MATLAB-based In-service Transmission Surveillance and Self Restoration System for Optical Access Network

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Summary
This paper presented a MATLAB-based system named Smart Access Network Testing, Analyzing and Database (SANTAD), purposely for in-service transmission surveillance and self restoration against fiber fault in tree-based structured optical access network. The developed program will be installed with optical line terminal (OLT) at central office (CO) to monitor the status and detect any fiber fault that occurs in the optical access network downwardly from CO towards customer premises. SANTAD is interfaced with optical time domain reflectometer (OTDR) to accumulate every network testing result to be displayed on a single computer screen and then specify the failure location in the network system. This approach has a bright prospect to improve the survivability and reliability as well as increase the efficiency and monitoring capability in a tree-based structured optical access network.
Key words:
SANTAD, in-service transmission surveillance, self restoration, fiber fault, optical access network.

1. Introduction

An access network refers to the connections that extend from the CO to a neighborhood and further to individual businesses and homes. This network often is called *last leg* or *last mile*. Traditionally, copper wires were used as the transmission medium in the access network, since using optical fibers cost-effectively in these transmission spans is a major challenge. However, various means of using fibers in the access network have been explored. These schemes are known by the all inclusive term fiber-to-the-x (FTTx), where x is some letter designating at what point the fiber terminates and copper wires (or wireless links) again take over. The reach of various FTTx schemes are fiber-to-the-neighborhood (FTTN), fiber-to-the-curb (FTTC), fiber-to-the-building (FTTB), fiber-to-the-office (FTTO), and fiber-to-the-home (FTTH) [1]. FTTH will soon become fiber-to-every-home (FTEH) and FTTO will also become fiber-to-every-office (FTEO) as standard for new construction in many developed countries by 2010. The optical access network has been widely deployed to fully support the triple-play services including data, voice, and video.

FTTH has played the major role in alleviating the last mile bottleneck for next generation broadband optical access network [2]. A number of factors are increasing the interest among network service providers in offering the triple play services of voice, video, and high-speed data access. Most importantly, subscribers are finding a growing number of applications that drive their desire for higher bandwidth, including Internet access, interactive games, and video delivery. The first serious interest in FTTH began in the late 1980s as the telephone companies gained experience with Integrated Services Digital Network (ISDN) wideband services to subscribers [3]. Today, FTTH has been recognized as the ultimate solution for providing various communications and multimedia services, including carrier-class telephony, high-speed Internet access, digital cable television (CATV), and interactive two-way video-based services to the end users [4].

FTTH technology using passive optical network (PON) is the most promising way to provide high quality broadband access. PON are nowadays extensively studied and some commercial deployments are already reported [5]. The PON is commonly deployed as it can offer a cost-efficient and scalable solution to provide huge-capacity optical access [6]. Since the PON can accommodate a large number of subscribers, when any fault occurs in FTTH, the network will without any function behind the break point. Any service outage due to a fiber break can be translated into tremendous financial loss in business for the network service providers [7].

Meanwhile, the laser (optical source) is highly explored at the transmission end when an optical line broken. Optical fiber communication systems often use semiconductor optical sources such as light-emitting diodes (LEDs) and semiconductor lasers because of several inherent advantages offered by them. Some of these advantages are compact size, high efficiency, good reliability, right wavelength range, small emissive area compatible with fiber core dimensions, and possibility of direct modulation at relatively high frequencies [8]. The semiconductor laser diode is similar to other laser, such as conventional solid

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state and gas laser, but the output radiation is highly monochromatic and the light beam is very directional [1].

