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Fiber Fault Localization with Centralized Failure Detection System (CFDS) in FTTH Access Network

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Abstracts: This paper introduces a MATLAB-based graphical user interface (GUI) development named as Centralized Failure Detection System (CFDS) to increase the efficiency, survivability and reliability of fiber to the home (FTTH) access network. The developed program will be installed with optical line terminal (OLT) at the central office (CO) to monitor the status and detect the failure line that occurs in the drop region of FTTH network. The objective of this paper is to accumulate every network testing result to be displayed on a single computer screen and then specify the failure location in drop region of FTTH network downwardly. Conventionally, the failure line of FTTH network can be measured using optical time domain reflectometer (OTDR). A craftsman is send to the customer premises side to inject an OTDR pulse into the drop fiber upwardly, from optical network unit (ONU) to the OLT. This approach would require much time and effort. Moreover, OTDR can only display a measurement result of a line in a time. Passive optical splitter that used as the power splitting element in passive optical network (PON) architecture is blocking the reflected signal to be analysed by OTDR. At the same time, it also cannot transmit any failure indication in drop region to the CO. Therefore, it becomes a hindrance to detect failure of optical line with a large number of customer premises and large coverage area downwardly in the fiber plant by using an OTDR. CFDS is interfaced with the OTDR to display multi measurement results on a single computer screen in a time and also the further information when click on each individual line. The program will identify and present the parameters of optical 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 analysis result will be sent to field engineer or service provider for promptly action.

Key words: Centralized Failure Detection System (CFDS), graphical user interface (GUI), in-line monitoring, fault localization, in-service monitoring, drop region, FTTH access network.

INTRODUCTION

An access network refers to the connections that extend from the CO to a neighborhood and further to individual businesses and homes. 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. 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. Owing to the very high capacity of optical fibers, FTTH can deliver greater capacity than competing copper-based technologies (Keiser, 2000). FTTH provides triple-play services to the customer premises via the optical distribution network (ODN). ODN is commonly deployed in two specific configurations. In the first one, fiber is dedicated to each user in the access network. This is called a point-to-point (P2P) network. In the second, one fiber is shared (via a power splitter) among a set number of users. This is called a passive optical network (PON) or point-to-multipoint (P2MP) network.

FTTH-PON is the major role in alleviating the last mile bottleneck for next generation broadband optical access network (Yeh, *et al*, 2005). Since such architecture can accommodate a large number of subscribers, any service outage due to a fiber break can be translated into tremendous financial loss for the service

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providers (Chan, *et al.*, 1999). Moreover, the semiconductor-based laser diodes are the most widely used optical sources in fiber communication systems. They are similar to other laser, such as conventional solid state and gas laser, but the output radiation is highly monochromatic and the light beam is very directional (Keiser, 2000). If an optical line break, the laser explored at the transmission end. Even thought low power laser with just few miliwatts, but it still can cause the retina eye burning and permanent damage in seconds or even less time (Ng, 2008).

Fault Localization Technology:

A conventional optical fiber line testing system, which uses OTDR based on a single wavelength source, is used to detect failure in an optical fiber (Chan, *et al*., 1999). OTDR testing is the only method available for determining the exact location of broken optical fiber in an installed fiber optic cable when the cable jacket is not visibly damaged. It provides the best method for determining 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 (Chomycz, 1996).

An OTDR is fundamentally optical radar. In the same way radar locates distant objects, an OTDR can locate defects and problems in an optical fiber. Although their method is different where radar used radio frequency (RF) signal scanned over an area, meanwhile an OTDR used short pulses of light transmitted down a narrow fiber, but both techniques rely on signals reflected back to a receiver. Typical targets that an OTDR can detect and locate include connections, splices, cracks and bends along a fiber that can extend for over 100 km. OTDR can also measure characteristics such as total fiber loss, connector insertion loss and loss per unit length. These days, OTDR works with multimode fibers that conduct light at wavelengths of 850 nm and 1300 nm and with single mode fibers that conduct light at 1310 nm, 1550 nm and 1625 nm (or 1650 nm) wavelengths.

However, OTDR has some disadvantages. The OTDR signatures are sometimes difficult to interpret and hence, it is not presently recognized as a standard attenuation measurement method. For single-mode fiber, OTDR has low signal-to-noise (SNR) ratios and this limits the lengths that can be measured using a laser diode source. The resolution of the best and currently available OTDR's is of the order of 100 m, hence, it is impossible to resolve the first one or two splices in an installed fiber link. Also OTDR’s do not measure loss directly, as with the cut-back method, but the loss is inferred from the measured backscatter signature of the fiber. Differences in the backscatter capture coefficient along the fiber link produces inaccurate loss values, especially when the fiber spot-size are different, and many times a splice gain is reported. This can be eliminated by averaging two bidirectional measurements, but only at the cost of doubling the time and effort required to make the attenuation measurement (Sunak, 1988).

