

Design of a novel passive optical line protection for fiber to the home networks

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Abstract

In this paper, a theoretical design of a novel passive optical line protection device for fiber to the home networks is presented and discussed. Such a device has been designed to overcome several issues of the conventional optical line protection which is based on a switching mechanism controlled electronically. The proposed design is suitable for multiplexed passive optical networks, especially, the dense wavelength division multiplexing technology. This unit is installed at both ends of the network and is composed of a 1×2 splitter to deliver the transmitted multiplexed signal to 2 optical paths and a 2×1 (99.9/0.1) coupler allowing an automatic control when a problem appears. Two optical line protection units exchange optical data through 2 dual fibers. In the case where the primary link suffers from a transmission problem, it automatically switches without any electronic control whatsoever to the backup link through a passive (99.9/0.1) coupler with an average total loss estimated to be of 3.2 dB.

1. Introduction

In recent years, the ever-increasing growth of internet traffic and multimedia services pushed telecommunication operators to propose a convenient way to deliver the huge amount of data all the way to user's home through a next generation access technology called fiber to the home (FTTH). This technology has been introduced in the local loop, by taking credit of optical fiber multiple advantages [1,2].

This promising technology is considered as the ultimate solution to a future broadband access and high-speed network. Lately, multiple technological developments have brightened the outlook on FTTH networks. In a short amount of time, it has spread all over the world because it simply represents a future-proof infrastructure by offering higher bandwidth and lower signal loss comparing to the asymmetric digital subscriber line (ADSL) technology [3].

Overall, FTTH systems provide different services with a really high speed estimated by multi Gigabit-per

second over only one single bidirectional fiber, using the passive optical network - dense wavelength division multiplexing (PON-DWDM) technology according to the International Telecommunication Union (ITU) recommendations. This technology will ultimately add attractive features to FTTH networks such as broad bandwidth, high capacity, high flexibility, easy management, and lower costs [4,5].

One of the main advantages of PON networks is the fact that only a single shared optical fiber can support multiple users through the use of inexpensive passive components where up to 256 optical terminals can share one fiber connection to the ends of the network. This makes it an interesting option for service providers who are looking for upgrading their network performances, particularly in high-density urban areas [6].

The large amount of traffic circulating through the multiplexed FTTH-PON access network revealed a very disturbing issue of how to maintain this gigantic transmitted throughput, as well as the network connectivity when the only and main fiber experiences faults caused by multiple exterior sources which are beyond the human control - this is where intelligent devices and schemes are essential to eliminate such

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faults. In order to overcome this kind of problem, an optical line protection (OLP) unit, based on a 1×2 splitter and a switch, is installed at both ends of the network; it can automatically identify the optical path for the data according to the signal status of the main and backup fibers. In case the current optical power of the main fiber is less than a pre-set switching threshold value, then the alarm is on and it would switch to a standby optical fiber automatically to protect the optical transmission system line. In this way, when the main optical cable has a total resistance obstacle, the system can be protected to operate normally and the service quality of the operator can be maintained [7-9].

This switching unit is controlled electronically with an estimated total loss that could reach 4.5 dB. It can provide two types of optical line protection devices for network protection: OLP 1:1 (selective transmitting, selective receiving) and OLP 1+1 (dual-transmitting, selective receiving). Both of them require a spare fiber optic path. But they use different methods to secure the optical communication networks [7,8].

In this paper, we propose a much simpler and cost effective substitute version of the OLP based on a switching mechanism. The novelty of this work resides in a design of an OLP composed of only passive components, by replacing the switch with an optical (99.9/0.1) coupler.

By designing this OLP, a full passive network that means less energy consumption and a minimal insertion loss will be guaranteed. Since the proposed OLP used only passive optical components, there is no need for the energy feeding (0-Watt power consumption). However, other commercialized OLPs based on active optical switches and 3-dB splitters, cited in Refs. 7 and 10, present a power consumption lower than 6 Watts and their insertion losses for transmitting end is of 4 dB. On the other hand, the passive OLP described here presents a lower insertion loss which is estimated by 3.2 dB.

The operation principle of this novel OLP will be demonstrated and discussed in Section 2, while a simulation of this device via the *Optisystem* software will be done in Section 3.

