Remotely Control, Centralized Monitoring and Failure Analyzing in PON

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Summary

This paper presented a centralized monitoring and failure analyzing approach for passive optical network (PON) using Smart Access Network Testing, Analyzing and Database (SANTAD). SANTAD is developed for downwardly monitoring and failure detection in PON from central office (CO) towards customer premises. SANTAD interfaced with optical time domain reflectometer (OTDR) test module via Ethernet connection for remotely control and operate from CO. SANTAD accumulated every OTDR measurement to be displayed on a single computer screen for centralized monitoring and further data analyzing. SANTAD enable each status of customer premise equipment (CPE) connected line to be displayed a single screen with capability to configure the attenuation and detect the failure simultaneously. The analysis results and information will be delivered to the field engineers for promptly actions. This paper also discussed the uses of laser as optical source in optical fiber communication system as well as the eye safety issues with laser.

Key words:

SANTAD, downwardly monitoring, failure detection, OTDR, data analyzing.

1. Introduction

FTTH is a broadband network architecture in which a communications path is provided over optical fiber cables extending from the telecommunications operator's switching equipment (at CO, head end, or local exchange) to the boundary of the home living space or business office space. This communications path is provided for the purpose of carrying the triple-play (high speed data access, voice, and video) services traffic to one or more subscribers [1]. Owing the very high capacity of optical fibers, FTTH can deliver greater capacity as compares to copper-based technologies [2].

The key drivers for deploying FTTH infrastructures are advanced multimedia services, including Internet Protocol television (IPTV), high definition television (HDTV), and video on demand (VoD), ultra high bit rate Internet access (50-100 Mbps), and corporate broadband applications such as videoconferencing, hosted voice over IP (VoIP), and IP virtual private networks (VPNs) [3].

There are two fundamental FTTH architectures deployed in today's access networks: point-to-point (P2P), which is commonly referred to as active optical network (AON) or active Ethernet; and point-to-multipoint (P2MP), which is commonly referred to as PON. In the AON architecture, a single fiber runs all the way from CO to the home. However, PON has a single fiber that runs from CO to deep in the network and usually terminates at a splitter cabinet [3]. This architecture is called passive because all intermediate equipment between the CO and the optical network units (ONUs) are passive, it has no active electronics and therefore does not need separate power [4]. Both architectures installations as can be seen in Fig. 1

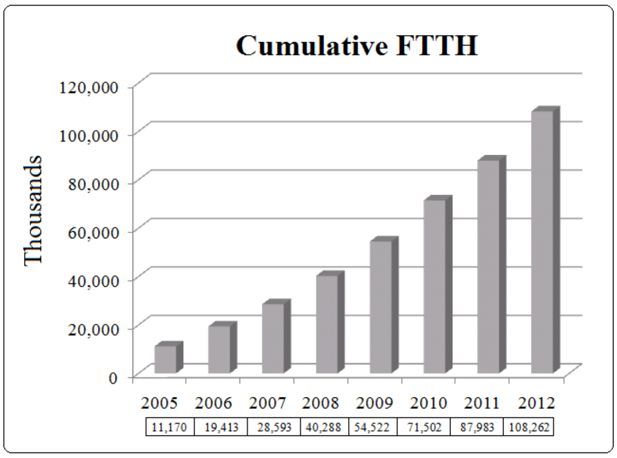

Fig. 1 Cumulative global growth of FTTH for the years 2005–2012.

PON using tree topology or P2MP configuration is one of the most promising solutions for fiber-to-the-office (FTTO), fiber-to-the-business (FTTB), fiber-to-the-curb (FTTC), and FTTH, since it breaks through the economic barrier of traditional P2P solutions. The P2MP cable plant provides branching optical paths from the telecommunications operators switching equipment (optical line terminal, OLT) to more than one contiguous location such that portions of the optical paths are shared by traffic to and from multiple locations [1].

