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Detecting faulty fiber with centralized failure detection system (CFDS) in fiber-to-the-home (FTTH) access network

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A new technique for detecting any faulty fiber and identifying the failure location occurring in tree-based structured fiber-to-the-home (FTTH) access network with centralized failure detection system (CFDS) based on Visual Basic is proposed and experimentally demonstrated in the paper. CFDS is installed with optical line terminal (OLT) at central office (CO) to monitor the network system and detect any failure that occurs in multi-line drop region of FTTH access network downwardly from CO towards customer premises. CFDS enables the status of each optical network unit (ONU) connected line to be displayed on a computer screen with capability to configure the attenuation and detect the failure simultaneously. The failure analysis and information is delivered to the field engineers for prompt actions, and meanwhile the failure line is restored to stand-by line to ensure a continuous traffic flow. This approach has bright prospects of improving the survivability and reliability as well as increasing the efficiency and monitoring capabilities in FTTH access network. Besides, it is able to overcome the upwardly or downwardly monitoring issues with conventional fiber fault localization technique by using optical time domain reflectometer (OTDR). With CFDS database, the histories of scanning process and data can be recalled and further analysis can possibly be conducted.

Keywords: detection of faulty fiber, identification of failure location, fiber-to-the-home (FTTH), centralized failure detection system (CFDS), Visual Basic, downwardly.

1. Introduction

Fiber-to-the-home (FTTH) is a network technology that deploys optical fiber cable directly to the home or business to deliver triple-play (data, voice, and video) services with a high speed up to the customer premises [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].

Since such architecture can accommodate a large number of subscribers, when a fiber break occurs in the feeder region, the access network is devoid of any function behind the breakpoint. The upstream or downstream signal after the breakpoint becomes unreachable [3]. Any service outage due to the fiber break can be translated into tremendous financial loss in business for the network service providers [1].

Conventionally, optical time domain reflectometer (OTDR) is used to identify a faulty fiber in FTTH access network upwardly from the customer premises side towards central office (CO). However, this approach would require much time and effort. Moreover, OTDR can only display a measurement result of a line at a time. Therefore, it becomes a hindrance to detection of 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 failure in a point-to-multipoint (P2MP) connectivity which is equipped with passive optical splitter by using an OTDR downwardly from CO because the Rayleigh back-scattered (RBS) light from different branches overlap each other in the OTDR trace and cannot be distinguished [1]. Therefore, CFDS has been introduced in this paper as a solution that is expected to reduce the capital and operational expenditures (CAPEX and OPEX) for FTTH access network.

2. Conceptual design for CFDS

This paper presents the development of a new technique for locating faulty fiber in FTTH access network with CFDS after taking into consideration the requirement for network monitoring capabilities, maintenance and repairing cost, restoration time, expandability, dependability, and redundancy. CFDS has potential for improving the survivability and increasing the monitoring capabilities in FTTH access network. This program is our second generation based on the Microsoft Visual Basic software. The first generation CFDS which was developed by using MATLAB software has been proposed in our previous paper [4]. It can reduce the time needed to restore the fiber fault to maintain and operate the optical access network more efficiently. However, it is quite inconvenient to use MATLAB software for the analysis due to its own limitation. Furthermore, this required much more steps and time for the data analysis.

Therefore, we demonstrate in this paper a second generation based on the Microsoft Visual Basic software, with the complexity being reduced and a few additional features introduced. It has greater functionality as compared to our first approach. The program developed not only enables one to monitor the status for each optical fiber line and detect the failure location in FTTH access network downwardly, but also to determine the status, deployment, connection, and configuration in the network. It comes together with the additional features such as tracking the optical signal level (input power and output power) and losses (*e.g.*, connection losses, splice losses, optical components/devices losses, fiber losses or attenuation) as well as monitoring the network performance.

