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# Optical Fault Monitoring Method in 8-branched PON-based *i*-FTTH

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**Abstract:** This study highlights Centralized Failure Detection System (CFDS) that specially developed for centralized monitoring and degradation/failure detection in passive optical network (PON)-based Intelligent Fiber-To-the-Home (*i*-FTTH) from Central Office (CO) in the downstream direction. This simple and cost-effective technique detects and localizes the fiber failures in point-to-multipoint (P2MP) networks by monitoring the loss of a reflective event that indicates presence of component at the same location. The failures in drop fibers as well as feeder fiber can be localized by accessing a commercially available Optical Time Domain Reflectometry (OTDR) for conducting live testing and service monitoring from CO through Smart Access Network_Testing, Analyzing and Database (SANTAD). SANTAD is successfully detecting a fault occurred at distance 11.4152 km from CO in PON-based *i*-FTTH network testbed composed of 19.4 km with system loss 20.85 dB within 15 min by setting the acquisition parameters in OTDR with operating wavelength and pulse width equal to 1625 nm and 1 μsec, respectively. This method provides a distance deviation up to 65 m from the exact failure location in real scenario.

**Key words:** CFDS, centralized monitoring, failure detection, OTDR, SANTAD

## INTRODUCTION

Fiber-To-The-Home (FTTH) has been considered an ideal solution for access networks since the invention of optical fiber communications because of huge capacity, small size and lightness and immunity to electromagnetic interference of optical fibers (Kim, 2003). Access network such as PON are an experiencing paradigm shift where these last mile networks are experiencing the need to provide converged services to the end-user at home. Triple-play services such as data and voice as well as video at a minimal speed of 2.5 Gbps are demanded to achieve an all optical network revolution (Kim, 2003; Lee *et al.*, 2006).

According to a Fiber-To-the-Home Council study released in September 2008, the annual growth rate for FTTH deployments in North America is 76% as the highest of any country or region in the world. The total number of North American subscribers that have chosen

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FTTH network as their technology of choice for receiving high bandwidth Internet and video services now stands at 3.76 million. With the current global trend towards FTTH, it is estimated that in 2011, there will be 10.3 million FTTH households in USA alone (Lee and Choi, 2007). FTTH is a promising solution that can break through the economic barrier of traditional point-to-point (P2P) solutions (Kim, 2003). FTTH segment has widely accepted PONs as the main branching network due to its advantages like protocol and data rate independency, economic benefit and convenience of deploying in fields without any electrical power requirements, etc. PONs combine support triple-play services which are individually reaching from various origins. The wavelength of operation of voice and data are 1310 nm upstream and 1490 nm downstream. The wavelength of operation of video is 1550 nm (Varghese and Nair, 2009).

It would be necessary to have the capability of detecting and localizing the fiber failures without delay in the practical deployments of PON-based FTTH. The network services providers (NSPs) (or operators) need a fast and cost-effective method of turning up and restoring service. Traditional troubleshooting methods require time and cost consuming coordination between CO (Network Operations Center (NOC) or head end) and field engineers/technicians using OTDR to conduct optical testing and localize the fiber failures (JDSU Uniphase Corporation, 2009). A crucial feature of any communication network is its survivability which refers to the ability to withstand component failures and to continue providing services in disruption conditions. Providing resilience against failures is therefore an important requirement for many high-speed networks. As these networks carry more and more data, the amount of disruption caused by a network fault or attack becomes more and more significant (Rejeb *et al*., 2010).

Most of PON-based FTTH architectures do not provide self-protection capability against fiber failures. For this problem, we develop new survivable network architecture namely *i*-FTTH for PON. This intelligent network is associated with centralized monitoring, failure troubleshooting, protection switching and automatic recovery features. The system design of PON-based *i*-FTTH consists of 5 major elements: (1) Centralized Failure Detection System (CFDS), (2) Smart Access Network_Testing, Analyzing and Database (SANTAD), (3) Access Control System (ACS), (4) Multi Access Detection System (MADS) and (5) Customer Access Protection Unit (CAPU). Figure 1 shows PON-based *i*-FTTH system architecture where a conventional PON-based FTTH connects an Optical Line Termination (OLT) in CO to several optical network units (ONUs) in customer premises.

