The Influence of Rayleigh and Brillouin Backscattering on the Performance of a 10 Gb EPON System

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Abstract. In order to improve the performance of 10 Gb Ethernet passive optical network (EPON), this paper builds a single channel bi-directional 10Gb EPON simulation system on the VPI simulation platform. By changing the system parameters such as Brillouin Scattering, Rayleigh back-scattering and AmplitudeRF, observed and analyzed the waveform, spectrum, eye diagram and bit error rate of uplink optical line terminal (OLT) received signal. Experimental results show that both Rayleigh and Brillouin backscattering have an impact on the performance of the system, but the Brillouin scattering effect is more affected when the two effects are simultaneously existed. In addition, the effect of Brillouin backscattering can be reduced by phase modulation of the optical uplink carrier.

Introduction
EPON, that is Ethernet-based PON access network, which uses Ethernet as a carrier on the PON layer and uplinks to transmit data streams in a burst Ethernet packet manner. 10 Gb Ethernet PON evolved from the EPON, the downlink rate of 10 Gb/s, the uplink rate of 2.5 Gb/s [1]. Back Rayleigh scattering is an important physical process in optical fiber and belongs to a kind of linear process caused by local unevenness of optical fiber [2]. Brillouin scattering refers to a nonlinear light scattering caused by the interaction between the incident light field and the elastic sound field in the fiber [3].

VPI transmission Maker is a powerful simulation software that simulates optical fiber communication systems and optimizes designs by changing different parameters for different modules [4]. It can manually modify the important structural physical parameters of various parts of the interior. By simulating the time-domain waveforms, spectra, eye diagrams, bit error rates and other results, the understanding of optical communication technology is reinforced. At the same time, before the actual implementation of optical fiber communication system, through the VPI simulation can also be ruled out some problems encountered in the implementation process, thereby enhancing the efficiency of building optical fiber communication systems.

At present, there are many researches on the Rayleigh backscattering and Brillouin backscattering in fiber and the factors affecting the performance of EPON system. However, there are few researches on the effects of the two effects in a complete EPON system. Therefore, based on the VPI simulation platform, this paper constructs a single-channel bi-directional 10 Gb Ethernet PON simulation system. The effects of two kinds of effects on the performance of 10 Gb Ethernet PON system are observed experimentally, and the simulation results are qualitatively analyzed.

A Single Channel bi-directional 10 Gb Ethernet PON System Architecture Based on VPI
As shown in Fig. 1, the VPI-based single channel bidirectional 10 Gb EPON system includes an OLT, an optical network unit (ONU), an Optical Amplifier, an Optical Splitter Combiner, and the Universal Fiber. Among them, the Universal Fiber model simulates a wideband nonlinear signal transmission in optical fibers with piecewise constant parameters specified for each fiber span individually, taking into account Brillouin Scattering and Rayleigh back-scattering at each joint between spans. In the
upstream direction, the ONU to OLT is a point-to-point communication mode. The information sent by the ONU only reaches the OLT, but not the other ONUs. Time division multiple access (TDMA) is adopted in the uplink direction, and each ONU sends a data packet within a specified time slot to prevent collision of uplink information.

Figure 1. A single channel bi-directional 10 Gb Ethernet PON system architecture based on VPI.

Experiment and Performance Analysis

System Basic Simulation Settings and Results

The system default setting parameters are shown in Table 1, and the performance of the uplink OLT received signal is observed and analyzed by changing the parameters of Brillouin Scattering, Rayleigh back-scattering and AmplitudeRF.