CFDS can be broken down into three main parts to support its operation, including optical line measurement, interfacing OTDR with personal computer (PC), and data

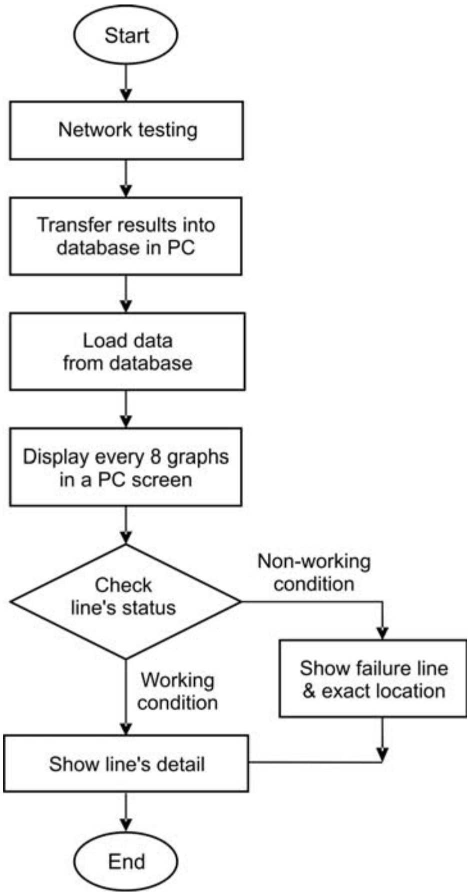

Fig. 1. Flow chart of the mechanism of CFDS detection.

analysis. The whole operation process can be simplified in the flow chart, as depicted in Fig. 1. CFDS has the same features of the OTDR and computer-based OTDR emulation software for performing more OTDR trace processing functions, but with more flexibility used for optical communication link especially in the FTTH access network.

2.1. System architecture

To locate a fiber fault without affecting the transmission of services to other subscribers, it is essential to use a wavelength different from those of the triple-play signals for failure detection [5]. As illustrated in Fig. 2, CFDS uses a 1625 nm signal for failure detection control and in-service troubleshooting. The triple-play signals (1310 nm, 1490 nm, and 1550 nm) are multiplexed with a testing signal (1625 nm) from OTDR. The OTDR is installed with the OLT at CO and will be connected to a PC to display the troubleshooting result.

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)

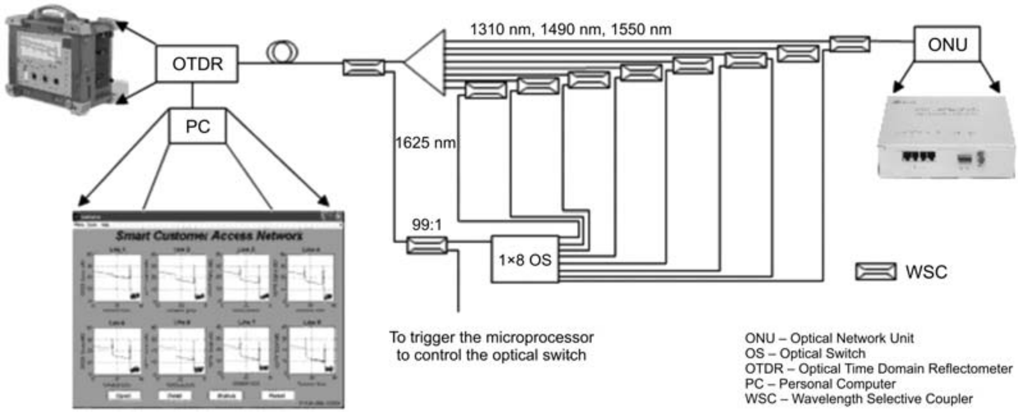

Fig. 2. The system architecture for CFDS.

coupler, which is installed before the splitter. The WSC only allows the testing signal at 1625 nm to enter 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 is in turn connected to a splitter before it reaches the ONUs at different residential location. The distance between the OLT and ONU is about 20 km. 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 a splitter, with each of its outputs being connected to a single line of ONU. The operation of optical switch is controlled by microprocessor system that is activated by 1% of 1625 nm signal. With the method described in this article, no any expensive additional equipment or devices are required and it also enables the upwardly or downwardly monitoring issues to be overcome by means of conventional techniques.