2. Design and analysis of the proposed passive OLP

Theoretical scheme of the proposed passive OLP deployed at both ends of a multiplexed FTTH-PON network: the optical line terminal (OLT) and the optical network terminals (ONTs), is presented in Fig. 1. An OLP unit is composed of a 1×2 optical splitter and a (99.9/0.1) optical coupler, the total insertion loss of the passive OLP is estimated to be of 3.2 dB. The reason behind using 2 OLP units in one single FTTH network, as shown in Fig. 1, is to secure and maintain both downlink and uplink data transmission.

2.1 1×2 optical splitter

In FTTH-PON access networks, optical splitters play an important role by allowing a single PON interface to be shared among the subscribers according to the splitting ratio (that number could increase in case of a multiplexed DWDM network). Splitters contain no active electronics and do not require any power to operate [11,12].

Uniform power splitter with a 1:N or 2:N splitting ratio is one of the most common splitters deployed in the FTTH-PON system, where N is the number of output ports. The optical input power is distributed uniformly across all output ports [12].

In a described case, a 1×2 optical splitter is used to ensure two optical paths, the main and the backup fibers. The optical signal delivered by the OLT will be uniformly divided into two equal signals, one for each fiber.

It should be taken under consideration that the optical splitter presents the largest attenuation in a PON system which is considered as splitting loss between ports caused by splitting the light into multiple equal parts [13]. It is theoretically calculated as shown below in Eq. (1):

$$3 * \log_2 N, \tag{1}$$

where N is the number of output ports.

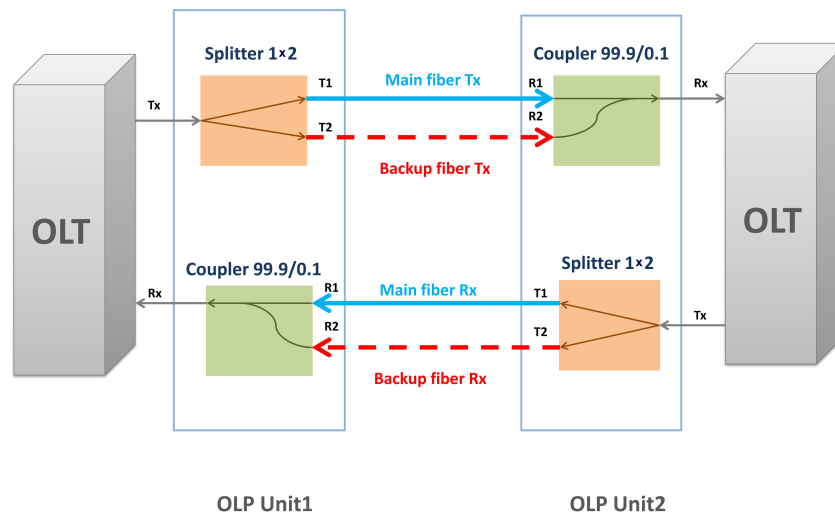


Fig. 1. The schematic of the proposed passive OLP unit.

Thus, the used optical splitter is a symmetrical 1×2 splitter having 2 output ports, its theoretical inevitable power loss will be estimated by 3 dB.

2.2 (99.9/0.1) optical coupler

Fiber couplers are considered to be an important component of the light wave technology. They are four-port devices (two input and two output ports) that are used routinely for a variety of applications related to fiber optics. Their function is to split or mix light from two inputs. The outputs contain a mixed signal in ratios depending on the coupling ratio with typical values being (50/50), (90/10), (95/5), and (99/1) [14,15].

For the present work, the coupler will replace the switch. It is used to mix light from two inputs, designated Signal 1 (coming from the main fiber) and Signal 2 (coming from the backup fiber). The first output will contain a mixed signal composed of both Signal 1 and Signal 2 with a (99.9/0.1) coupling ratio [15] while the second output port will not be used.

During the transmission, two scenarios are possible. The first one is presented in Fig. 2a), where the main and the backup fibers are perfectly operating at the same time. It means that the two inputs of the coupler (port 1 and port 2) receive 100% of the power of the multiplexed optical signal from both the main and the backup fibers. It results in the fact that the coupler combines two powers with a minimal loss to the port 4 leading to the end of the network. The second scenario shows [Fig. 2b)] that if the main fiber is deficient, the coupler, according to its own coupling ratio, will transfer 99.9% of the power received from the backup fiber to the port 3, then, to the optical terminal device or to the end of the network.