The wavelength range used in modern optical systems is around 1550 nm (near infrared). In this wavelength region, powers greater than 21.3 dBm emanating from a fiber end are considered to be intrinsically hazardous to the eye. High power levels in optical communications systems are typically associated with the output of optical amplifiers such as erbium doped fiber amplifiers (EDFAs) or Raman fiber amplifiers [9]. The unprotected human eye is extremely sensitive to laser radiation and can be permanently damaged from direct or reflected beams. The site of ocular damage for any given laser depends upon its output wavelength. According to Bader and Lui, laser light in the visible and near infrared spectrum (400 nm - 1400 nm) can cause damage to the retina resulting in scotoma (blind spot in the fovea) [10]. This wave band is also known as the retinal hazard region. Meanwhile, laser light in the ultraviolet (290 nm - 400 nm) or far infrared (1400 nm - 10600 nm) spectrum can cause damage to the cornea and/or to the lens. The extent of ocular damage is determined by the laser irradiance, exposure duration, and beam size.

According to the cases reported to the Federal Communication Commission (FCC), more than one-third of service disruptions are due to fiber cable problems. These kinds of problems usually take longer time to resolve compared to the transmission equipment failure [11]. Therefore, fiber fault within FTTH becomes more significant due to the increasing demand for reliable service delivery [6]. Conventionally, OTDR is used to identify a fiber fault in FTTH upwardly from multiple optical network units (ONUs) at different residential customer locations toward OLT at CO (in upstream direction). OTDR testing is the best method for determining the exact location of broken optical fiber in an installed optical fiber cable when the cable jacket is not visibly damaged. It determines the loss due to individual splice, connector or other single point anomalies installed in a system. It also provides the best representation of overall fiber integrity [12]

Since a FTTH has many branches in the drop region, whenever a fault occurs, OTDR is plugged manually to the faulty fiber by the technician to detect where the failure is located. However, this approach would require much time and effort. Moreover, OTDR can only display a measurement result of a single line in a time. Therefore, it becomes a hindrance to detect a faulty fiber with a large number of subscribers and large coverage area in the fiber plant by using an OTDR. Besides, it is difficult to detect a failure in optical line equipped with passive optical splitter by using a conventional OTDR in the CO downwardly from CO (in downstream direction), because the Rayleigh back-scattered (RBS) light from different branches overlap (accumulate) with each other in the OTDR trace and cannot be distinguished [7].

2. SANTAD

To reduce the cost and enhance the benefits, we presented the implementation of SANTAD in a tree-based structured optical access network in this paper, which is involved in the failure detection, automatic recovery and increases the survivability and maintainability of FTTH. SANTAD is a centralized access control and surveillance system that enhances the network service providers with a means of viewing traffic flow and detecting any breakdown as well as other circumstance which may require taking some appropriate action. It is the new upgraded values of recent FTTH technology toward the implementation of smart network.

The principle operation of SANTAD can be divided into three main parts consists of measuring optical fiber lines with OTDR, interfacing OTDR with personal computer (PC), and system testing and analyzing with SANTAD. This paper is focus on demonstrating the execution displays of SANTAD for identifying faulty fiber and locating failure location in the optical access network system.

SANTAD is potentially used to increase survivability, efficiency, and flexibility of optical access network with point-to-multipoint (P2MP) connectivity between the OLT at CO and multiple ONUs at different residential customer locations, particularly for downwardly in-service transmission surveillance and self restoration against fiber fault. Overall, it can reduce the time needed to restore the fault to maintain and operate the optical access network more efficiently.

2.1 Principle Enhancement of SANTAD

SANTAD not only enables the field engineers to monitor the status and determine any failure or circumstance which may require promptly action in optical access network, but also to determine deployment, connection, and losses (connection losses, splice losses, optical device/component losses, fiber losses or attenuation) in the network system. Besides, it also able to track the optical signals level (input/output power) and losses at each point as well as monitoring the network performance. The developed program also provides the network service providers with a control function to intercom all subscribers with CO. The mechanism of SANTAD detection is illustrates in Fig. 1.

Whenever a failure occurs on the primary entity, the traffic (service delivery) is switched from the working (primary) line to the protection (backup) line to ensure the traffic flow continuously and the failure status will be automatically sent to the field engineers through the mobile phone or Wi-Fi/Internet computer using wireless technology for repairing and maintenance operation. After the restoration/maintenance process, the traffic will be switched back to the normal operation. The whole operation process can be simplified in the flow chart as depicts in Fig. 2.

