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Centralized Monitoring and Self-protected against Fiber Fault in FTTH Access Network

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Abstract**—**This paper presented a new approach for centralized monitoring and self-protected against fiber fault in fiber-to-the-home (FTTH) access network by using Smart Access Network Testing, Analyzing and Database (SANTAD). SANTAD will be installed with optical line terminal (OLT) at central office (CO) for in-service transmission surveillance and fiber fault localization within FTTH with point-to-multipoint (P2MP) configuration downwardly from CO towards customer residential locations based on the graphical user interface (GUI) processing capabilities of MATLAB software. SANTAD is able to detect any fiber fault as well as identify the failure location in the network system. SANTAD enable the status of each optical network unit (ONU) connected line is displayed onto one screen with capability to configure the attenuation and detect the failure simultaneously. The analysis results and information will be delivered to the field engineer for promptly actions, meanwhile the failure line will be diverted to protection line to ensure the traffic flow continuously. This approach has a bright prospect to improve the survivability and reliability as well as increase the efficiency and monitoring capabilities in FTTH.

Keywords**—**Fiber fault, FTTH, SANTAD, transmission surveillance, MATLAB.

I. Introduction

FTTH is a broadband network technology that delivering triple-play (data, voice and video) services with a high speed to the home or business via optical fiber cable. FTTH is the major role in alleviating the last mile bottleneck for next generation broadband optical access network [1]. 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 [2]. Owing the very high capacity of optical fibers, FTTH can deliver greater capacity as compared to copper-based technologies [3].

FTTH technology using passive optical network (PON) with P2MP configuration or tree topology is the most promising way to provide high quality broadband access. PON has been early described for FTTH as early as 1986. PON are nowadays extensively studied and some commercial deployments are already reported [4]. The PON is commonly deployed as it can offer a cost-efficient and scalable solution to provide huge-capacity optical access [5].

Since this kind of architecture can accommodate a large number of subscribers, when any fault occurs at one point in an optical fiber line, the access network will without any function behind the break point. It leads to affect the whole services transmission. The upstream signal from multiple ONUs at different customer residential locations to OLT at CO or the downstream signal from OLT to multiple ONUs after the break point will become unreachable if the fault occurs in the feeder region [1]. However, if the fault occurs in an individual subscriber's infrastructure such as drop fiber or customer premises equipment (CPE) (e.g. ONU), since the signals from OLT are successfully shared among other subscribers' ONUs via a passive optical splitter, thus only one subscriber's service is affected [6]. Any service outage due to a fiber break can be translated into tremendous financial loss in business for the network service providers [7].

A failure due to fiber break in current optical communication system could make the network service providers very difficult to restore the system back to normal. According to the cases reported to the Federal Communication Commission (FCC), more than one-third of service disruptions are due to fiber cable problems. This kind of problem usually take longer time to resolve compared to the transmission equipment failure [8]. Moreover, the laser source used in optical communication system may explore at the break point, it can caused the retina eye burning and may be damaged temporarily or permanently (blind) in a few seconds or even less time depending to the energy absorbed by the retina eye [9]. Therefore, the survivability of the whole network has to be examined more seriously. Lack of survivability is one of main factor that FTTH is still not been deployed in certain areas.

II. Fiber Localization Fault In Ftth

Fiber fault within FTTH becomes more significant due to the increasing demand for reliable service delivery [5]. It is important to be able to locate any fiber break after the installation of FTTH access network. Furthermore, a simple and effective monitoring configuration is highly desirable for timely failure detection along the fiber [7]. A particular

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problem in this regard is that a failure occurred at the drop region must be located without affecting the service transmission to other subscribers [10]. A good fault surveillance system is essential to identify fiber fault without interrupting the services, while other channels are still in service to maximize the link utilization [7]. Therefore, an optical line monitoring and testing system is essential for failure detection to improve the service reliability and reduce the maintenance costs of FTTH.

Optical time domain reflectometer (OTDR) was first reported in 1976 [11] as a telecommunications application and became an established technique for attenuation monitoring and fault location in optical fiber network within the telecommunications industry [12]. OTDR is a well-known means of testing an optical fiber cable assembly in optical networks. The OTDR launches a very narrow pulse into the fiber and then records the response of the cable/connector assembly to this pulse. Both reflections and absorption can be observed in the cable, providing the troubleshooter with the information needed to diagnose cable problems [13].