This particular value of the coupling ratio allows the optical coupler to present a total insertion loss worth of 0.2 dB according to Ref. 15.

The utility of the designed OLP in a FTTH-PON access network is the fact that it will transfer, passively without any external control, the received signals at its inputs to the optical terminal device with a minimum of insertion loss. Therefore, such approach will protect the transmission from any kind of problem that would interrupt it or, in the worst case, annul it.

3. Simulation model and parameter setting of the designed passive OLP

This section describes both simulation model and parameter settings of the FTTH-PON system architecture provided with a device for the line protection. It is dedicated to the simulation of an experiment setup of a 16-channel multiplexed FTTH-PON network using the *Optisystem* software. The designed passive OLP will be placed at both ends of the network as it will be specifically tested in a DWDM-Gigabit passive optical networks (GPON) system (defined by ITU-T recommendation series G. 984.1 [16]) through a simulation. Where a 50-km long single mode fiber (SMF), with an attenuation of 0.2 dB/km, will transmit a DWDM multiplexed signal delivered by optical sources operating in the interval of 1260–1310 nm with a spectral spacing of 0.4 nm between each wavelength. This multiplexed signal is transporting a total bit rate of 2.5 Gbps to the optical terminal device situated at the end of the network.

In order to get a closer and simpler look at how the designed OLP works, only the down link of the FTTH network will be tested as represented in Fig. 3.

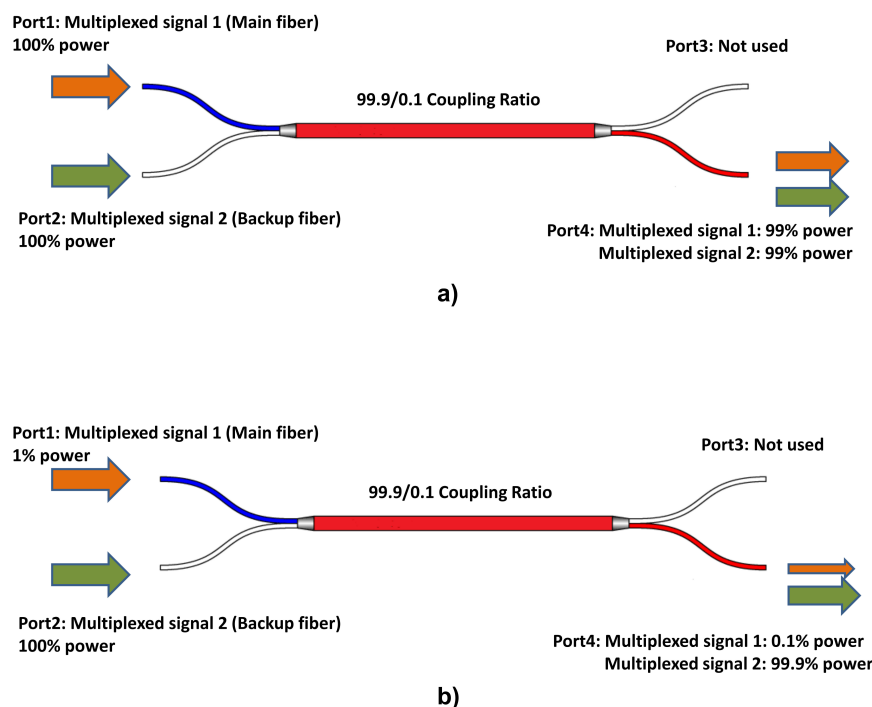


Fig. 2. a) Operation principle of the (99.9/0.1) coupler when the main and the backup fibers are operating at the same time; b) Operation principle of the (99.9/0.1) fused coupler when the main fiber is down and the backup fiber is operating.