2.2 Measurement System Configuration

Our system architecture design is presented in Fig. 3. The distance between the OLT and ONU is about 20 km. A commercially available OTDR with a 1625 nm laser source is used in failure detection control and in-service troubleshooting without affecting the triple-play services transmission. The OTDR is connected to a PC or laptop to display the troubleshooting results via RS-232 connection (using DB-9 extension cable to connect both serial ports at PC and OTDR). The triple-play signals (1310 nm, 1490 nm, and 1550 nm) are multiplexed with 1625 nm testing signal. When four kinds of signals are distributed, the testing signal will be split up by wavelength selective coupler (WSC), which is installed before the optical splitter. The WSC only allow the 1625 nm signal to enter into the taper circuit and reject all unwanted signals (1310 nm, 1490 nm, and 1550 nm) that contaminate the OTDR measurement.

The downstream signal will go through the WSC, which in turn connected to optical splitter before it reaches the optical network units (ONUs) at different residential customer locations. On the other hand, the testing signal which is demultiplexed by WSC will be split up again in power ratio 99:1 by using directional coupler (DC) to activate the microprocessor system. The 99% 1625 nm signal will then be configured by using optical splitter, which each output is connected to single line of ONU.

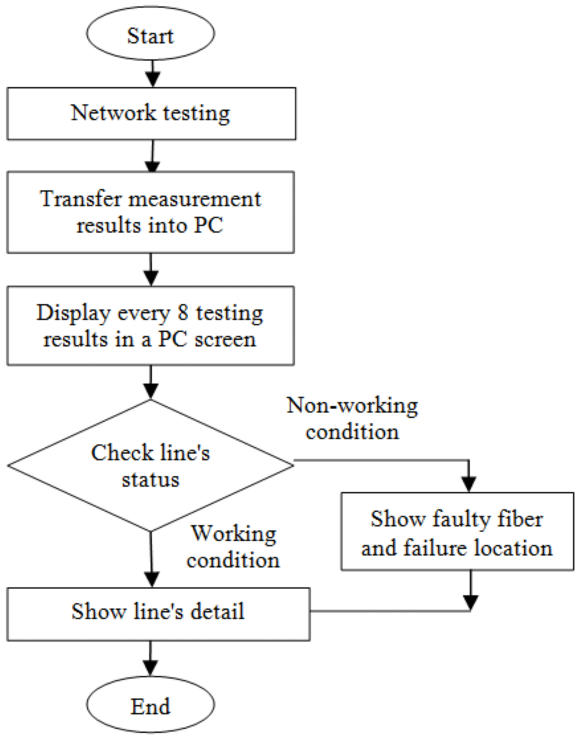

Fig. 1 Flow chart for mechanism of SANTAD detection.