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).

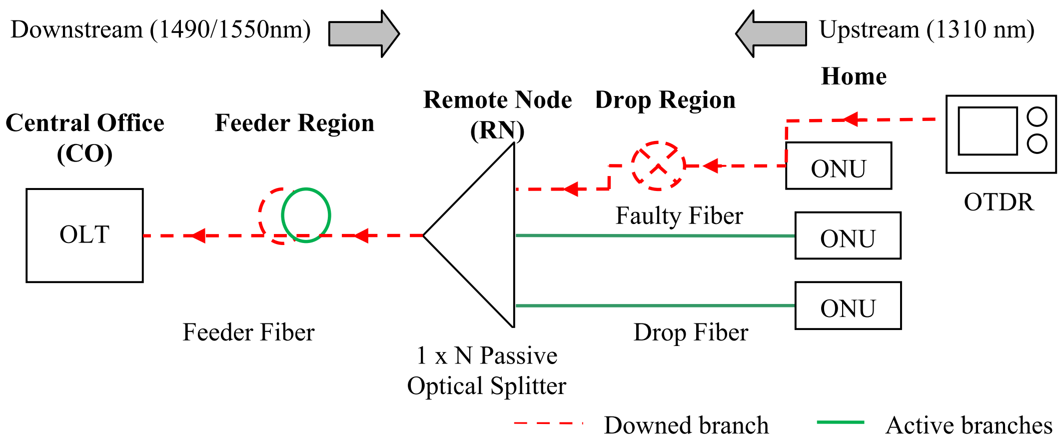

Fig. 1 Identify faulty fiber and localize failure location in FTTH by using OTDR upwardly from multiple ONUs at different customer residential locations toward OLT at CO (in upstream direction)

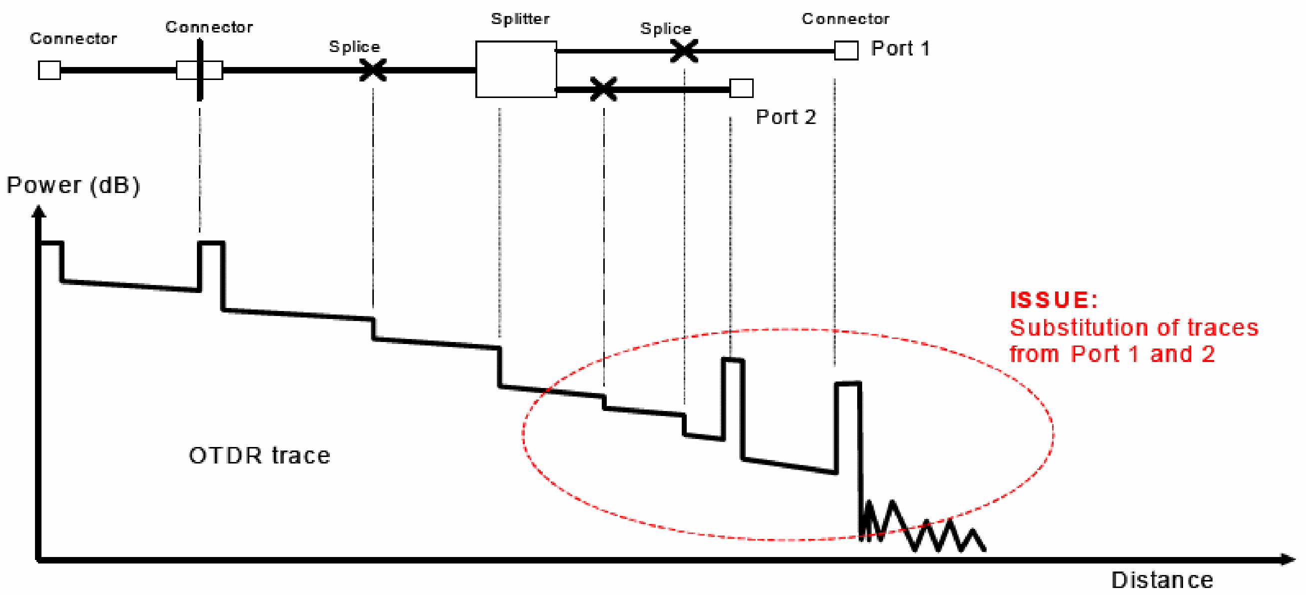

Fig. 2 Monitoring issue with using OTDR in the downstream direction from CO towards customer residential locations [15].