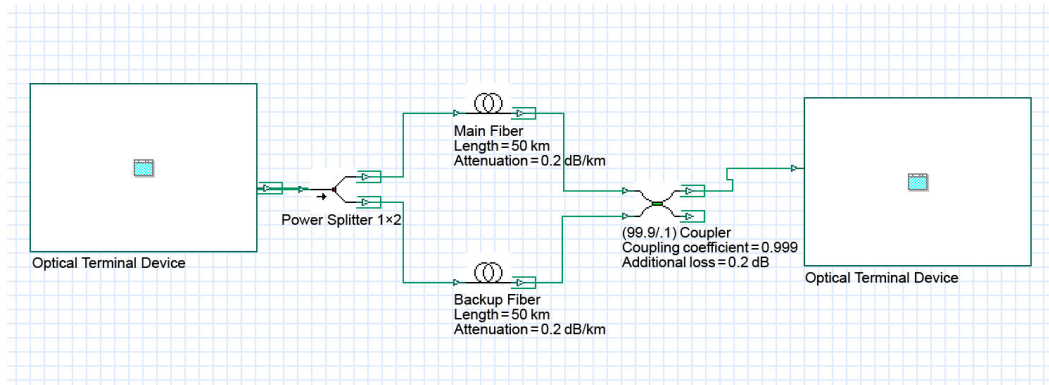


Fig. 3. The overview of the multiplexed FTTH-PON system provided with the designed passive OLP to Optisystem.

The efficiency of such device will be quantified and determined after the simulation by measuring its own total insertion loss, as well as checking how the multiplexed FTTH-PON network would respond after implementing the novel OLP. It means checking the bit error rate (BER) and the Q factor of the received multiplexed signal at the end of the network.

3.1 Total insertion loss of the designed OLP

While executing the system shown in Fig. 3, it was possible to measure the total insertion loss of the components composing the novel OLP by using an optical power meter found in the Optisystem library.

Table 1 displays the measured power of the multiplexed signal delivered by the OLT, the power at the two outputs of the splitter and the power of the output of the coupler.

Because the splitting loss equals a difference between the power measured at the input of the splitter (dBm) and the power measured at the output of the splitter (dBm), hence:

$$\text{Splitting loss(dB)} = 6.336 - 3.325 = 3.011 \text{ dB.}$$

On the other part, the coupler insertion loss equals a difference between the power measured at the input of the coupler (dBm) and the power measured at the output of the coupler (dBm), hence:

$$\begin{aligned} \text{Coupler insertion loss (dB)} &= 3.325 - (0.2 \cdot 50) + 6.875 \\ &= 0.2 \text{ dB.} \end{aligned}$$

Table 1. Measured powers of the multiplexed signal at different inputs and outputs.

	Measured power in (W)	Measured power in (dBm)
The input of the 1x2 splitter	$4.301 \cdot 10^{-3}$	6.336
The output of the 1x2 splitter	$2.15 \cdot 10^{-3}$	3.325
The output of the (99.9/0.1) coupler	$205.36 \cdot 10^{-6}$	-6.875

It can be now guaranteed that the simulation results match the theoretical estimation, since it is confirmed that a passive OLP has a total insertion loss equal to 3.2 dB.

The two scenarios mentioned in the previous section are reproduced by the simulation, as is described below.

3.2 The first scenario

In this case, the main fiber manages to transmit a multiplexed signal with only an attenuation of 0.2 dB/km which means the two inputs of the optical coupler receive 99 % of the power corresponding to -3.872 dBm, therefore, the FTTH-GPON system is perfectly working. Figure 4 shows the eye diagram of the first user for the simulated system, where the bit error rate is of around $1.56 \cdot 10^{-41}$ which is quite below the acceptable level ($BER < 10^{-9}$); this low error rate implies an acceptable Q factor ($Q > 6$) of 13.44. The remaining 15 users showed similar BER and Q values.

3.3 The second scenario

In this scenario the designed passive OLP was put under the test where, in this case, the main fiber faced an obstacle represented in the simulation by an attenuator. This can normally cause a problem with the connectivity of the network since a transmitted signal would be either partially or completely attenuated. However, the proposed device did the required job by maintaining the whole system working and stable even when the power at the input corresponding to the main path was extremely low by providing at its output 100% of the power delivered by the secondary path corresponding to -3.910 dBm. It was as if the main fiber was still delivering the signal to the input of the coupler as shown in Table 2.

Table 2. Measured powers of the multiplexed signal at different inputs and outputs according to the second scenario.