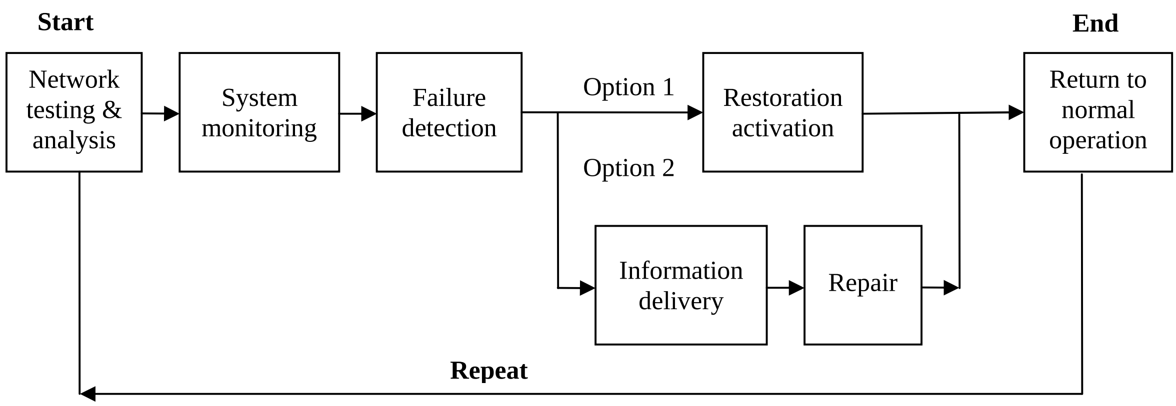

Fig. 2 The process flow for failure detection and self restoration in SANTAD.

The operational of optical switch is controlled by microprocessor system that is activated by 1% of 1625 nm signal. With the method described in this paper, no any expensive additional equipments or devices are required.

3. Experimental Setup and Network Testing

SANTAD is focusing on providing survivability through event identification against losses and failures. SANTAD involves the fiber fault detection, notification, verification, and restoration functions. Under working condition, it allows the network services providers to determine the path used by the services through the network, whereas under non-working conditions, it allows the fields engineers to identify the faulty fiber and failure location without making a site visit. SANTAD enable the network service providers and field engineers to analyze the optical fiber line's status, display the line's detail, track the optical signal level, and losses as well as monitor the network performance. In combination of the distinctive features, SANTAD provides a convenient way to solve the particular upwardly or downwardly measuring issues with OTDR and produce capability of fiber fault localization in a tree-based structured optical access network.

SANTAD will be designed to operate by itself with a minimum need for operator action. SANTAD ensures that when detect a fiber fault occurs on the primary entity in optical access network, it is automatically reported the failure status to the field engineers, and the field engineers can determine sharply the break point before taking some appropriate actions. Meanwhile, activate the restoration scheme to switch the traffic from failure line to protection line to ensure the traffic flow continuously. This functionality alerts the service providers and field engineers of a fiber fault before it is reported by the customer premises or subscribers.

In order to gauge the effectiveness and benefits of SANTAD, we tested our technique on a P2MP network. The instruments and measurement equipments used in the experiment are summarized in Fig. 3 with the help of the block diagram. After that, the measurement results for each line are saved in the OTDR and then transferred into PC. After completing the transferring process, all the results are be recorded in database and then loaded into the developed program for further analysis as shown in Fig. 4 and 5.

As a first step, no default was introduced in the network and OTDR measurements were performed. One can indeed observe that the OTDR testing signals in for each connection in a working (good/ideal) condition in Fig. 6. Then, we introduced a fiber break in one of the branches at distance of 15 km and 30 km. The optical fiber is not connected to any device at another end (unplugging) to represent the break point in a testing line. It visualized the actual break point of an optical line at that distance in a real condition. The analysis result for a non-working (failure/breakdown) condition is presented in Fig. 7 and 8.

