depicted in Fig. 4(b). It was shown that the intensity of the identification tag F₂ was significantly suppressed by 9.4dB, indicating a fiber failure in branch B₂.

**Design Considerations**

Assume that the cavity length is L, the captured RF frequency span is M, and the sampling rate is high enough to fulfill the sampling theorem. After FFT, the identification tag's major lobe is 2π/M wide. On the other hand, the RF signal frequency spacing F=c/2nL. After FFT, the identification tags should be at the position of 2πF=4πnL/c. In order to differentiate two tags, their interval should be larger than two times of the main lobe's width. Thus (4πnL/c)> 4π/M, so the difference in cavity length should satisfy ∆L>c/nM. In our experiment, M=1GHz, so ∆L>0.2m. If the cavity lengths are varied from 5m to 10m, then this scheme can accommodate 25 ONUs.

In practical application, the wavebands of 1.3 μm, 1.48 μm and 1.55 μm have been allocated for data and video services. Considering that the 20 dB spectral width of FP-laser is about 15 nm, 1.2 μm waveband might be an available choice for monitoring with enough isolation from data signal.

**Conclusions**

A surveillance scheme for in-service fiber fault identification in PON using low cost FP-lasers is proposed and demonstrated. The monitoring signal is generated with external fiber cavity. By analyzing the RF spectrum of the common surveillance channel at the central office, the link quality of all fiber branches can be monitored constantly and simultaneously without interrupting the existing data channels.

**References**

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