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The splitter cabinet typically contains a 1xN passive optical splitter (power splitting element/branching device). The optical splitter is positioned not more than 1 km from the customer residential locations, in order to minimize the fiber usage. Each customer/subscriber has a dedicated short fiber, but shared the long distribution trunk fiber which is not more than 19 km [5]. The triple-play signals from CO are passively split to share between a number of ONUs at different residential customer locations (with split ratios of 1:8, 1:16, 1:32, 1:64, and 1:128). The 32 or 64 ways splitting are the most common today, but other splits are possible.

PON has been early described for FTTH as early as 1986. The first trial PON system was developed and deployed by British Telecom around 1989. First generation PON systems were developed by both major equipment vendors and start-up companies. The first deployments of commercial PON systems targeted business customers. The market was relatively small, however, since it was uncommon to have a cluster of business customers wanting access to bandwidth greater than DS1/E1 that were all reachable by the same PON [6].

Nowadays, PON is commonly deployed as it can offer a cost-efficient and scalable solution to provide huge-capacity optical access [7]. The cost effectiveness of PON depends on numbers of ONUs per OLT optical transceiver, the cost of fiber and its installation, the cost of the DSL transceivers at ONU and subscriber premise equipments, the overall cost of powering ONU, and the real estate cost of placing the ONU [6]. Fixed network and exchange costs are shared among all subscribers. This reduces the key cost per subscriber metric. The PON solution benefits from having no outside-plant electronic to reduce the network complexity and life-cycle costs, while improving the reliability of FTTH [8].

2. Fiber Fault in PON

Since the PON can accommodate a large number of subscribers, when any occurrence of fiber cut/fault, the access network will without any function behind the break point. Due to the large transport capacity achieved by optical access network, failures caused huge losses of data and greatly influence upon a large number of users over a wide area. Any service outage due to a fiber break can be translated into tremendous financial loss in business for the network service providers [9]. Meanwhile, the laser light (optical source) is highly explored at the transmission end when an optical line broken. Even thought low power laser with just few miliwatts (mW), but it still can cause burning in the retina that lead to damage temporarily or permanently (blind) in a few seconds or even less time depending to the energy absorbed by the retina (This will be happen when the optical fiber cable is broken and exposed to human skin) [10, 11]. Therefore, the survivability of PON has to be examined more seriously.

Lack of survivability in the safety issues is one of main factors that PON is still not been deployed in certain developing countries. According to the cases reported to the Federal Communication Commission (FCC) in US, 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 [12].

2.1 Laser and Eye Safety

Light Amplification by Stimulated Emission of Radiation (LASER) is a device that emits light (electromagnetic radiation) through a process called stimulated emission. Laser light is usually spatially coherent, which means that the light either is emitted in a narrow, low-divergence beam, or can be converted into one with the help of optical components such as lenses. Typically, lasers are thought of as emitting light with a narrow wavelength spectrum. The coherence of typical laser emission is distinctive.

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 [13]. The concept of the semiconductor laser diode was proposed by Basov and Javan. The first laser diode was demonstrated by Robert N. Hall in 1962. Hall's device was made of Gallium Arsenide (GaAs) and emitted at 850 nm in the near infrared region of the spectrum. The first semiconductor laser with visible emission was demonstrated later the same year by Nick Holonyak, Jr. As with the first gas lasers, these early semiconductor lasers could be used only in pulsed operation, and indeed only when cooled to liquid nitrogen temperatures (77 K). The semiconductor laser is similar to other lasers, such as conventional solid state and gas laser, but the output radiation is highly monochromatic and the light beam is very directional [2].

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 [14]. 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 [15], 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). 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.

2.2 Fiber Fault Localization in PON using OTDR

Fiber fault within PON becomes more significant due to the increasing demand for reliable service delivery. OTDR was first reported in 1976 [15] as a telecommunications application and became an established technique for attenuation monitoring and fault location in optical fiber network within the telecommunications industry [17]. OTDR is optical measurement equipment that used to analyze the attenuation (light loss) in an optical fiber and optical access network troubleshooting. It injects a short, intense laser pulse into optical fiber and measures the backscatter and reflection of light as a function of time. The reflected light characteristics are analyzed to determine the location of any optical fiber fault/break or splice loss.