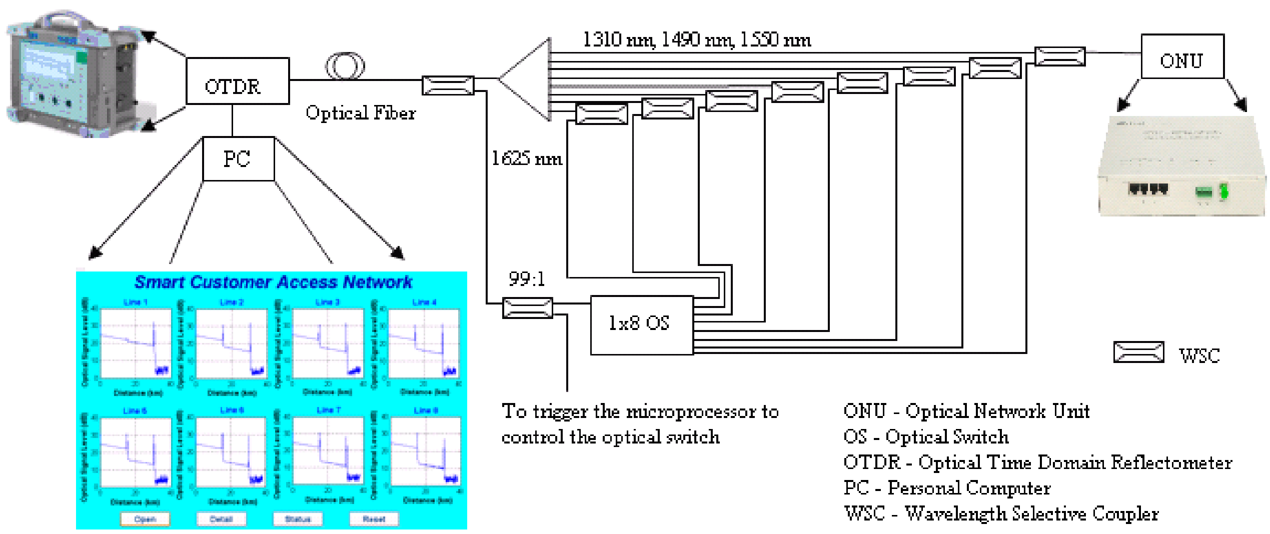

Fig. 3 SANTAD is installed at CO for centralized monitoring and fiber fault identification downwardly from CO (in downstream direction).

4. Execution Display for SANTAD

Fig. 4 and 5 shows the ability of SANTAD to specify a faulty fiber and failure location among a number of optical fiber lines in an optical access network by measuring the optical signal level and losses. Every eight network testing results will be displayed in *Line's Status* window for centralized monitoring, where the distance (km) represented on the x-axis and optical signal level (dB) represented on the y-axis. A failure message "*Line x FAILURE at z km from CO!*" will be displayed to inform the field engineers if SANTAD detect any fiber fault in the network system.

To obtain further details on the performance of specific line in the network system, every measurement results obtained from the network testing are analyzed in the *Line's Detail* window. SANTAD is able to identify and present the parameters of each optical fiber line such as the line's status, magnitude of decreasing at each point, failure location and other details as shown in the OTDR's screen.

SANTAD has the same features of the OTDR and computer-based emulation software for performing more OTDR trace processing functions, but with more additional features and flexible to use in optical communication link. SANTAD displayed every status for the testing line in the *Line's Detail* form. A "*Good condition*" or "*Decreasing y dB at z km*" message displays at the line's status panel in a working condition (see Fig. 6).

However in the non-working condition, a failure message "*Line x FAILURE at z km from CO!*" displays to show the faulty fiber and failure location in the network as illustrated in Fig. 7 and 8. It is flexible and easily to use for those who are inexperience in the optical fiber testing by just reading the information gain from the messages. As a remark, we highlight that our strategy may also be modified to be applicable in the long haul optical communication link or other FTTx schemes.

The optical signal level is giving a visual representation for the network deployment and connection. SANTAD can tracks all losses and attenuation in the network for the preventive maintenance and network performance monitoring purposes. When a fiber fault occurs, the field engineers may determine sharply the break point before it is been restored the stand-by line and repaired for post-fault maintenance through SANTAD. By in-service monitoring with SANTAD, the field engineers can view the service delivery and detecting any breakdowns as well as other circumstances which may require some promptly

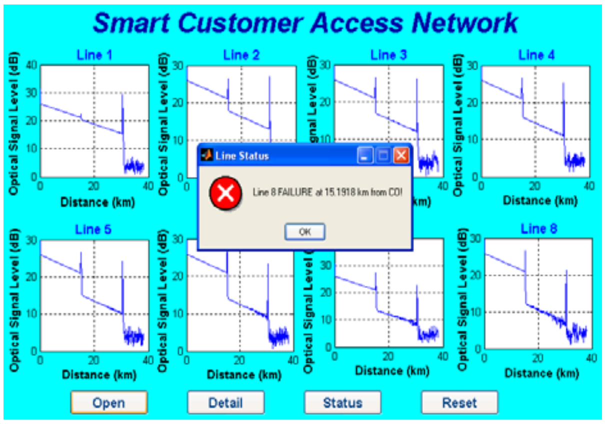

Fig. 4 Eight graphs are displayed on the *Line's Status* window. A failure message displays to show the faulty fiber and failure location in the network system (for single event).