It is important to be able to locate any fiber break after the installation of FTTH-PON network. Furthermore, a simple and effective monitoring configuration is highly desirable for timely failure detection along the fiber link (Chan, *et al.,* 1999). A particular problem in this regard is that a failure occurred at the drop region must be located without affecting the service to other customers (Sankawa, *et al.,* 1990). The monitoring should be performed constantly while other channels are still in service to maximize the link utilization (Chan, *et al*., 1999). 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 access networks.

A FTTH-PON tree structured has many drop fibers (branches) in the drop region. Thus, it may be necessary to send a craftsman to the optical network terminal (ONT) or ONU side to inject an OTDR pulse into the drop fiber from customer premises to the CO. This approach would require much time and effort (Hilbk, *et al.,* 1997). It is difficult to detect a failure in optical line equipped with optical splitter by using an OTDR in the CO downwardly from CO to the customer premises, because the Rayleigh back-scattered (RBS) light from different branches accumulates in the OTDR trace and cannot be distinguished (Chan, *et al.,* 1999). To overcome these problems, several methods such as a tunable OTDR was realized by using tunable laser source (TLS) (Hilbk, *et al*., 1997) or based on a multi-wavelength source had been proposed (Yeh, *et al*., 2005). The failure of drop fiber can be monitored without affecting other in-service channels. However, the high cost of the application in the FTTH access network has prohibited them as a practical solution (Chan, *et al.,* 1999).

Smart Customer Access Network (SCAN):

The Laboratory of Optical Network and Intelligent System (ONIS) in Universiti Kebangsaan Malaysia (UKM) is developing a Smart Customer Access Network (SCAN), which involves in the failure detection, automatic recovery and increases the survivability and maintainability of the FTTH access network. SCAN network consist of 4 main subsystems that support the operations, they include Failure Detection System (FDS), Access Control System (ACS), Optical Cross Add and Drop Multiplexer (OXADM) and Optical In-line Taper (OIT) (Rahman, *et al*., 2006).

CFDS is one of the subsystems for the SCAN network, which able to monitor the status for each line and detect the failure in multi-line drop region of FTTH network downwardly. CFDS is a centralized monitoring and access control program that provides the service provider of the FTTH access network with a means of viewing optical signals flow and detecting breakdowns and other circumstances which may require some action with the graphical user interface capabilities of Visual Basic. CFDS has the same features of the OTDR and computer-based emulation software for performing data post-processing which given more OTDR processing functions but with more flexibility and reliability of FTTH access network used for optical communication.

To locate a failure without affecting the transmission services to other customers, it is essential to use a wavelength different from the triple-play services operating wavelengths for failure detection. SCAN network is using the operating wavelength 1625 nm for failure detection control and in-service troubleshooting. When four kinds of signals, operating at 1310 nm, 1490 nm, 1550 nm and 1625 nm are distributed from the CO to eight customer premises, the wavelength selective coupler (WSC) or Wavelength Division Multiplexing (WDM) coupler that used in this proposed design only allow the OTDR signal at 1625 nm to enter into the taper circuit and reject all unwanted signals (1310 nm, 1490 nm and 1550 nm) that contaminate the OTDR measurement (Girard, 2005).

CFDS is interfaced with the OTDR to accumulate every testing result to be displayed on a single computer screen for further analysis. The analysis result will be sent to field engineer or service provider for promptly action. Anywhere, the traffic from the failure line will be diverted to stand by (protection) line to ensure the traffic flow continuously. CFDS is focusing on providing survivability through event identification against losses and failures. CFDS used event identification to differentiate the mechanism of the optical signal at working and non-working (breakdown or failure) condition. The CFDS will be designed to operate by itself with a minimum need for operator action. It will be automatically inform the operator regarding the failure location and the information will be sent to field engineer through the wireless technology through the mobile phone or WiFi / Internet computer. It is ideal for users who are inexperienced or non-specialized in optical fiber testing. With CFDS no more cost and time misspending due to the troubleshooting mechanism is done downwardly.