According to Chomycz [18], 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.

The OTDR measurements can easily be transmitted into computer for advanced OTDR analyzing via RS-232 (serial port) connection, high-speed universal serial bus (USB) interface, ActiveX, General Purpose Interface Bus (GPIB), Ethernet Transmission Control Protocol/Internet Protocol (TCP/IP) connection, and extended memory option (manually transfer through floppy disk or USB memory) in a proprietary encoding format such as .TRC (trace). The users can convert the OTDR traces into text file or American Standard Code for Information Interchange (ASCII) format for subsequent use by spreadsheet software (e.g., Microsoft Excel or Lotus 1-2-3).

2.3 Analyzing PON Equipped with Passive Optical Splitter

Passive optical splitter (power splitting element/branching device) or optical coupler is device used to broadcast an optical signal from one fiber to many fibers. In the most general case, optical splitter is configured as 1x*N*, there are 1 input port and *N* output ports. Optical signals on the input port are branched to all the output ports. Optical splitter may also be used to multiplex the optical signals from several fiber lines onto a single line. However it is used, optical coupler poses several problems in the OTDR testing [19].

If the OTDR is connected to the *N* side of a 1x*N* optical splitter, then the waveform shows a large loss at the optical splitter (see Fig. 2), where 3.0 dB (50%) for splitting ratio 1:2, 6.0 dB (25%) for 1:4, 9.0 dB (10%) for 1:8, 12 dB (6.25%) for 1:16, and 15 dB (3.125%) for 1:32. This large loss limits the OTDR’s ability to test far beyond the optical splitter because the loss represents an effective loss in the OTDR’s dynamic range. When connected to the input side of a 1x*N* optical splitter, the waveform shows a smaller drop than if the OTDR was connected to one of the *N* output ports. The higher signal level results because the combined signatures of all the *N* fibers on the branching side of the optical coupler are superimposed (see Fig. 3). This superimposition makes it very difficult and sometimes impossible to associate events on the waveform with the specific lines on which the events occur. This is probably the most common problem faced by technicians when dealing with optical splitter [19].

2.4 Recommended Fiber Fault Localization Technologies

Some researchers had discussed about the monitoring issues in PON with using OTDR and recommended a number of possible methods to overcome the upwardly testing (from different customer residential locations toward at CO (in upstream direction)) and downwardly testing (from CO towards multiple customer residential locations (in downstream direction)) problems to achieve desired network survivability, such as such as fiber fault monitoring technique that proposed by C.H. Yeh [20] or fiber-break monitoring system that proposed by A.A.A. Bakar [12].

The faulty fiber can be monitored without affecting other in-service channels. However, these methods need relatively expensive additional sources or devices that impose high-maintenance cost. Since the network service providers need to keep capital and operational expenditures (CAPEX and OPEX) low in order to be able to offer economical solutions for the customers. Therefore, improving network reliability performance by adding redundant components and systems have shortcomings in terms of implementation cost and flexibility [21]. Also these methods are complex and difficult to implement has prohibited them as a practical solution [7].

3. REMOTELY CONTROL WITH SPCI COMMANDS

Standard commands for programmable instruments (SCPI) is defined a standard set of commands to control programmable test and measurement devices in instrumentation systems, e.g. power supplies, loads, and measurement devices such as voltmeters and oscilloscopes. SCPI commands are ASCII textual strings, which are sent to the instrument over the physical layer, such as Ethernet and GPIB. SCPI simplifies programming process of measurement instruments for both users and manufacturers. SCPI consists of standard ASCII commands that are portable to any system that supports SCPI standard. The same command can cause the same function to execute even the instruments are different. It also enables easy replacement of old instruments (upgrade) with the instruments from the same or other manufacturer. SCPI command allows use of keywords or mnemonics. Mnemonic is a short form (4 characters) of a keyword determined by the SCPI regulations. Command can be <MEAS:ARR:VOLT?> or <MEASURE:ARRAY:VOLTAGE?>. SCPI does not differ upper and lower case characters except parameters. Command <MeaS:ARraY:VOltaGe?> is also correct.