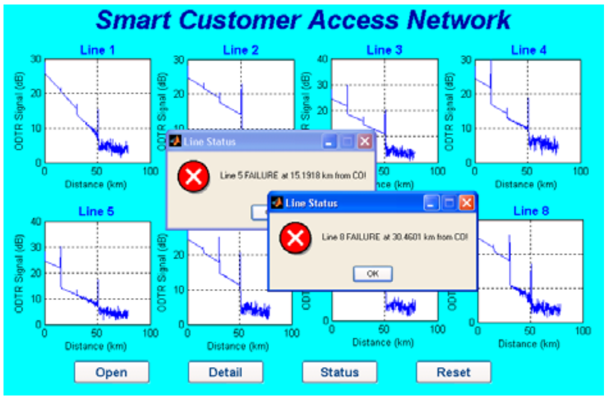

Fig. 5 Two failure message display to show the faulty fibers and failure locations in the network system (for two events).

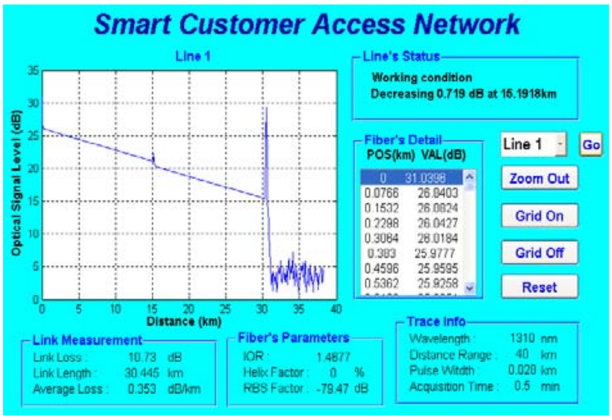

Fig. 6 An example of working line in the *Line's Detail* window. The optical power level in line 1 is decreasing 0.719 dB at distance 15.1918 km.

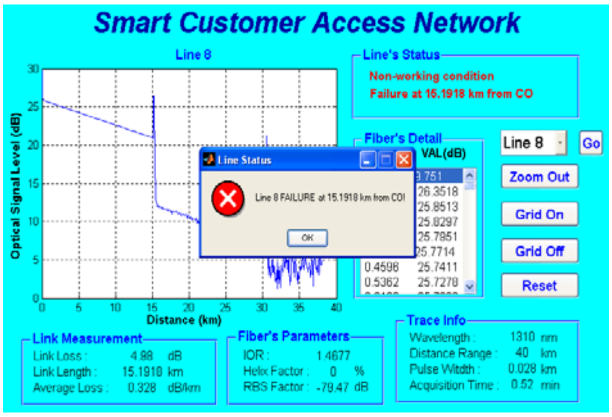

Fig. 7 An example of failure line in the *Line's Detail* window. The line 8 is failure at 15.1918 km when the fiber is unplugged at distance 15 km to represent the break point in a testing line. It represented the break point occurs at that distance in optical access network system in a real condition.