MADS taps 10% of 1550 nm video signal at drop section to firstly detect the faulty line and the exact failure location will be determined by SANTAD. CFDS and SANTAD are integrated with OTDR for centralized monitoring and troubleshooting any degradation or fault that occurs in PON-based *i*-FTTH downwardly from CO towards customer residential locations (in downstream direction). CAPU is implemented at the end-users side just before ONU to perform self-restoration against fiber failures. ACS is deployed at middle of the network system for controlling the mechanisms of optical switching in CAPUs and responsible to route the 1625 nm OTDR testing signal to each individual fiber link in drop section. Any failure/breakdown occurs in the network system will be restored by switching the distributed signals to protection line by CAPU that coupled with Asymmetric Digital Subscriber Line (ADSL) copper wire from CO through ACS. In case of both working line and protection line is failure, the traffic can be recovered by using neighbor line.

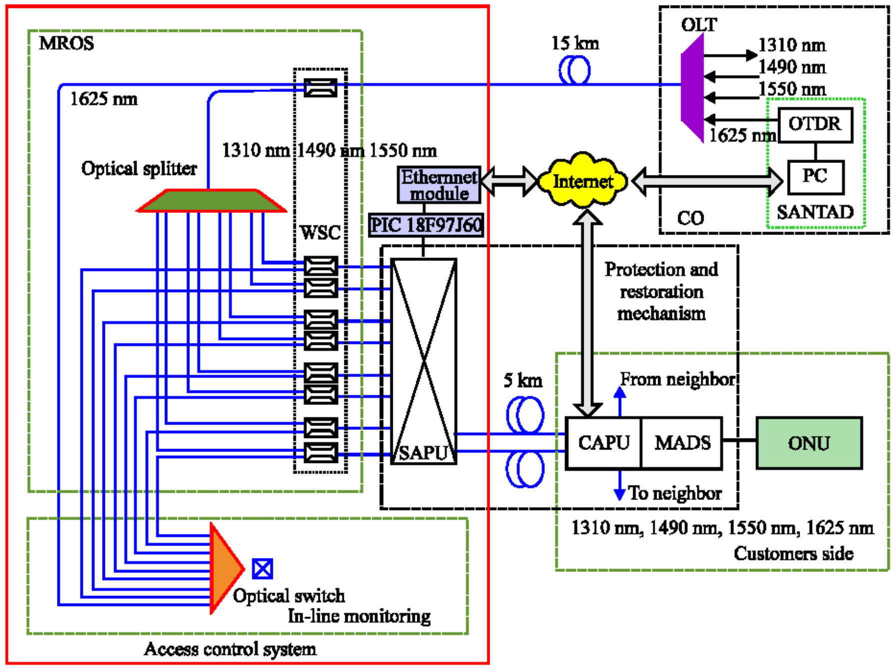



Fig. 1: PON-based intelligent fiber-to-the-home (*i*-FTTH) system architecture

## CENTRALIZED FAILURE DETECTION SYSTEM (CFDS)

In this study, we focus our discussions on optical fault monitoring method in 8-branched PON-based *i*-FTTH using broadband light source 1625 nm pulse. An OTDR is used for characterization of PON-based FTTH networks and live fiber troubleshooting at 1625 nm (out of band) without interfering with other signals. The OTDR is will be located at CO and accomplished through the 10/100 Ethernet port connect to a remote workstation (Personal Computer (PC) or laptop) as shown in Fig. 2. The Ethernet remote interface allowed the users to access (connect) the OTDR test module over any Internet-connected PC. This enable the users to run and operate the OTDR test module from a remote workstation at CO, remote site, or from anywhere in the world without on-site personnel for distant monitoring.

An alternative optical test solution is presented in Fig. 1 to alleviate the critical issues for fiber characterizations in conventional PON-based FTTH consist of passive branching device. CFDS solves this problem by replacing the passive optical splitter/coupler with an active system namely ACS. In this enhancement, a tapper circuit is design with the application of customized Wavelength Selective Couplers (WSCs), the triple-play signals (1310, 1490 and 1550 nm) and OTDR testing signal (1625 nm) are combined and split in the proposed configuration. The 1625 nm OTDR testing signal is tapped to bypass the 1×8 optical splitter when emitted from CO towards customer sites for optical monitoring and troubleshooting in downstream direction and ACS is responsible to route it into each corresponding line in drop section for degradation and failure detection via remote controlling from monitoring webpage.