SCPI command structure tree is generated hierarchically what means one command consists of two or more mnemonics or keywords separated by ':' character. There are many reasons to use this type of structure. Instruments support many different commands so the "4 character commands" are not enough. Besides that tree structure enables use of one mnemonic many times. Its position in the tree presents the meaning of it. Some functions are in use often than others. It is important that such commands are made of short and simple form. SCPI allows headers where one or more mnemonics are missed. Interpreter

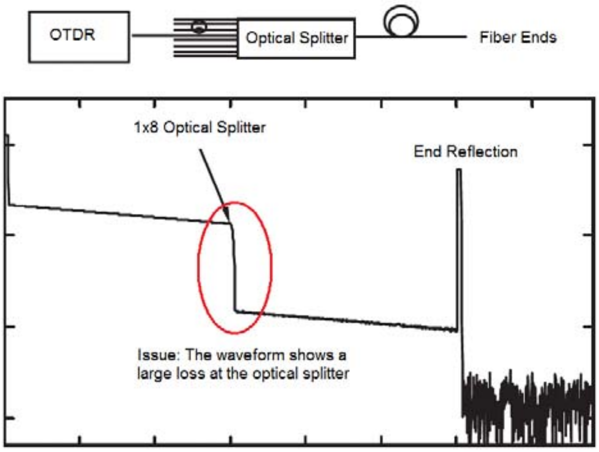


Fig. 2 Monitoring issue in PON equipped with 1x8 optical splitter using OTDR in the upstream direction [19].

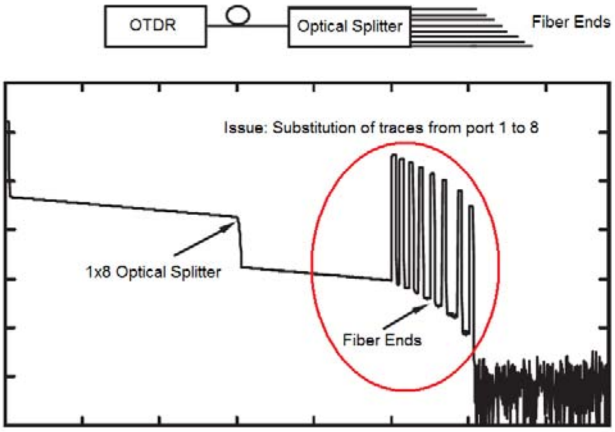
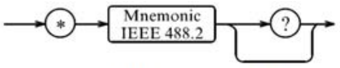
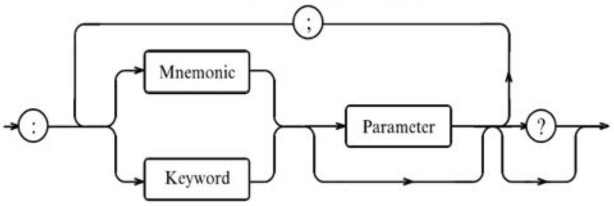


Fig. 3 Monitoring issue in PON equipped with 1x8 optical splitter using OTDR in the downstream direction [19].



(a) General form of SCPI commands and queries



(b) In general SCPI commands control instrument functions and enable usage of measurement functions

Fig. 4 Creating form of common commands and queries [22].

automatically calls the appropriate service function. MEASure:SCALar:VOLTage? or MEASure:VOLTage?

Commands for instrumentation control can be divided in two major groups, common commands (commands and queries mandated by Institute of Electrical and Electronics Engineers (IEEE) 488.2 – Fig. 4a) and SCPI commands (Standard commands – Fig. 4b). Common commands mostly control instrument operations with meaning of checking instrument status registers. Common command consists of 4 or 5 ASCII characters starting with '*' mark. Command can have normal and query form (*IDN?, *RST, *CLR,...). Each command consists of header and parameters. Header consists of one or more mnemonic or keywords separated by ':' character. As shown in figure query form of command and parameters are not obligatory [22].