CFDS is interfaced with the OTDR to accumulate every network testing result to be displayed on a single PC screen for further analysis. The analysis result is sent to field engineers or network service providers through the mobile phone or Wi-Fi/ Internet computer using wireless technology for prompt action. Anywhere, the traffic from the failure line is diverted to stand-by (protection) line to ensure a continuous traffic flow. After the restoration/maintenance process, the traffic is switched back to the normal working line.

2.2. Experimental setup and network testing

To verify the concept and benefits of CFDS, we conducted two experiments through a point-to-point (P2P) network testbed, mainly focusing on the identification of the faulty fiber and locating failure. The fixed connection (FC) connector and optical attenuator are the two optical devices used in the experiments. The FC connector is used to establish connection between two fibers under test, whereas the optical attenuator was used to represent the breakpoint in an optical fiber line in the first experiment. It visualized the actual breakpoint of an optical line at that distance in real conditions. The optical attenuator was also used to reduce (attenuate) the optical signal level (optical power) in a line tested in the second experiment. The characteristics of the optical fiber line under working (good/ideal) and non-working (failure/breakdown) conditions are measured at an early stage by using an OTDR. Then, the measurement results for each line are saved in the OTDR and then transferred into the PC. After completing the transferring process, the results need to be recorded in database and then loaded into CFDS for further analysis.

3. Execution display for CFDS

One of the basic functionalities of CFDS is to detect failure in FTTH access network. The CFDS consists in: *i*) plotting optical signal level (dB) versus distance (km) graph, *ii*) checking the status of each optical fiber line, and *iii*) displaying line details. CFDS also tracks the optical signal level and monitors the network performance. There are other functionalities of CFDS that are not described in detail nor demonstrated in this paper. The CFDS provides a convenient way to solve the particular upwardly or downwardly measuring issues with OTDR and capability of fiber fault localization in FTTH access network.

3.1. Analyzing line status

Figure 3 shows the ability of CFDS to specify a faulty fiber and failure location among a number of optical fiber lines in FTTH access network through measuring the fiber attenuation, connection losses, spice losses, and optical components/devices losses. In the first experiment, it is assumed that there is a fiber fault occuring in an individual subscriber's infrastructure among eight subscribers. OTDR is an instrument that is used to measure the fiber attenuation, locate fault, measure splice loss and fiber

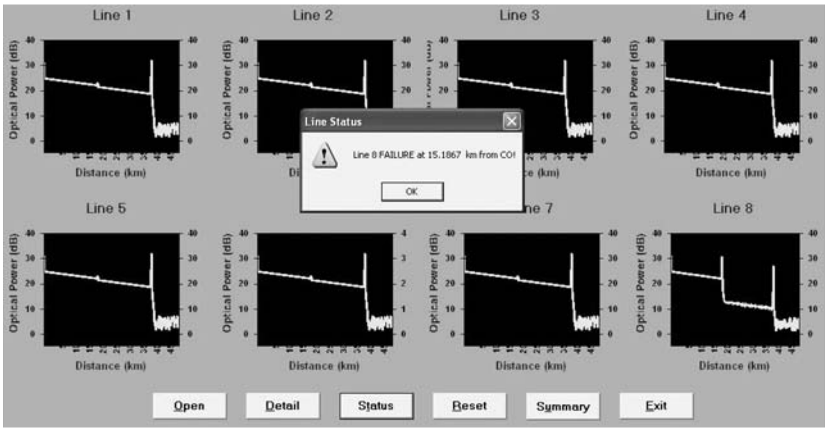

Fig. 3. Eight graphs are displayed in the *Line Status* form. A failure message is displayed to show the faulty line and failure location in FTTH access network.

uniformity or the attenuation coefficient throughout the installed fiber length. The measurement results are recorded in the OTDR and then transferred into the database in PC.