CFDS integrated with ACS and CAPU through a customized web browser to facilitate NSPs and field engineers for distant monitoring and remote controlling the OTDR module as

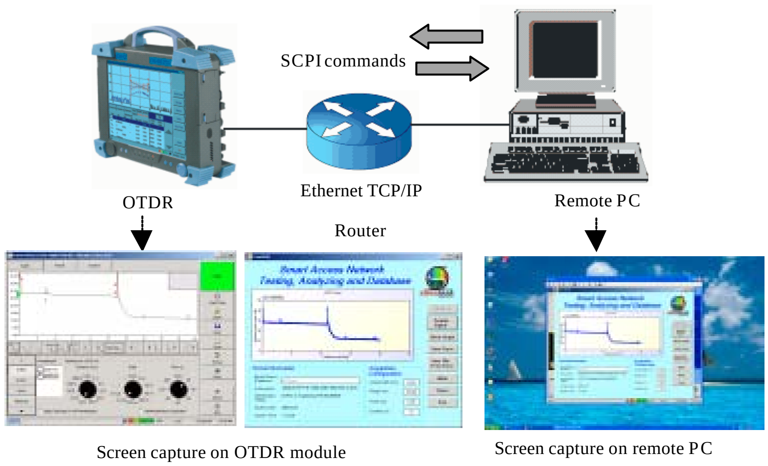



Fig. 2: Ethernet remote interface between remote PC and OTDR module

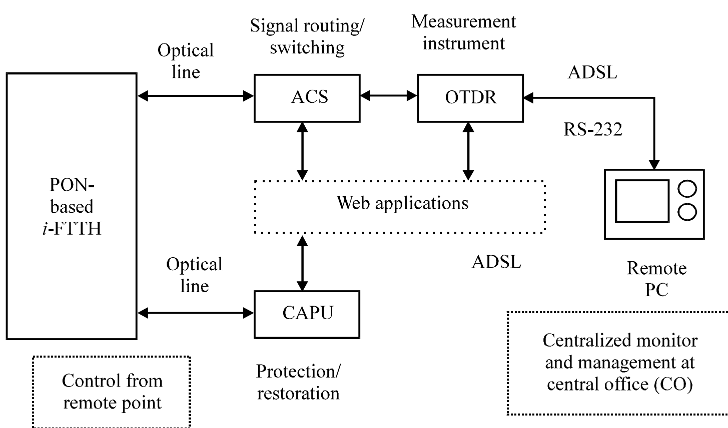



Fig. 3: Web service applications for multi devices interfacing in PON-based *i*-FTTH

well as the mechanisme of ACS and CAPU without making a site visit (Fig. 3 and 4). All the latest simulation results will be updated into SANTAD monitoring web page for to allow NSPs to obtain further information and detail by accessing over any Internet-connected PC. The ACS remote control web page control the mechanisms of optical switching between working line and protection line splitting from $1\times N$ optical splitter as well as route the 1625 nm OTDR testing signal into each drop fiber according to their sequent, meanwhile the CAPU configuring webpage controls the on and off of 16 combinations of $2\times1$ and $2\times2$ optical switches for recovering the distributed signals.

## SMART ACCESS NETWORK_TESTING, ANALYZING AND DATABASE (SANTAD)

SANTAD is a centralized remote control and test system that enables NSPs to test and monitor the current status of each fiber link in the PON-based *i*-FTTH network system with