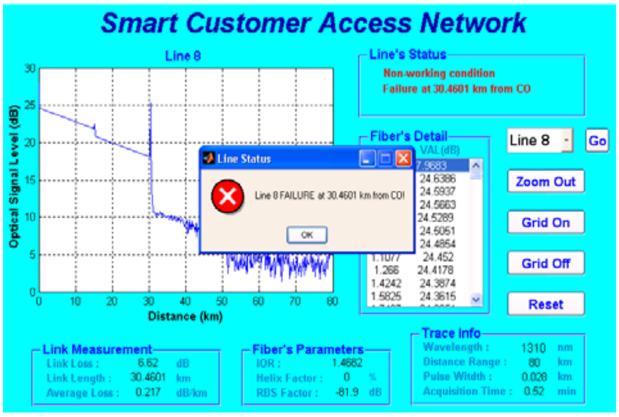

Fig. 8 Another example of failure line in the *Line's Detail* window (for two events). The line 8 is failure at 30.4601 km when the fiber is unplugged at distance 30 km.

action before it turns into big trouble and causes a tremendous financial loss.

5. Conclusions

Each status of optical line within an optical access network has been investigated using a commercially available OTDR. The proposed MATLAB-based system accumulated all the measurement results from OTDR into a PC screen and accurately determined the faulty fiber as well as the failure location in the network system using event identification method. It is a cost-effective way to detect any failure occurs within the tree-based structured optical access network to improve the service reliability and reduce the restoration time and maintenance cost. In future research activity, we aim to add in some new features for this program based on Microsoft Visual Basic software.

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References

[1] G. Keiser, Optical Fiber Communication, 3rd ed., New York: McGraw Hill, 2000.

[2] C.H. Yeh, and S. Chi, "Optical Fiber-fault Surveillance for Passive Optical Networks in S-band Operation Window", Opt. Express, vol. 13, no. 14, pp. 5494-5498, 2005.

[3] S.S. Gorshe, "FTTH Technologies and Standards Industrial Highlights", available: www.ezcom.cn/English/digital%20library/200612/13.pdf.

[4] L. Lee, S.B. Kang, D.S. Lim, H.K. Lee, and W.V. Sorin, "Fiber Link Loss Monitoring Scheme in Bidirectional WDM Transmission using ASE-injected FP-LD", IEEE Photon. Technol. Lett., vol. 18, no. 3, pp. 523-525, 2006.

[5] M. Wuilpart, A. Grillet, K. Yuksel, D. Gianone, G. Ravet, and P. M´egret, "Dynamics Enhancement of OTDR-based Monitoring Systems for Passive Optical Networks", Proceedings Symposium IEEE/LEOS Benelux Chapter, Brussels, pp. 167-170, 2007.

[6] J. Prat, "Optical Networks: Towards Bandwidth Manageability and Cost Efficiency", available: http://www.e-photon-one.org/ephotonplus/servlet/Utils.MostrarFitxerPublic?fitxer=D_VD-A_3.pdf&pathRelatiu=EPhoton+One+ %2B%2FPublic%2FPublic+Deliverables%2F, 2007.

[7] C.K. Chan, F. Tong, L.K. Chen, K.P. Ho, and D. Lim, "Fiber-fault Identification for Branched Access Networks using a Wavelength-sweeping Monitoring Source," IEEE Photon. Technol. Lett., vol. 11, no. 5, pp. 614-616, 1999.

[8] G.P. Agrawal, Fiber-optic Communication Systems, 3rd ed., New York: John Wiley & Sons, 2002.

[9] K. Hinton, P. Farrell, A. Zalesky, L. Andrew, and M. Zukerman, "Automatic Laser Shutdown Implications for All Optical Data Networks", J. of Lightwave Technol., vol. 24, no. 2, pp. 674-680, 2006.

[10] O. Bader, and H. Lui, "Laser Safety and the Eye: Hidden Hazards and Practical Pearls", available: http://www.dermweb.com/laser/eyesafety.html, 1996.

[11] A.A.A. Bakar, M.Z. Jamaludin, F. Abdullah, M.H. Yaacob, M.A. Mahdi, and M.K. Abdullah, "A New Technique of Real-time Monitoring of Fiber Optic Cable Networks Transmission", Optics and Lasers in Engineering, vol. 45, pp. 126-130, 2007.

[12] B. Chomycz, Fiber Optic Installation: a Practical Guide., New York, US: McGraw-Hill, 1996.

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