Conventionally, OTDR is used to identify faulty fiber in FTTH upwardly from multiple ONUs toward CO as shown in Fig. 1 (in upstream direction). OTDR is the most costly among the optical fiber test gears, but it is most frequently used for characterizing a long haul communication link. According to Chomycz [14], OTDR testing is the best method for determining the exact location of broken optical fibers in an installed optical fiber cable. Whenever a fault occurs, a technician is called to plug OTDR manually to the faulty fiber to detect where the failure is located. A high intensity optical pulse is launched into a fiber and a high speed optical detector recorded and graphically displays the observed reflection in the screen. The technician can observe losses due to splice, break, connector, and other attenuation in an optical line by looking at the visual representation on the OTDR's screen.

However, this approach would require much time and effort. Moreover, OTDR can only display a measurement result of a 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). The optical splitter will make the identification of a fiber fault beyond the splitter very difficult. The OTDR testing signal from all the splitter ports is added into one trace in downstream direction as summarized in Fig. 2. Therefore it can become very complicated to localize the failure in the correct split branch of tree-based structured optical access network [15].

Some researchers had discussed about the monitoring issues with OTDR and recommended a number of possible methods to overcome these problems to achieve desired network survivability such as Centralized Optical Monitoring using a Raman-assisted OTDR (proposed by Yuksel [5]) or OTDR-based testing system using reference reflectors or fiber selectors (proposed by Tomita [16]). 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 [8]. Also these methods are complex and difficult to implement has prohibited them as a practical solution [2].

III. Conceptual Design Of SANTAD

To reduce the cost and enhance the benefit, we proposed a centralized monitoring and self-protected system named SANTAD, which is involved in the failure detection, automatic recovery, and increases the survivability and maintainability of FTTH after taking consideration into the requirement for network monitoring capabilities, maintenance and repairing cost, restoration time, expandability, dependability, and redundancy. 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 GUI processing capabilities of MATLAB software.

SANTAD consists the new upgraded values of recent FTTH technology toward the implementation of smart (intelligent) network. It can reduce the time needed to restore the fault to maintain and operate the FTTH more efficiently. SANTAD is potentially to improve the survivability and increase the monitoring capabilities in FTTH and capable to overcoming the upwardly or downwardly monitoring issues with OTDR. It 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 especially in FTTH.

A. Measurement System Configuration

To locate a fiber fault without affecting the services transmission to other subscribers, it is essential to use a wavelength different from the triple-play services signals for failure detection [17]. As illustrates in Fig. 3, a commercially available OTDR with a 1625 nm laser source is used in failure detection control and in-service troubleshooting in the proposed scheme without affecting the triple-play services transmission. OTDR is the instrument that used to measure the fiber attenuation, locate fault, measure losses, and fiber uniformity or the attenuation coefficient throughout the installed fiber length.

The triple-play signals (1310 nm, 1490 nm, and 1550 nm) are multiplexed with a testing signal (1625 nm) from OTDR. When four kinds of signals are distributed, the testing signal will be split up by the wavelength selective coupler (WSC) or wavelength division multiplexing (WDM) coupler, which is installed before the splitter. The WSC only allow the 1625 nm testing 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 the optical splitter before it reaches the multiple ONUs at different residential location. 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. The operational of optical switch is controlled by microprocessor system that is activated by 1% of 1625 nm testing signal.

The OTDR is installed with OLT and connected to a PC/laptop to display the troubleshooting results in a proprietary encoding format with remotely controlled by Ethernet Transmission Control Protocol/Internet Protocol (TCP/IP) with Standard Commands for Programmable Instruments (SCPI) commands for data archiving (Most of the recent version OTDR are available with remote control capabilities). The OTDR also can be remotely controlled through GPIB with GPIB PC card (either built-in or external) and the appropriate drivers to measure the optical fiber and troubleshoot the optical access network.