Every eighth network testing results are displayed in the *Line Status* form for centralized monitoring. CFDS uses an event identification method to differentiate the mechanism of the optical signal in working and non-working condition. The loss in reflective fault event is representing the condition of a tested line. A failure message *Line x FAILURE at z km from CO!* is displayed to inform the user if it has detected any fiber fault in the network.

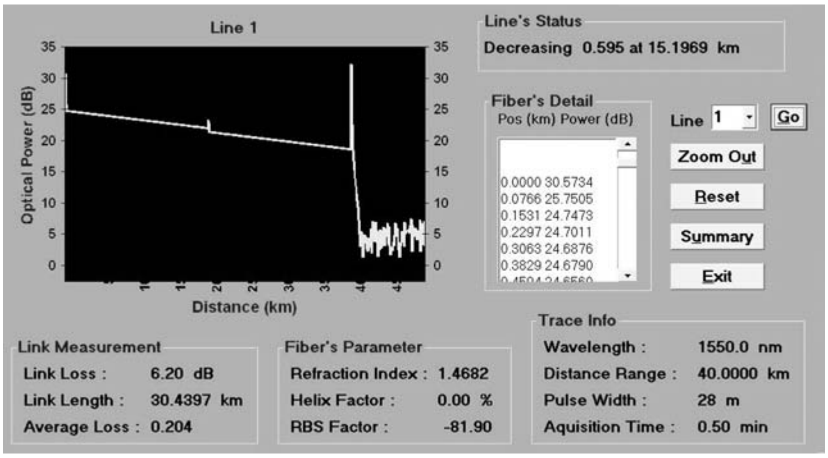

Fig. 4. An example of working line in the *Line's Detail* form. The optical power level in line 1 is decreasing 0.595 dB at a distance of 15.1969 km.

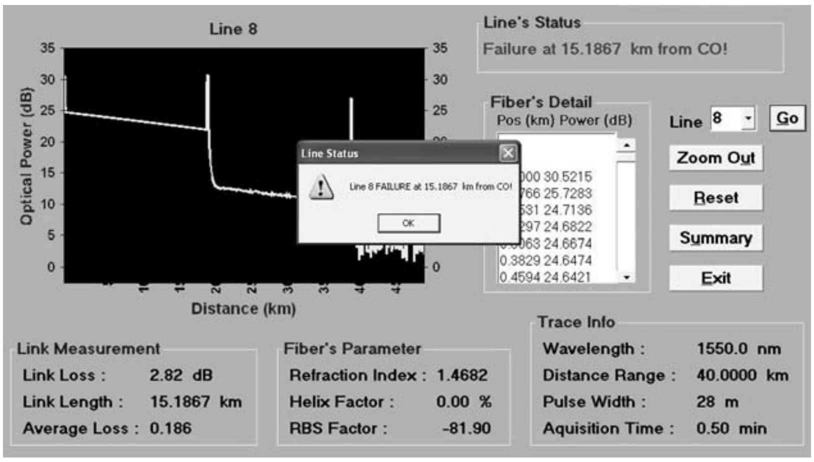

Fig. 5. An example of failure line in the *Line's Detail* form. The line 8 undergoes failure at 15.1867 km when the attenuation in an optical attenuator is 13 dB, which shows the breakpoint occurring at that distance in the real condition.

3.2. Displaying line's detail

The developed program is able to identify and present the parameters of each optical line such as the line's status either in working condition (normal operation) or non--working condition (breakdown), the magnitude of attenuation as well as the location, and other details (breakdown location, line's parameter such as return loss, crosstalk, *etc*.) are shown in the computer screen. The advantage of this feature as compared to the OTDR and computer-based emulation software is CFDS displayed every status for the testing line in the *Line's Detail* form which display onto one screen board. A *Good condition* or *Decreasing y dB at z km* message displays at the line's status panel in a working condition (see Fig. 4). 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 as illustrated in Fig. 5. 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.