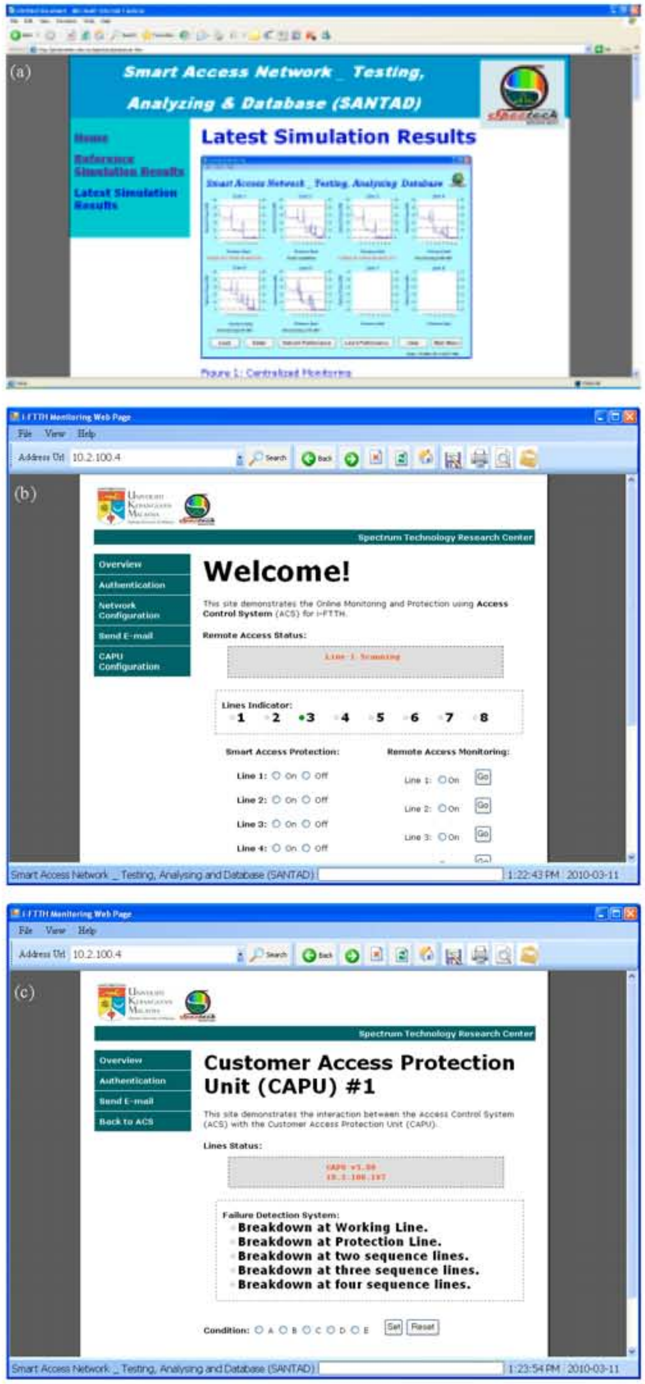



Fig. 4: Web-based remote control and monitoring applications for SANTAD, ACS and CAPU in PON-based *i*-FTTH. (a) SANTAD monitoring web page, (b) ACS remote control web page and (c) CAPU configuring webpage

the graphical user interface (GUI) processing capabilities of Visual Basic programming. There are 3 main features of the developed program: (1) Remote access control the OTDR module from CO or remote site, (2) Centralized monitoring and advanced data analyzing and (3) Documentation and database.

SANTAD is synchronizing with ACS to automatically run the optical testing and fiber characterization every 4 h and 6 times per day. SANTAD automatically set the acquisition configuration (testing parameters) of OTDR module such as operating wavelength, pulse width, distance range and acquisition time when emitting the OTDR pulse; however it may be necessary to manually reset the testing parameters in order to obtain the desired results. All the OTDR measurement are recorded in database and then loaded into the developed program for advanced data analyzing. SANTAD accumulates every 8 OTDR measurements to be displayed in centralized monitoring form for centralized monitoring and advanced data analyzing.

SANTAD is focusing on providing survivability through event identification against the loss result of a reflective event that indicates presence of connectors, mechanical splice, etc at the same location. Reflective event appears as spikes in the fiber trace. They are caused by an abrupt discontinuity in the index of refraction (IOR). Here, we monitor the loss results of ACS that specified for reflective event. SANTAD uses 2 event identification methods to determine the tested fiber link is either in good, degradation or failure condition. In the first status checking process, SANTAD firstly divides the measurement results into 2 categories, either in working condition (good or degradation) or in non-working condition (failure). In the second status checking process, SANTAD measures the loss of a reflective event for each fiber link at the same location and compares with the reference value in order to identify the testing line is either in good condition or in degradation condition. If the measured loss result is same or less than the reference value, it will consider as good condition, else the exceedition value is the degradation loss of measured fiber link. If SANTAD detects any occurrence of degradation or fault in the network system, the failure information will be sent to field engineers via e-mail for repairing and maintenance operations.

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 lines detail form. The developed program is able to identify and present the parameters of each optical fiber line such as the lines status, the magnitude of attenuation as well as the location and other details (breakdown location, lines parameter such as return loss, crosstalk, etc.) are shown in the PC screen. With 24/7 monitoring such parameters in network infrastructures, SANTAD can distinguish failures, thus eliminating unnecessary field trips for maintenance. The systems flow for degradation and failure detection in PON-based *i*-FTTH is illustrated in Fig. 5.