Conceptual Design of CFDS:

CFDS proposed as described below is divided into four parts to support its operations including optical line measurement, data exploitation, data receiving and data analysis. The whole process can simplify in the flow chart (see Fig. 1) and the optical network is setup as depicted in Fig. 2. Network testing has been done to measure the characteristics of the optical line under working condition and non-working (failure/breakdown) condition by using a mini OTDR.

The fixed connection (FC) connector is used to connect between two fibers under test, meanwhile an optical attenuator used to reduce (attenuate) the optical signal level and represent the break point in an optical line as shown in Fig. 3. In the first two test, two FC connectors used as the both device under test (DUT). Then the optical attenuator used to replace the FC connector as the first DUT and the attenuation at optical attenuator set as 1 dB. After that, the attenuation at optical attenuator increased 2 dB for every following test until the optical signal in the line is failure. Eventually exchanged the position of FC connector with OPTICAL ATTENUATOR and repeated the same experiment.

Measurement for each optical line saved in the OTDR in trace (TRC) file and then transferred into the computer through a serial port extension cable. This process involved the data exploitation and data receiving. After completing the process, the results need to be converted into American Standard Code for Information Interchange (ASCII) form. All the results are saved in database. Then all the results loaded into the developed program from database. Every 8 testing results displayed on a computer screen for further analysis as depicted in Fig. 4 and 5.

This program used event identification to differentiate the mechanism of the optical signal at working and non-working condition. Reflective fault event representing the number of events or conditions occur in an optical line. There is a loss at the reflective fault event for line under working condition. If the loss is 0 dB, then CFDS displayed a "*Good condition*" message at the line's status panel in Linedetail window, else a "*Decreasing y dB at z km*" message displayed (see Fig. 7 to 12 and Fig. 16 to 18). However in the non-working condition, the event table did not display any loss at the reflective fault event. A failure message "*Line x FAILURE at z km from CO!*" displayed when CFDS unable to find the loss for a line (see Fig. 14 and 20). Thus, CFDS able to detect the failure line or under non-working condition when checking each line's status.

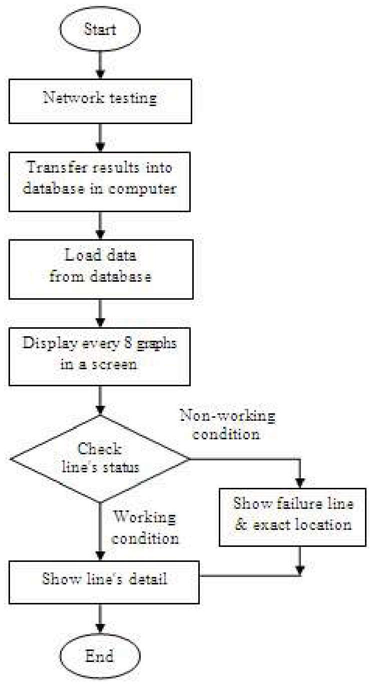


Fig. 1: Flow chart for mechanism of CFDS detection.

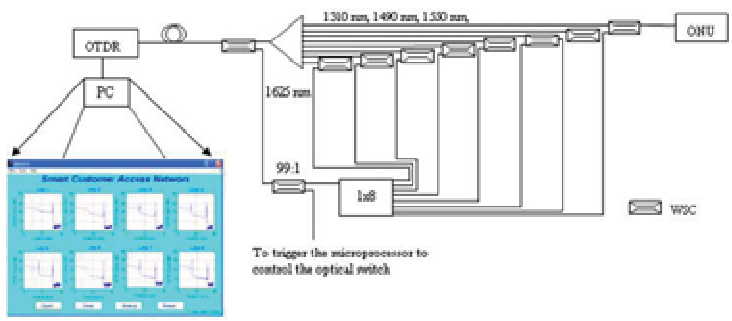


Fig. 2: The interconnection of optical switch to splitter and microprocessor system.

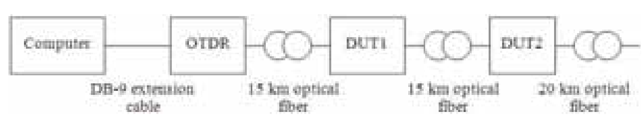


Fig. 3: The block diagram of experimental setup in P2P testing.

Modeling A Designed Concept:

CFDS built by using the GUIDE Layout Editor in MATLAB software. A GUI can layout easily by clicking and dragging GUI components such as panels, buttons, text fields, sliders, menus and so on into the layout area. GUIDE automatically generates two files for each window, a FIG-file that contains the layout of the GUI and an M-file that contains initialization code and templates for some callbacks that are needed to control GUI behavior. GUIDE assigns the name specifies for the FIG-file to both the FIG-file and the M-file, for example, *launch.fig* and *launch.m*.