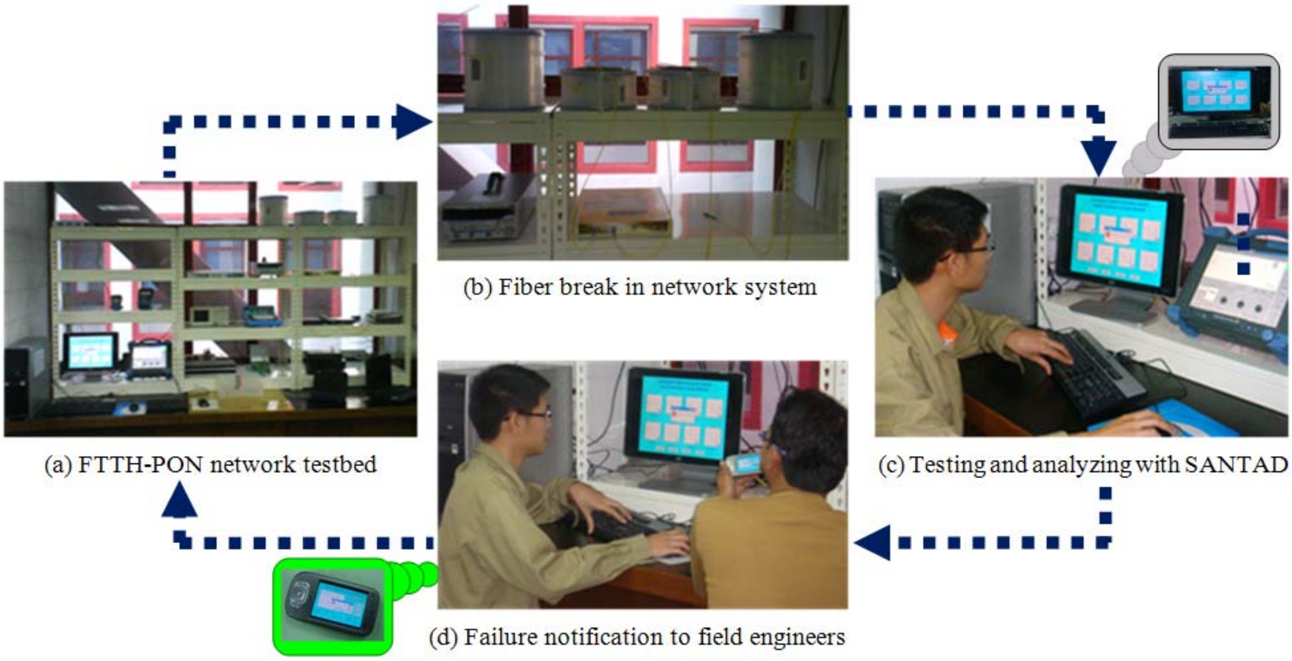
4. SANTAD

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 with the graphical user interface (GUI) processing capabilities. The working principles of SANTAD are structured into three main parts: (i) Optical monitoring with a commercial available OTDR, (ii) Interfacing OTDR test module with remote personnel computer (PC) via Ethernet TCP/IP connection, and (iii) Advanced data analyzing with SANTAD, to support its operations.

4.1 Measurement System Configuration

The principle of our technique is presented in Fig. 5. 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. In this design, the OTDR pulses emitted from CO towards multiple ONUs at different customer residential locations (in downstream direction) bypassing the 1x*N* optical splitter.

The OTDR is installed at CO and connected to a PC/laptop to display the troubleshooting results in a proprietary encoding format with remotely controlled by Ethernet TCP/IP with SCPI commands for data archiving (Most of the recent version OTDR are available with remote control capabilities). The OTDR must be equipped with an Ethernet PC card (either built-in or external) to be connected to an Ethernet local area network (LAN) to allow direct communication between OTDR with PC [23].