3.3. Tracking optical signal level and losses

This feature enables CFDS to compare every line's optical power and losses. In the second experiment, optical attenuator is used to reduce the optical power in the

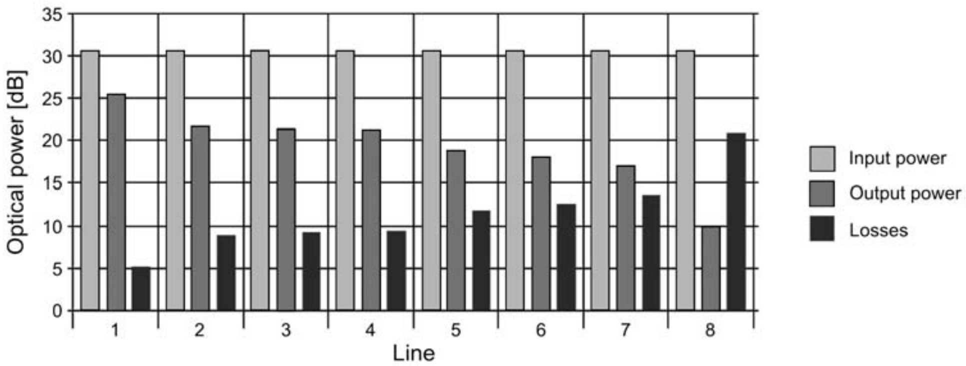

Fig. 6. The summary of optical signal level among eight lines.

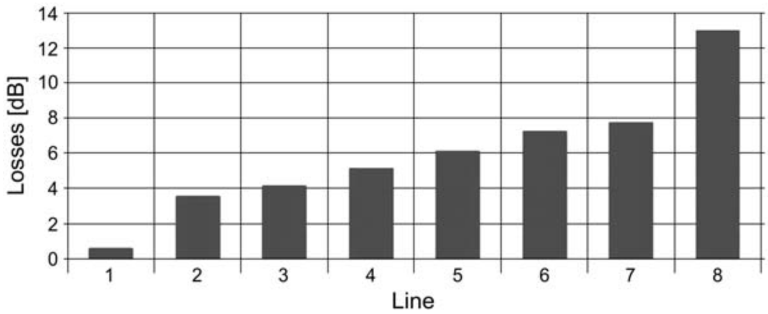

Fig. 7. The summary of system losses among eight lines.

tested line. The attenuation of optical attenuator is set to 0 dB and increased by 2 dB for every following test. CFDS tracks the input power, output power, and losses for each line in the *Optical Power Comparison* form, as shown in Fig. 6. Figure 7 gives the comparison for losses among the eight lines in the *Losses Comparison* form.

3.4. Monitoring network performance

At the same time, CFDS stores the analysis results in database for further processing and queries. All kinds of additional information can be easily accessed and queried later. We can evaluate the performance of the network via the summarized daily and monthly network performance graph, as illustrated in Figs. 8 and 9. In the daily network performance form, we can evaluate the daily network performance which may

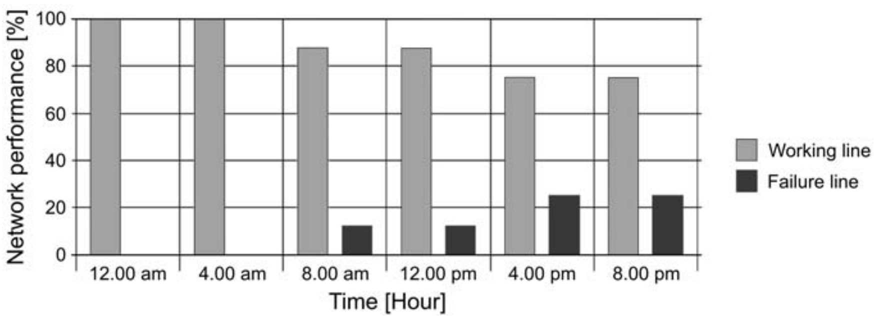

Fig. 8. The summary of daily network performance. The daily network performance (%) versus time (hour) plot is recording the network performance (in unit %) every 4 hours.