CFDS is developed by combining the Launch, Linestatus and Linedetail three windows. Only the Linestatus window and Linedetail window are involved in monitoring each optical line's status and detecting the failure that occurs in the FTTH network. Both of them contain the characteristics and details of each optical line. Three main functions in the developed program are plotting graph, checking line's status and showing line's detail.

RESULTS AND DISCUSSION

Testing Results and Analysis:

All the results from database are load into MATLAB Current Directory when pressed the 'Open' button in Linestatus window. CFDS accumulated all the results in a single screen for centralized monitoring. Every 8 graphs that represented the characteristics of optical lines displayed in Linestatus window, where the distance (km) represented on the x-axis and optical signal level (dB) represented on the y-axis as depicted in Fig. 4. CFDS checked each optical line's status by finding every loss in a line when pressing the 'Status' button. Two failure messages "*Line 5 FAILURE at15.1918 km from CO!*" and "*Line 8 FAIL URE at 30.4601 km from CO!*" displayed to show the failure locations in the optical network (see Fig. 5).

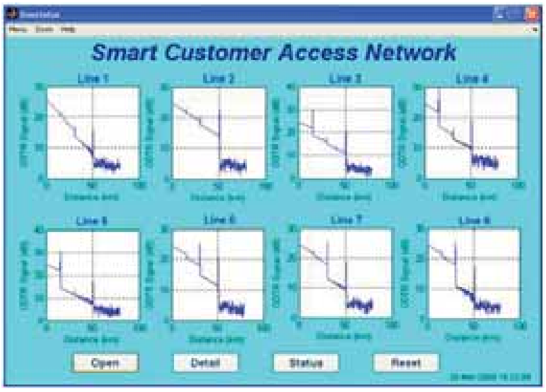


Fig. 5: Every 8 graphs display in Linestatus window for centralized monitoring.

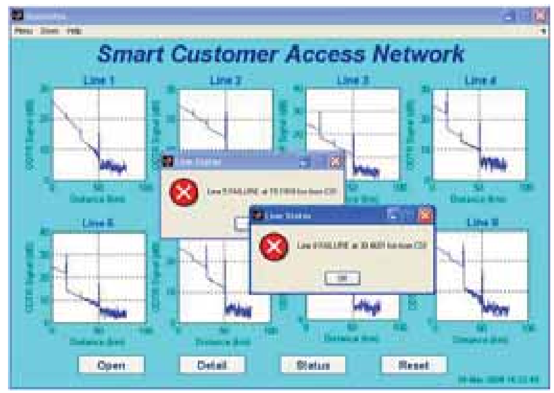
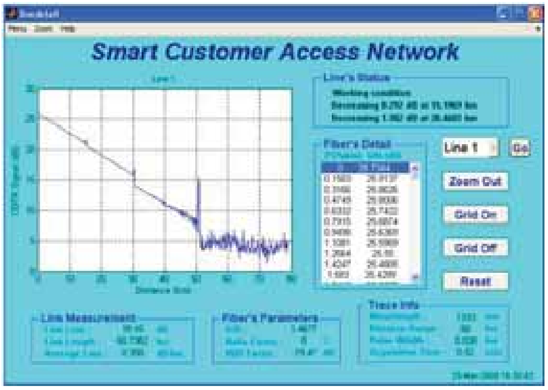


Fig. 6: Two failure messages display to show the failure locations in the optical network.

The first two tests were featuring with two different wavelengths 1310 nm and 1550 nm by using FC connectors as both DUTs in the optical network. The optical power in line 1 is decreasing 0.292 dB at distance 15.1969 km and 1.582 at distance 30.4602 km (Fig. 7). The decreasing power is the device loss generated by the FC connector. Theoretically, a signal is transmitted through a medium without any loss in a good (ideal) condition and we will get a straight line in a power-distance graph. However the OTDR don't show this characteristic in the real case due to there is a device loss. When the optical signal travels through a FC connector, it losses its energy in overcoming the resistance of the device. Besides, the optical power also is attenuated (reduction of the signal strength or loss of energy) through scattering and absorption mechanisms in the glass fiber. For guided media such as fiber optic, the signal strength normally decays exponentially. Normally the logarithmic power ratio measures the changes in the strength of a signal at two different points in unit of decibels (dB) (Forouzon, 2007).