	Measured power in (W)	Measured power in (dBm)
The input of the coupler (main path)	0	-100
The input of the coupler (backup path)	$215.04 \cdot 10^{-6}$	-6.675
The output of the (99.9/0.1) coupler	$205.20 \cdot 10^{-6}$	-6.878

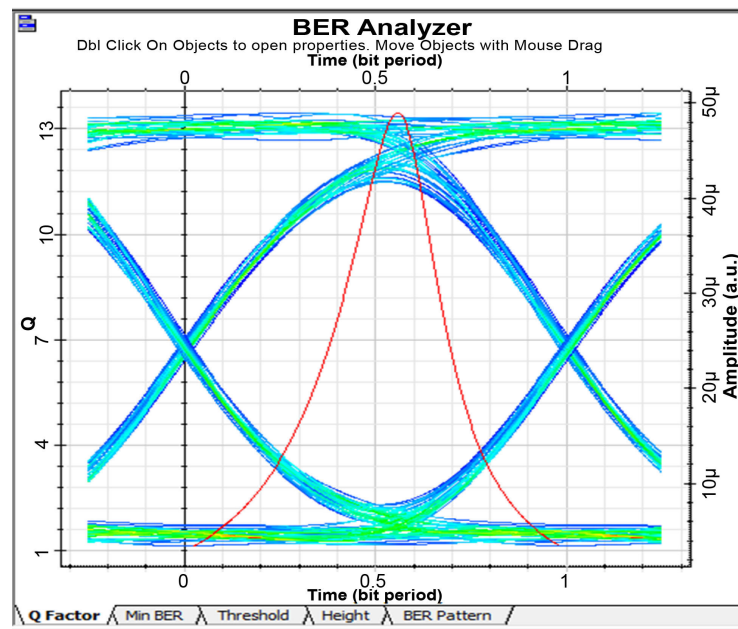


Fig. 4. Eye diagram of the first user for the simulated system according to the first scenario.

In the case of the second scenario, the BER is around $1.6 \cdot 10^{-41}$ and this low error rate implies an acceptable Q factor of 13.45. These values imply the exact same eye diagram shown in Fig. 4. The remaining 15 users showed approximately similar BER and Q values.

All the measures taken from the simulation (insertion loss, BER curve, and Q factor) confirmed that the proposed passive OLP device is suitable for FTTH-PON applications. It performed an excellent job by maintaining the connectivity and stability of the entire system transmission when the primary link was deficient, by effectively solving the problems of fiber transmission damage, line interruption, and equipment power failure.

4. Conclusions

In this paper, a theoretical design of a novel passive optical line protection is presented. This device is dedicated to the FTTH networks based on the multiplexed (DWDM) PON systems. The purpose behind proposing this designed OLP is to upgrade the quality of service that telecommunication operators have to offer when it comes to FTTH applications. As it has been proved, it is essential to add the OLP optical protection equipment to the optical transmission network at both ends. At the same time, it is necessary to provide different routing lines for a transmitted multiplexed signal. The conventional OLP, already existing, is based on a switching mechanism meaning the necessity of an electronic control to switch the path of the transmitted optical signal when the main fiber is deficient. The novelty of the proposed OLP is replacing the switch with an optical coupler with a (99.9/0.1) coupling ratio, in this case, if the main fiber encounters any problem. The optical terminal devices situated in homes would still receive the totality of the optical signal without no need for electronic control. The new

OLP device, as proved by the simulation results, showed an excellent performance when the primary link was deficient with a BER estimated by $1.6 \cdot 10^{-41}$ corresponding to a Q factor of 13.45, as if the transmission faced no problem. It was also proved that the passive OLP is characterised by an insertion loss of 3.2 dB instead of 4.5 dB given by the OLP deployed in current optical networks. In addition to that, the novel OLP maintains the principle of all passive components in the FTTH-PON network, meaning that it requires no specific power, no climate control, no maintenance whatsoever.

Author's statement

Research concept and design, I. Hacene and F. Karim; collecting and/or assembly of data, I. Hacene; data analysis and interpretation, I. Hacene; writing the article, I. Hacene; critical revision of the article, F. Karim; final approval of article, I. Hacene and F. Karim.

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