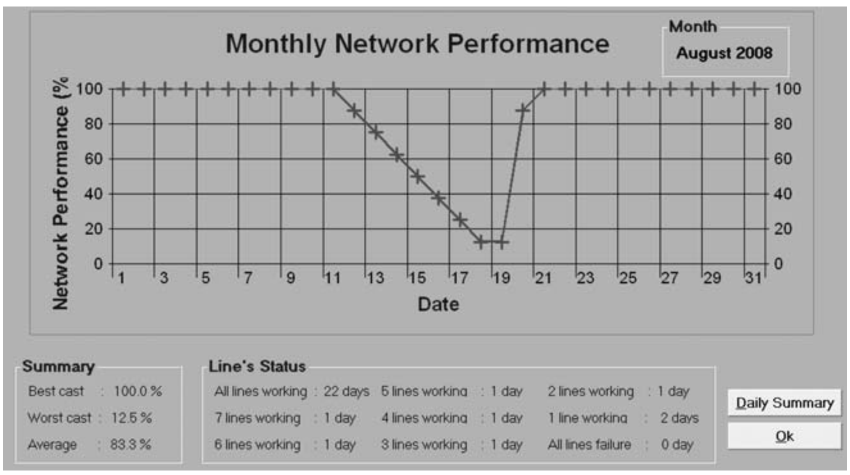

Fig. 9. The summary of monthly network performance.

require some prompt action. The network performance can be monitored by CFDS 24 hours a day and 7 days a week. In the monthly network performance form, the graph is able to give an overview to show the daily network performance for the respective month. It clearly shows the best cast (higher performance), worst cast (lowest performance) as well as the average performance for the respective month.

4. Discussion

The optical signal level gives a visual representation for the network deployment and connection. CFDS observes the optical fiber line's attenuation characteristics and losses through events identification method. CFDS can track 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 breakpoint before it has restored the stand-by line and repaired for post-fault maintenance through CFDS. With CFDS database, the histories of scanning can be recalled and further analysis can be conducted. Through in-service monitoring with CFDS, the field engineers can view the service delivery and detect any breakdowns as well as other circumstances which may require some prompt action before it turns into a big trouble and causes a tremendous financial loss.

5. Conclusions

Locating a fiber fault within FTTH access network becomes more and more important due to the increasing demand for reliable service delivery. CFDS can help any network service providers and field engineers to monitor the status and detect the failure location in tree-based structured FTTH access network downwardly. It is a cost--effective way to detect the failure location within FTTH access network with CFDS to improve the service reliability and reduce the restoration time and maintenance cost. It should be mentioned that CFDS is not limited to scenario with a single event (single condition), but could be applied to more complicated network configurations. In future research activity, we aim to develop the third generation of this program based on underlying software code (such as C or C++ language) which will be focused on adding extra new features and larger database. Finally, we highlight the possibility of modifying our strategy so that it would be applicable to the long haul optical communication link with various topologies or other fiber-to-the-*x* (FTT*x*) schemes.

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References

[1] CHAN C.K., TONG F., CHEN L.K., HO K.P., LAM D., *Fiber-fault identification for branched access networks using a wavelength-sweeping monitoring source*, IEEE Photonics Technology Letters **11**(5), 1999, pp. 614–616.

[2] LEE K.L., KANG S.B, LIM D.S., LEE H.K., SORIN W.V., *Fiber link loss monitoring scheme in bidirectional WDM transmission using ASE-injected FP-LD*, IEEE Photonics Technology Letters **18**(3), 2006, pp. 523–525.

[3] YEH C.H., SHIH F.Y., CHANG G.K, CHI S., *Reliable tree-type passive optical networks with self--restorable apparatus,* Optics Express **16**(7), 2008, pp. 4494–4498.

[4] RAHMAN M.S.A., NG B.C., *MATLAB-based graphical user interface development for centralized failure detection system (CFDS) in SCAN network*, Journal of Optical Communications **29**(3), 2008, pp. 152–156.

[5] GIRARD A., *FTTX PON Technology and Testing*, EXFO Electro-Optical Engineering Inc, Canada 2006.

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