Every results obtained from the network testing analysis in the Linedetail window are then compared with the simulation results from an emulation software for data post-processing at the every following figure to validate the correctness and accurateness. The developed program is able to identify and present the parameters of optical line such as status, magnitude of decreasing, failure location and details, which is unable to carry out in the computer simulations by using an emulation software. Conventionally, the emulation software is only available to show the trace display and event table as in the Fig. 8. At the same time, the optical power in line 2 is decreasing 0.263 dB at 15.1969 km and 1.227 at 30.4601 km (Fig. 8 and 9). The device losses in the line 2 is much more lower that the line 1 due to the optical line's attenuation at wavelengh 1550 nm (0.19 dB/km) is lower than 1310 nm (0.32 dB/km).

Then the FC connector in optical network replaced by optical attenuator as the first DUT. When the optical signal transmitted from the laser port to the end of fiber, the optical power in line 3 is decreasing 3.148 dB at distance 15.1918 km and 1.259 dB at 30.4652 km as shown in Fig. 10 and 11. The decreasing power is the device loss in the optical attenuator (first DUT) and FC connector (second DUT). When the attenuation is increasing, we can observe that the optical signal level at distance 15 km will be decreasing. The changes are clearly show in Figure 12 and 13. When the attenuation at optical attenuator increased up to 5 dB, the optical signal will breakdown at 15.1918 km (Fig. 15) and a failure message '*Line 5 FAILURE at 15.1918 km from CO!*' displayed in the Linedetail window (Fig. 14). It visualized the actual failure point of an optical line at that distance in the FTTH network in a real condition.



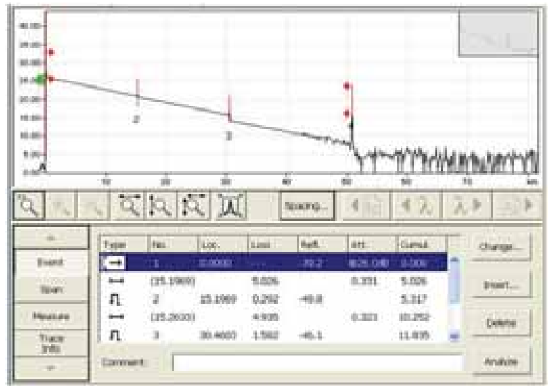
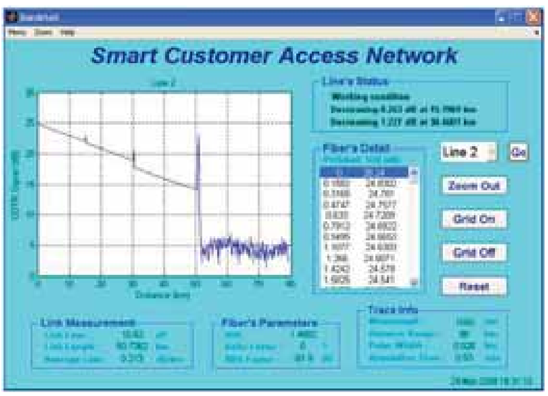


Fig. 7: The optical power level in line 1 are decreasing. 0.292 dB at 15.1969 km and 1.582 dB at 30.4602km

Fig. 8: Execution display for line 1 in an emulation software.



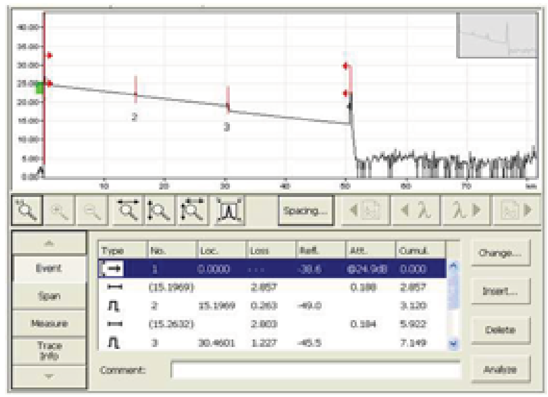
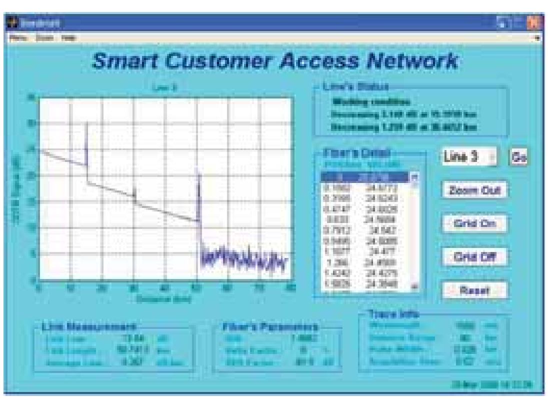


Fig. 9: The optical power level in line 2 are decreasing. 0.263 dB at 15.1969 km and 1.277 dB at 30.4601km

Fig. 10: Execution display for line 2 in an emulation software.