SANTAD is interfaced with the OTDR to accumulate every network testing result to be displayed on a single computer screen for advanced OTDR analyzing. The analysis results will be sent to field engineers or network service providers through the mobile phone or Wi-Fi/Internet computer using wireless technology for repairing and maintenance operation. Any failure/breakdown occurs in the network will be diverted to the protection (stand-by) line to ensure the traffic flow continuously. The whole operation process can be simplified in the flow chart as depicts in Fig 4. With the method described in this paper, no any expensive additional equipments or devices are required.

B. *The Network Testbed*

Our technique has been tested on an optical access network composed by 30 km fiber. The feeder fiber and drop fiber are 15 km long. 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. We conducted two experiments through the network testbed mainly focusing on the identifying the faulty fiber and locating the failure location in a failure link. 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.

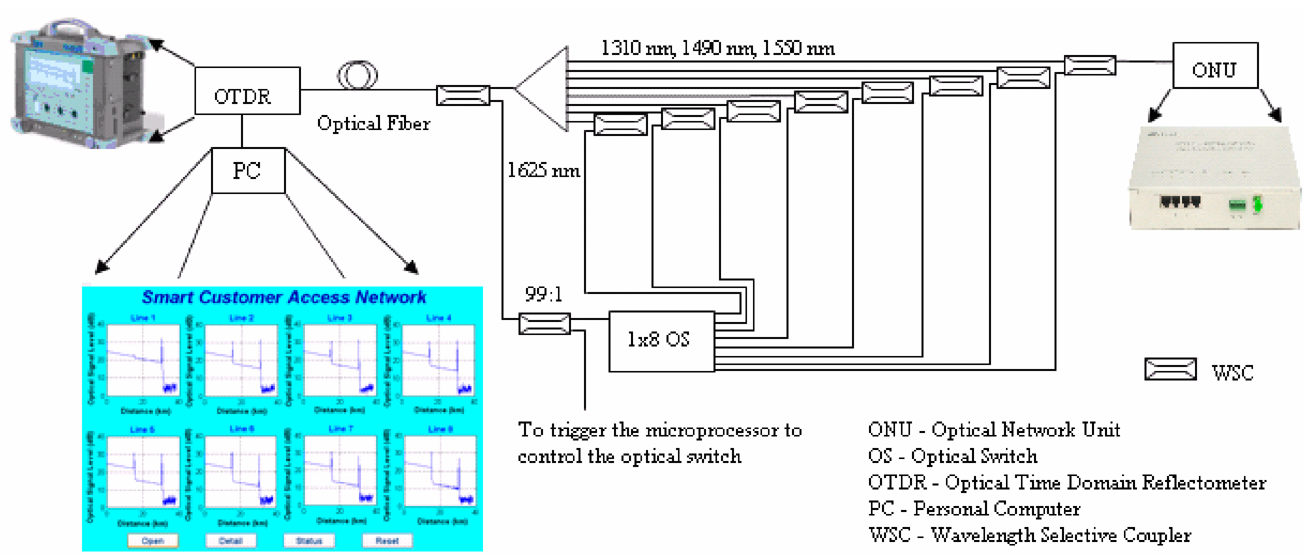

Fig. 3 Centralized monitoring and self-protected against fiber fault in FTTH using SANTAD in the downstream direction