<table>
<thead>
<tr>
<th>Default parameter</th>
<th>Default value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TimeWindow</td>
<td>512/10e9</td>
</tr>
<tr>
<td>BitRateDefault</td>
<td>10e9 bit/s</td>
</tr>
<tr>
<td>SampleRateDefault</td>
<td>8*10e9Hz</td>
</tr>
<tr>
<td>Loss</td>
<td>5</td>
</tr>
<tr>
<td>BrillouinScattering</td>
<td>NO</td>
</tr>
<tr>
<td>Rayleigh back-scattering</td>
<td>NO</td>
</tr>
<tr>
<td>AmplitudeRF</td>
<td>0</td>
</tr>
</tbody>
</table>

Under the default parameter setting, the spectrum diagram of OLT received signal, the eye diagram of OLT received signal and the wave chart of OLT received signal is shown in Fig. 2 (a), Fig. 2 (b) and Fig. 2 (c). The experimental error rate value is $9 \times 10^{-26}$. Normal communication bit error rate requirements below $10^{-9}$ [5]. It can be found from the experimental results that the quality of the received signal of the OLT is good and the bit error rate is very low, which can completely meet the requirement of normal communications, no matter before or after splitting.
The Impact of Rayleigh Back-scattering on the System

When all the other values are the default values, the value of Rayleigh back-scattering parameter is set to Yes. Observe and analyze the performance of the OLT received signal. The experimental results are shown in Fig. 3.

![Image](c) Wave chart of OLT received signal ![Image](d) BER of OLT received signal

Figure 3. The OLT received signal diagram.

The experimental error rate was $4.067 \times 10^{-7}$. Comparing the experimental results with Figure 2, we can find that the spectrum of the received signal of the OLT changes very little while the quality of the eye drops seriously, and the bit error rate increases to a certain extent, which cannot meet the needs of normal communication. Therefore, Rayleigh backscattering will make the system signal quality decline, the bit error rate increased dramatically, and affect the normal transmission of information system.

The Impact of Brillouin Scattering on the System

When all the other values are the default values, set the value of Brillouin Scattering to Yes. Observe and analyze the performance of the OLT received signal. The experimental results are shown in Fig. 4.

![Image](a) Spectrum diagram of OLT received signal ![Image](b) Eye diagram of OLT received signal

Figure 4. The OLT received signal diagram.
The experimental results show that the bit error rate is 0.33395. Comparing the experimental results with Figure 2, it can be found that the spectrum of OLT broadens and the frequency spectrum shifts before and after the splitting. The received signal of OLT is seriously distorted and the bit error rate is very high. Therefore, Brillouin Scattering will make the system signal quality serious decline, the signal error rate increased dramatically, unable to communicate properly.

**The Impact of both Brillouin Scattering and Rayleigh Back-scattering on the System**

When all the other values are the default values, set the Brillouin Scattering and Rayleigh back-scattering parameter values to Yes. Observe and analyze the performance of the uplink OLT received signal. The experimental results are shown in Fig. 5.

The experimental error rate was 0.3339. The experimental results shown in Figure 4 can be found that the OLT received signal spectrum, wave chart and eye diagram basically the same with Figure 4 and the error rate has not changed much. Therefore, when both the Brillouin Scattering and Rayleigh back-scattering effects coexist, BrillouinScattering has a great impact on system performance.

**The impact of Phase Modulation on Brillouin Scattering**

When all the other values are the default values, set the value of Brillouin Scattering to Yes and AmplitudeRF to 1. Observe and analyze the performance of the OLT received signal. The experimental results are shown in Figure 6.
Set AmplitudeRF to 1, which means that the optical uplink carrier is phase-modulated. Experimental results show that the bit error rate is 3.746*10^-11. Comparing the experimental results with Figure 4, it can be found that the broadening and frequency shift of signal spectrum do not occur and the quality of eye diagram is improved. The bit error rate can meet the requirements of normal communication. Therefore, phase modulation of the uplink carrier can effectively reduce the influence of Brillouin backscattering on the system and improve the quality of the received signal of the OLT.

Summary
Rayleigh and Brillouin Backscattering are two important effects in fiber. In this paper, we construct a single-channel bi-directional 10 Gb Ethernet PON simulation system. It can be seen from the experimental results that the Rayleigh and Brillouin backscatters have an impact on the system performance, but the Brillouin scattering effect is more affected when the two effects are simultaneously existed. In addition, phase modulation of the uplink carrier can effectively reduce the influence of Brillouin backscattering on the system. The related research work can provide reference for improving the performance of the 10 Gb Ethernet PON system.

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