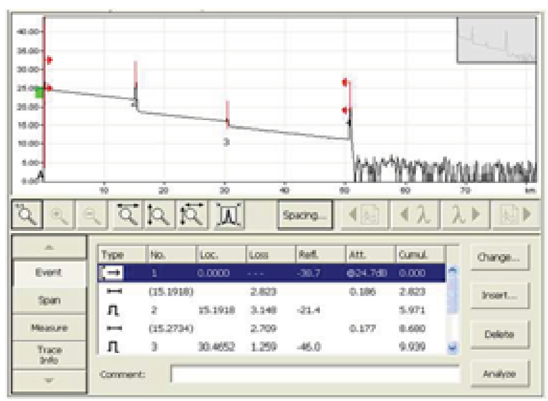
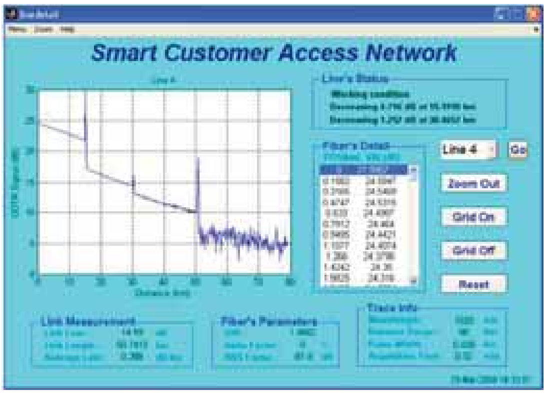


Fig. 11: The optical power level in line 3 are decreasing. 3.148 dB at 15.1918 km and 1.259 dB at 30.4652km

Fig. 12: Execution display for line 3 in an emulation software.



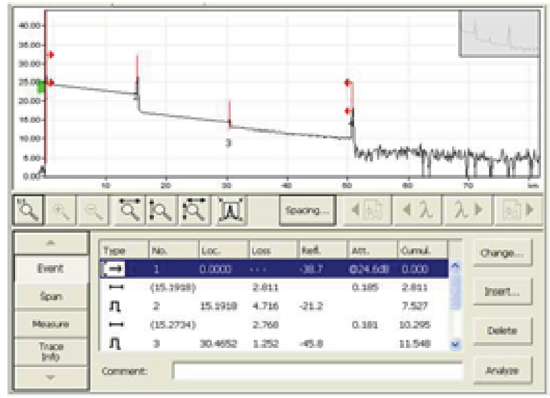
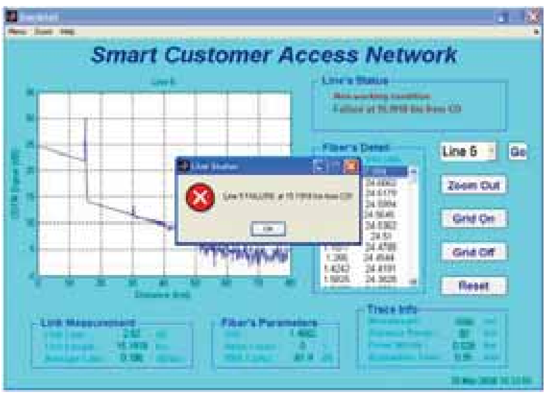


Fig. 13: The optical power level in line 4 are decreasing 4.716 dB at 15.1918 km and 1.252 dB at 30.4652 km.

Fig. 14: Execution display for line 4 in an emulation software.