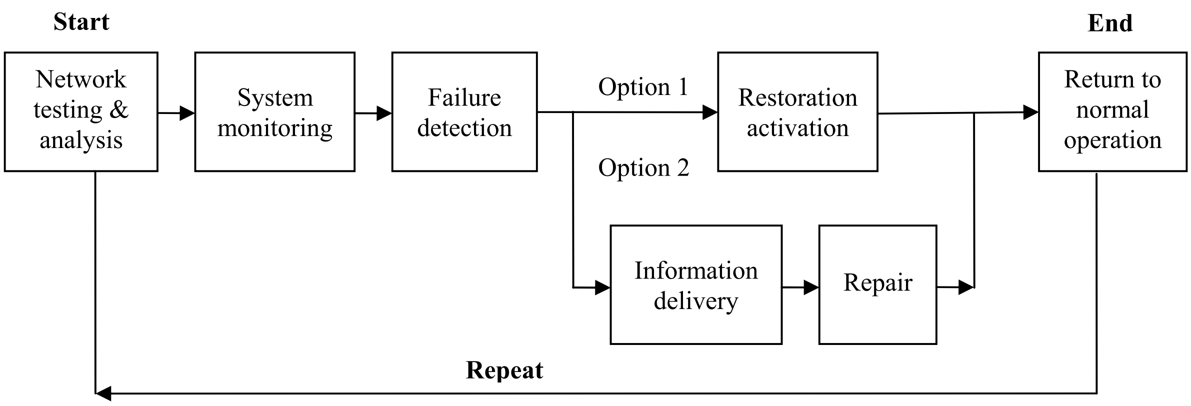

Fig. 4 The process flow for failure detection and restoration in SANTAD

After that, the OTDR measurement results for each line are transferred into PC. The communication between OTDR and PC was done over Ethernet connectivity. As a remark, previously we are using RS-232 (serial port) connection for data archiving. Transferring data between OTDR and PC requires serial ports on both units and RS-232 serial cable (null modem cable**)** is required to establish connection between OTDR and PC. However, some of the more recent PCs are not equipped with such ports (Serial port and parallel port) [18]. The instruments and measurement equipments used in the experiment are summarized in Fig. 3 with the help of schematic diagram.

IV. Execution Display For SANTAD

The developed program not only enables one to monitor the system's status and detect any failure in FTTH downwardly from CO (in downstream direction), but also to determine deployment, connection, and losses (connection losses, splice losses, optical device losses, fiber losses or attenuation) in the network system. 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. 5.

The functionalities of SANTAD can be generally be classified into: (i) Network system configuration management, (ii) Degradation management, and (iii) Fiber fault management. SANTAD can help network services providers and field engineers in FTTH network system to perform the following the following activities:

- Network system configuration management - provides the network service providers with a control function to intercom all subscribers with CO.
- Degradation management - in order to keep the system running and detect degradations before a fiber fault occurs for preventive maintenance.
- Fiber fault management - detects any fiber fault that occurs in the network system and troubleshoots it for post-fault maintenance.

Degradation management tries to prevent fiber fault from occurring. Although this is not always possible, however some types of failure can be predicted and prevented. Even with fiber fault prevention mechanisms, failures will still occur, so fiber fault detection techniques need to test each optical line in order to detect potential faults and precisely localize the exact failure location. With detected alarms, fiber fault identification processes will diagnose and determine the real causes. Appropriate recovery actions are taken to treats the link and fiber fault. In combination of the distinctive management operations, the network service providers and field engineers can centralize monitoring, testing, analyzing, configuring, and troubleshooting the FTTH network system more efficiency to provide the predefined quality of services (QoS) for customer premises/subscribers.

Fig. 6 and 7 showed the ability of SANTAD to specify a faulty fiber and failure location among a number of optical fiber lines in FTTH by measuring the optical signal level and losses. Every eight network testing results will be displayed in *Line's Status* window for centralized monitoring (in a single computer screen), where the distance (km) represented on the x-axis and optical signal level (dB) represented on the y-axis. SANTAD used event identification method respectively analyzes and identifies any faulty fiber and failure location that occurs in FTTH. A failure message "*Line x FAILURE at z km from CO!*" will be displayed to inform the field engineers if it detect any fiber fault in the network system.

To obtain further details on the performance of specific line in FTTH, every measurement results obtained from the network testing are analysis in the *Line's Detail* window. The developed program is able to identify and present the parameters of each optical fiber line such as the line's status (either in working or non-working condition), magnitude of decreasing as well as the location, failure location, and other details as shown in the OTDR's screen. The advantage of this feature compare to the OTDR and computer-based emulation software is SANTAD displayed every status for the tested line in the *Line's Detail* window.