(b) Fiber break in network system

(a) FTTH-PON network testbed

(c) Testing and analyzing with SANTAD

(d) Failure notification to field engineers

Fig. 5 Photographic view of network testing and troubleshooting on an P2MP network system.

The remote control is used to operate the measurement system running on a remote PC/laptop at CO or point of link control (remote site) for distant monitoring. Communication is achieved via SCPI commands, which are used for setup and results readout functions. The Ethernet TCP/IP allows the remote PC to transmit SCPI commands over the Ethernet interface of OTDR test module according to IEEE 488 standard. By using SANTAD together with a PC or laptop equipped with modem or LAN connection, the field engineers and technicians can communicate easily with the OTDR test module from anywhere in the world without on-site personnel, e.g. the field engineers and technicians in the field (fiber plant) can receive assistance from CO.

After completing the transferring process, all the results are be recorded in database and then loaded into the developed program for advanced OTDR analyzing. The simulation results are presented in Fig. 6 to 8.

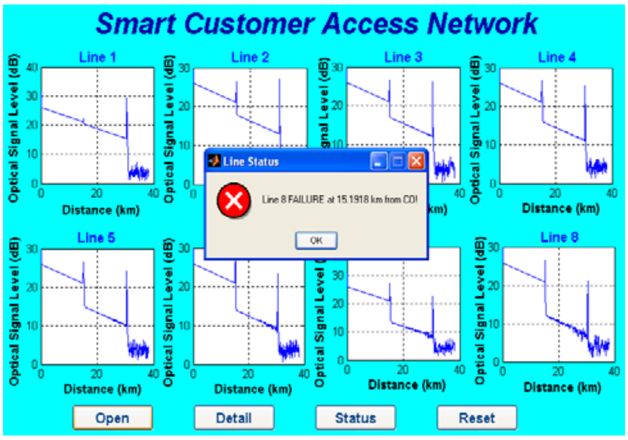
4.2 The Network Testbed

Our technique has been tested on a P2MP network system composed by 30 km fiber as depicted in Fig. 5. The feeder fiber and drop fiber are 15 km long. A microprocessor system is used to control the optical selector for optical switching. The testbed network was set-up to serve as a platform to study the mechanisms and characteristics of optical signal in working (good/ideal) condition and non-working (failure/breakdown) condition. As a first step, no default was introduced in the network and OTDR measurements were performed. During the experiment, 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.

While the test module is emitting optical signals, we disable (block) all other activities to ensure the laser safety. The laser light in the instrument is considered safe if handled carefully, but it is potentially harmful in direct intra-beam viewing.

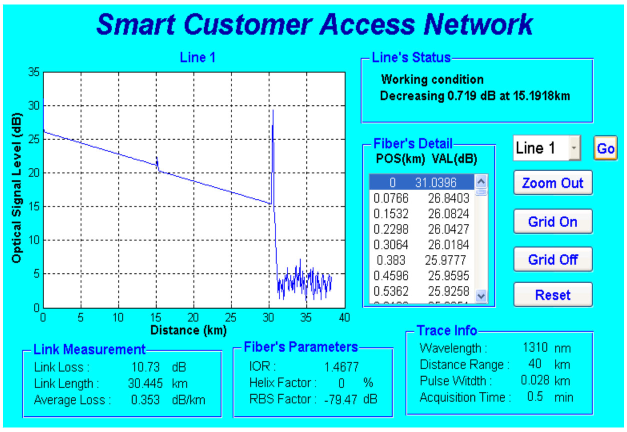
5. Principle Enhancement of SANTAD

SANTAD accumulated all OTDR measurement into a single computer screen for advanced data analyzing. Every eight OTDR testing will be displayed in *Line's Status* window for centralized monitoring, where the distance (km) represented on the x-axis and optical signal



Line 8 FAILURE at 15.1918 km from CO!

Fig. 6 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.