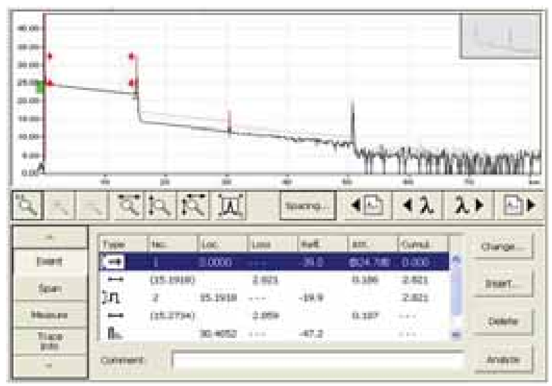
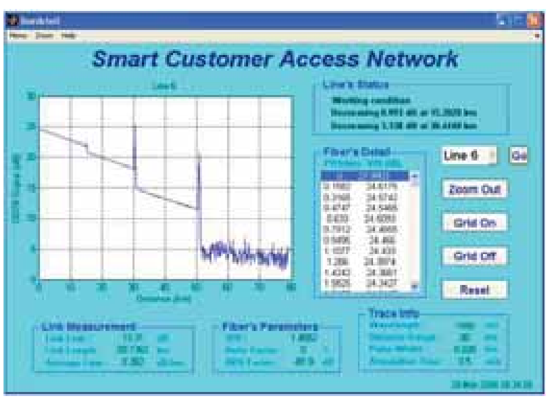


Fig. 15: Line 5 is failure at 15.1918 km when the attenuation at optical attenuator set as 5 dB.

Fig. 16: Execution display for line 5 in an emulation software.



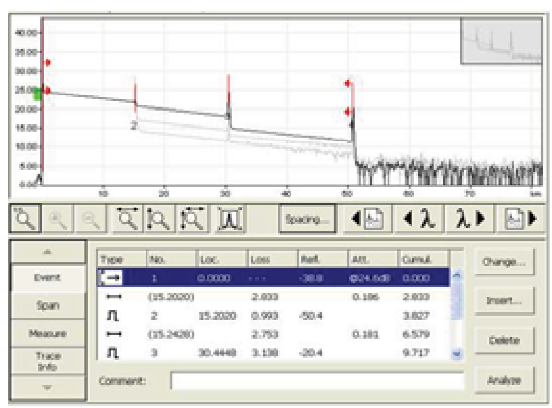


Fig. 17: The optical power level in line 1 are decreasing 0.993 dB at 15.2020 km and 3.138 dB at 30.4448 km.

Fig. 18: Execution display for line 6 in an emulation software.

After that, the position of optical attenuator in optical network exchanged with FC connector as the second DUT. There is reduction around 1 dB of the optical signal level when the signal travels through the FC connector at distance 15 km. The optical power also is attenuated at distance 30 km as shown in Fig. 16 to 19. Fig. 21 shows the optical signal will breakdown at 30.4601 km when the attenuation at optical attenuator increased up to 5 dB. A failure message '*Line 8 FAILURE at 30.4601 km from CO!*' displayed in Fig.20. It visualized the line 8 is breaking at that position in the FTTH network.

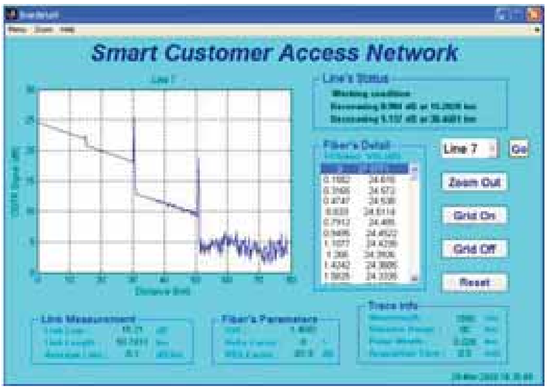


Fig. 19: The optical power level in line 7 are decreasing 0.984 dB at 15.2020 km and 5.137 dB at 30.4601 km.

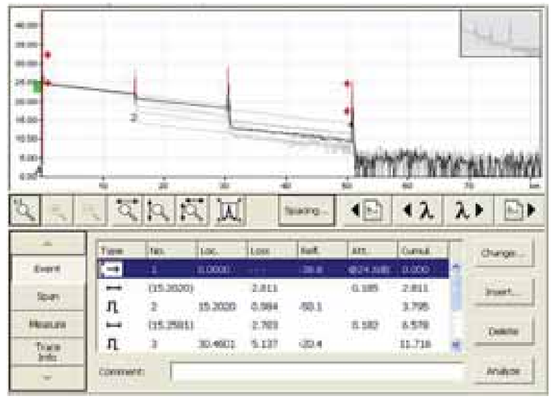


Fig. 20: Execution display for line 7 in an emulation software.