A "*Good condition*" or "*Decreasing y dB at z km*" message display at the line's status panel in a working condition (see Fig. 8 and 9). However in the non-working condition, a failure message "*Line x FAILURE at z km from CO!*" displayed to show the exact failure location in the network system as illustrated in Fig. 10 and 11. It is flexible and easily

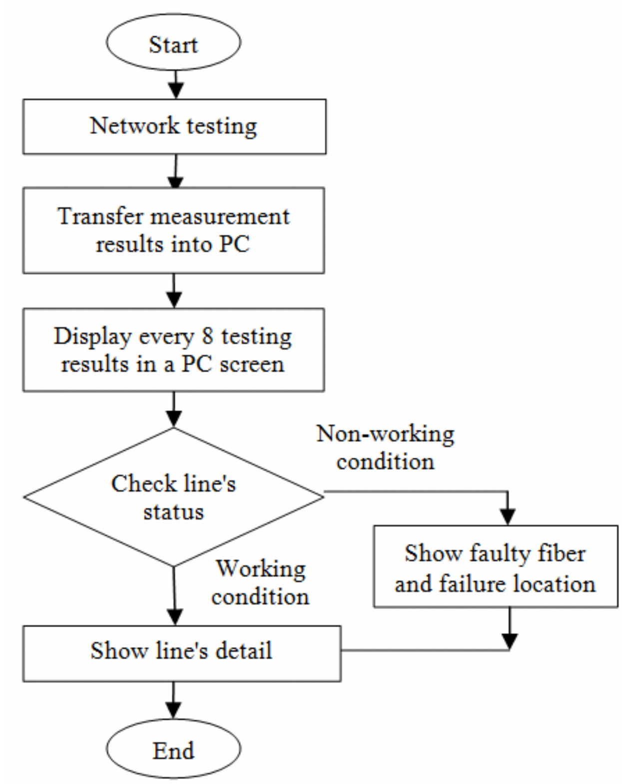

Fig. 5 Flow chart for mechanism of SANTAD detection

to use for those who are inexperience in the optical fiber testing by just reading the information gain from the messages.

Once any fiber fault in the primary entity is detected, it will automatically send the failure status to the field engineers through the mobile phone or Wi-Fi/Internet computer using wireless technology. The field engineers can determine sharply the break point just connect a laptop or personnel digital assistant (PDA) to a OTDR-based testing system through Ethernet connection without making a site visit before taking some appropriate actions, such as repairing or maintenance operation. Meanwhile, the field engineer will activate the restoration scheme to switch the traffic (service delivery) from the failure (primary) line to the protection line to ensure the traffic flow continuously.

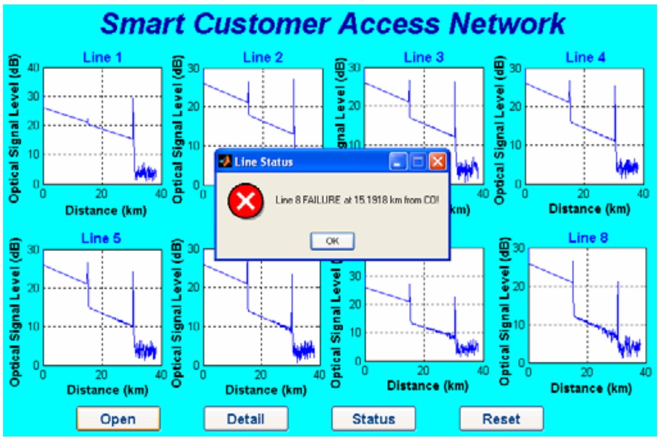

Fig. 6 Every eight measurement results are displayed on the *Line's Status* window