Line's Status
Working condition
Decreasing 0.719 dB at 15.1918km

Fiber's Detail

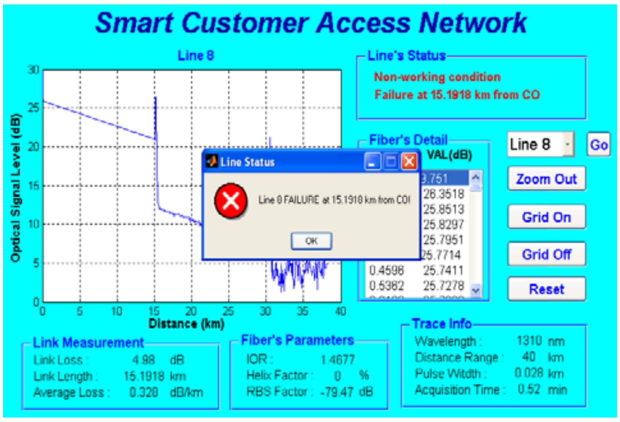
POS(km)	VAL(dB)
0	31.0396
0.0766	26.8403
0.1532	26.0824
0.2298	26.0427
0.3064	26.0184
0.383	25.9777
0.4596	25.9595
0.5362	25.9258

Link Measurement
Link Loss : 10.73 dB
Link Length : 30.445 km
Average Loss : 0.353 dB/km

Fiber's Parameters
IOR : 1.4677
Helix Factor : 0 %
RBS Factor : -79.47 dB

Trace Info
Wavelength : 1310 nm
Distance Range : 40 km
Pulse Witdth : 0.028 km
Acquisition Time : 0.5 min

Fig. 7 An example of working line in the *Line's Detail* window.



Line's Status
Non-working condition
Failure at 15.1918 km from CO

Line 8 FAILURE at 15.1918 km from CO!

Fiber's Detail
VAL(dB)
3.751
26.3518
25.8513
25.8297
25.7951
25.7714
0.4596 25.7411
0.5362 25.7278

Link Measurement
Link Loss : 4.98 dB
Link Length : 15.1918 km
Average Loss : 0.328 dB/km

Fiber's Parameters
IOR : 1.4677
Helix Factor : 0 %
RBS Factor : -79.47 dB

Trace Info
Wavelength : 1310 nm
Distance Range : 40 km
Pulse Witdth : 0.028 km
Acquisition Time : 0.52 min

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

level (dB) represented on the y-axis. SANTAD is focusing on providing survivability through event identification against losses and failures. A failure message “*Line x FAILURE at z km from CO!*” will be displayed to inform the users if SANTAD detect any occurrence of fiber cut/fault in the network system.

Fig. 6 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. 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 as illustrates in Fig. 7 and 8. 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. By monitoring such parameters, SANTAD can distinguish failures, thus eliminating unnecessary field trips for maintenance.

Optical diagnosis, performance monitoring, and characterization are essential for ensuring the high quality operation of any lightwave systems. In fact, an efficient and reliable optical network, such as PON, depends on appropriate testing and measurement. During the construction phase, proper testing is the only way to guarantee that all the required transmission specifications are met, the network is ready for actual traffic, and subscribers are provided with the expected service quality. During initial commissioning and subscriber activation, testing and diagnosis can ensure that the whole system operates within the acceptable specifications. When the network is activated and operation begins, the quality of service (QoS) must be tested and monitored in order to meet service-level agreements with subscribers. When problems are detected and diagnosed (e.g. low signal or no signal), troubleshooting networks help to minimize network downtime, rapidly restore failed services, and efficiently manage network performance [24].

5. Conclusions

In this paper, we successfully bring up a new centralized monitoring and failure analyzing approach for PON network system to ensure that it is running as efficiency as possible with SANTAD. Service reliability must be considered because a failure of broadband services may result in large data loss for subscribers as well as tremendous financial loss for network service providers. It is important to keep the system running and detect degradations before a fiber fault occurs for preventive maintenance. Although this is not always possible, however some types of failure can be predicted and prevented. Any failure should be localized without affecting the service delivery and troubleshoot in a short period to minimize the losses. It is a convenient and cost-effective way to improve the service reliability of PON and reduce the restoration time and maintenance cost with SANTAD.

Acknowledgments

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