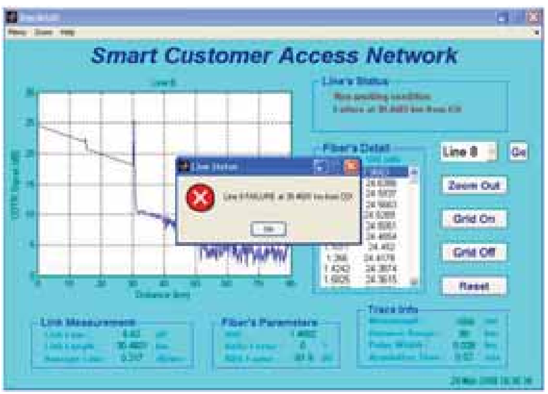


Fig. 21: Line 8 is failure at 30.4601 km when the attenuation at optical attenuator set as 5 dB.

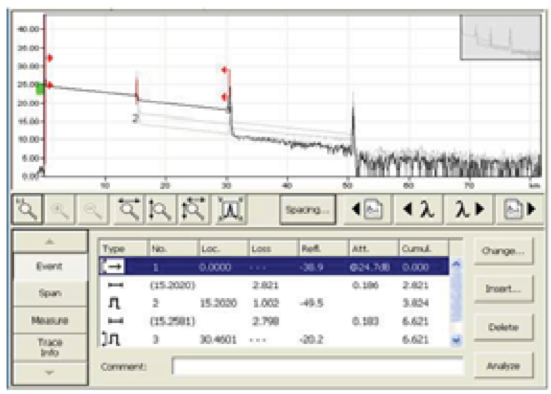


Fig. 22: Execution display for line 8 in an emulation software.

Discussion:

An OTDR trace is beginning with an initial input pulse. It can be having several common characteristics. Time period for the OTDR trace results from Rayleigh back scattering (RBS) as the laser source travels along the fiber section of optical line are interrupted by an abrupt shifts named as point defects. A point defect is a temporary or permanent local deviation of the OTDR signal either in upward or downward direction. Point defect caused by a connection, splice or failure along an optical line. The output pulse is indicated as end of an optical line from Fresnel reflection occurring at each fiber end.

Fiber point defects occur from splicing or bending during the fiber's plant installation. Point defect that occurs at a fiber joint is easily to identify if the location of a fiber joint is generally known. Normally, a reflective or non-reflective fault occurs at a fiber joint location. In most circumstances, an optical connector produces a reflective fault, while an optical splice produces a non-reflective fault. However reflective and non-reflective faults occur at other than fiber joint is identify as a fiber break, crack or bend. A fiber break produces a reflective fault, while fiber cracks and bends generally produce a non-reflective fault.

There are four types of events getting from this experiment, they are launch level, fiber section, reflective fault and reflective end. Reflective fault appear as spikes in the fiber trace. They are caused by an abrupt discontinuity in the IOR. Reflective faults caused a significant portion of the energy initially launched into the fiber to be reflected back towards the source. Reflective faults may indicate the presence of connectors, mechanical splices or even poor quality fusion splices. A loss and a reflective value are normally specified for reflective fault events. When the reflective spike reaches the maximum level, its top may be clipped due to the saturation of the detector. As a result, the dead zone or minimum distance for making a detection or attenuation measurement between this event and a second close by may be increased.

A reflective end indicates an abrupt discontinuity in the IOR, often caused by the glass-air interface at the end of the fiber. A reflective end normally appears as a steep downward slope corresponding to a loss considerably greater than normal fiber attenuation. The steep slope is often followed by low-level noise peaks. A reflectance value is specified for reflective end events. There is no loss specified for this type of event. There is followed by low-level noise after the reflective end (EXFO, 2000).

Even through CFDS can help any service providers and field engineers to monitor the status and detect the failure location of optical line, it still has its own limitations. Each of the network testing results need to be transfer into the computer manually after been measured with the OTDR. Furthermore, the network testing result can only be saved in TRC form in OTDR. However, MATLAB cannot directly extract the result. Thus the results need to be converted to another form such as ASCII form. There are some changes in the distance resolution and attenuation value after converted the results thus the display value might not be very accurate. For the meanwhile, the program can only measure the characteristics of optical line in specific units.

Conclusion and Future Plan:

CFDS able to differentiate every line's status and detect the failure occurs in multi-line drop region of the FTTH-PON network among 8 users over a maximum distance of 99.9999 km with a maximum of 2 different conditions. The user is directly being informed each status without analysis the trace display or event table from the execution displays in OTDR or emulation software. While the objective of the paper has been achieved, the program is still under the process of improvement. This program will be re-study and re-engineering to improve the accuracy of the displayed information. In the future, this program will be improved to investigate other parameters of the optical line and able to measure with other units. When the program is successfully developed, it may help the CO to monitor the status for each line and detecting the failure in drop region of FTTH network.

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