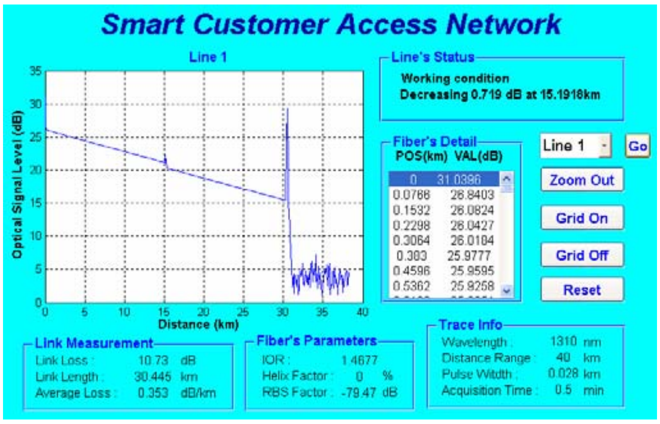

Fig. 8 An example of working line in the *Line's Detail* window for single event

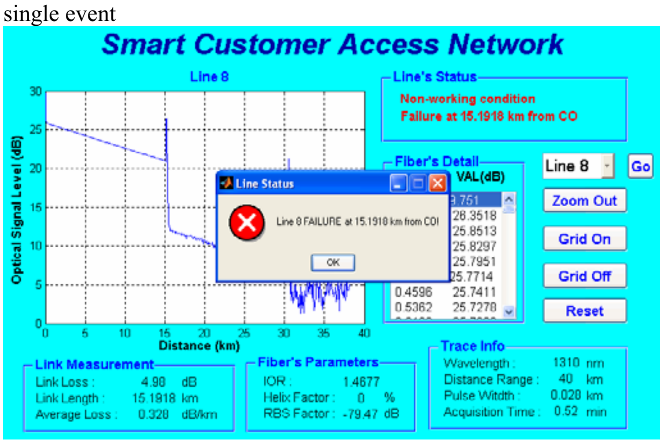

Fig. 10 An example of failure line in the *Line's Detail* window for single event

This functionality alerts the service providers and field engineers of a fiber fault before it is reported by the customer premises or subscribers. After the restoration/maintenance process, the traffic will be switched back to the normal operation. The detail of the fiber fault must be documentation. The record shows the faulty fiber, exact failure location, possible cause (i.e. construction is conducted in the nearby areas), action taken, cost, and time it took for each step. The documentation is extremely important for several reasons:

- The problem may recur. Documentation can help the present or future field engineers or technicians solve a similar problem.
- The frequency of the same kind of failure is an indication of a major problem in the system. If a fault happens frequently in one fiber/device/component at the same location (same point), it should be replaced with a similar one, or the whole network system should be changed to avoid the use of that type of fiber/device/component.
- The statistic is helpful to another parts of network management [18].

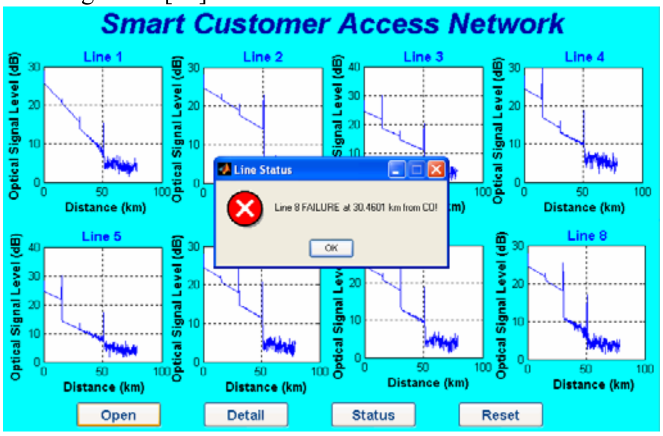

Fig. 7 A failure message displays to show the faulty line and failure location in the FTTH network system

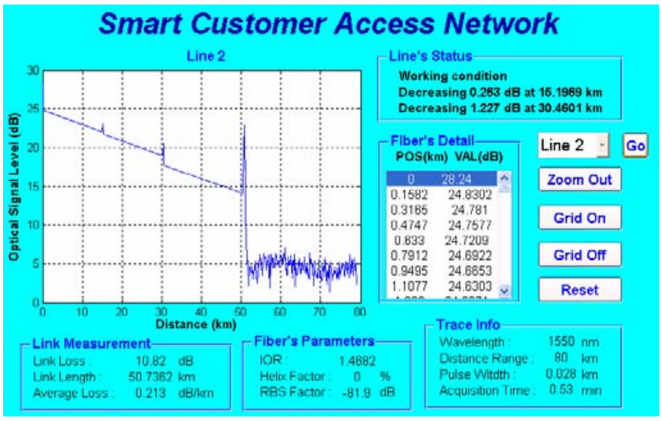

Fig. 9 Another example of working line in the *Line's Detail* window for two events

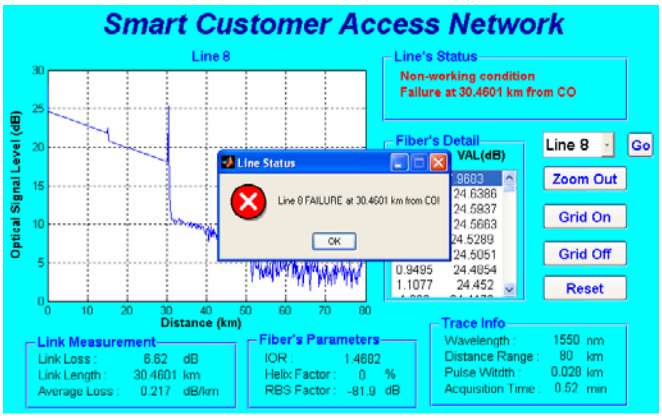

Fig. 11 Another example of failure line in the *Line's Detail* window for two events

V. Conclusion

In this paper, we successfully bring up a new approach for monitoring and controlling the FTTH network system to ensure that it is running as efficiency as possible with SANTAD using Operation, Administration, and Maintenance (OAM) features. 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 FTTH and reduce the restoration time and maintenance cost with SANTAD.

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References

[1] C.H. Yeh, F.Y. Shih, G.K. Chang, and S. Chi, "Reliable tree-type passive optical networks with self-restorable apparatus," *Opt. Express,* vol. 16, pp. 4494-4498, 2008.
[2] 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.
[3] G. Keiser, Optical Fiber Communication, 3rd ed., McGraw-Hill, New York, USA, 2000.
[4] M. Wuilpart, A. Grillet, K. Yuksel, D. Gianone, G. Ravet, and P. Megret, "Dynamics enhancement of OTDR-based monitoring systems for passive optical networks," Proc. Symposium IEEE/LEOS Benelux Chapter, Brussels, pp. 167-170, 2007.
[5] J. Prat. 2008. Optical networks: towards bandwidth manageability and cost efficiency, [Online]. Available: http://www.e-photon-one.org/ephotonplus/servlet/Utils.MostrarFitxerPublic?fitxer=D_VDA_3.pdf&pathRelatiu=E-Photon+One+%2B%2FPublic%2FPublic+Deliverables%2F.
[6] T. Okada, 2008. Expert's forum - novel FTTH technology for optical access networks, [Online]. Available: http://www.huawei.com/publications/view.do?cid=342&id=680&pid=61.
[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] 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.
[9] M.S.A. Rahman and B.C. Ng, "MATLAB-based graphical user interface development for Centralized Failure Detection System (CFDS) in SCAN Network," *J. of Opt. Commun*., vol. 29, no. 3, pp. 152-156, 2008.
[10] I. Sankawa, S.I. Furukawa, Y. Koyamada, and H. Izumita, "Fault location technique for in-service branched optical fiber networks," *IEEE Photon. Technol. Lett.*, vol. 2, pp. 766-768, 1990.
[11] M.K. Barnoki and S.N. Jensen, "Fiber waveguides: a novel technique for investigating attenuation characteristics," *Appl. Opt.*, vol. 15, pp. 2112-2115, 1976.
[12] D. King, W.B. Lyons, C. Flanagan, and E. Lewis, "Interpreting complex data from a three-sensor multipoint optical fiber ethanol concentration sensor system using artificial neural network pattern recognition," *Meas. Sci. Technol.*, vol. 15, pp. 1560-1567, 2004.
[13] D.N. Harres, "Built-in test for fiber optic networks enabled by OTDR," *25th Digital Avionics Systems Conference*, pp. 5A1-5A8, 2006.
[14] B. Chomycz, Fiber Optic Installation: a Practical Guide, McGraw-Hill, New York, USA, 1996.
[15] Network Infrastructure Committee. 2007. FTTH infrastructure components and deployment methods, [Online]. Available: http://www.europeftthcouncil .com/, 2007.
[16] F. Caviglia and V.C.D. Biase, "Optical maintenance in PONs," *24th European Conference on Optical Communication (ECOC'98)*, pp. 621-625, 1998.
[17] A. Girad, FTTX PON Technology and Testing, EXFO Electro-Optical Engineering Inc, Canada, 2006.
[18] EXFO, FTB-400 Universal Test System User Guide, EXFO Electro-Optical Engineering Inc, Canada, 2006.

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