## EXPERIMENTAL RESULTS

The laboratory prototype of CFDS and SANTAD are implemented in PON-based *i*-FTTH network testbed for network performance monitoring and fault detection as present in Fig. 6. The length of feeder fiber is 11.4 km. The fiber link in drop section between the optical splitter and each ONU is from 2 to 8 km. In normal operation, both the upstream and downstream signals travel through a transmission distance of 12.4 to 19.4 km from OLT towards each ONU with total system loss 17.81-20.85 dB. During the observation, we

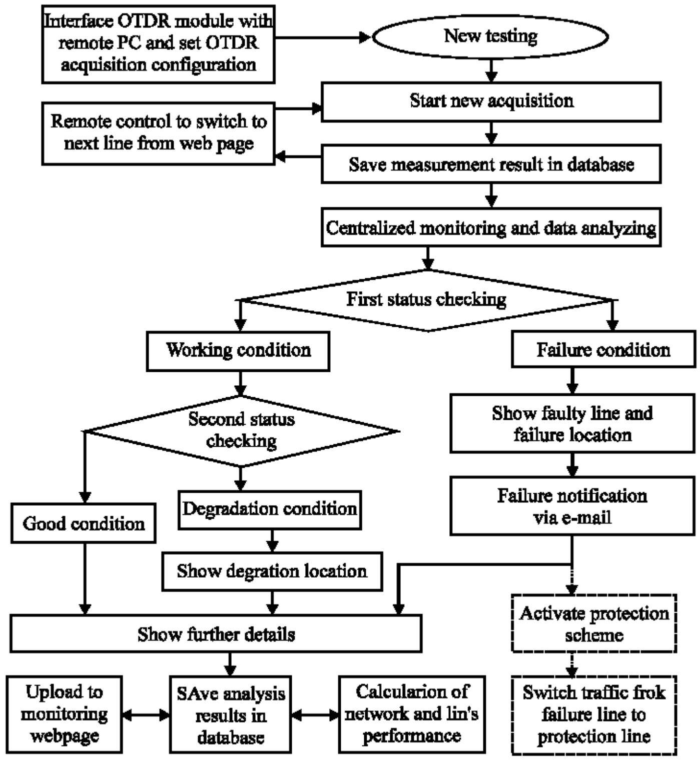



Fig. 5: Systems flow for degradation and failure detection in PON-based *i*-FTTH

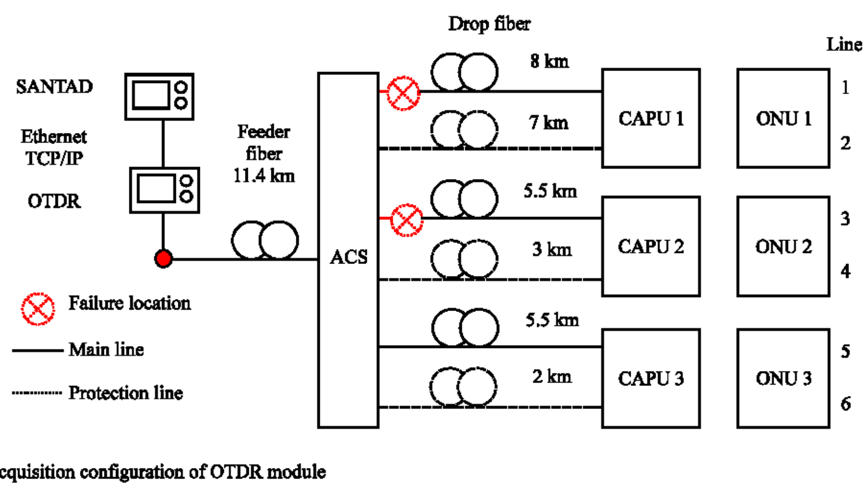



Fig. 6: Simplified diagram for optical testing and monitoring in PON-based *i*-FTTH network testbed. Acquisition configuration of OTDR module. Wavelength: 1625 nm, Distance range: 40 km, Pulse width: 1 μsec, Acquisition time: 15 sec

disconnected the fiber joints to represent a fiber break scenario at the corresponding position. It visualized the actual break point of an optical line at that distance in a real

Table 1: Optical loss for all fiber links in good condition and experimental implementation

| | Link loss of each fiber links (dBm) | | | | | |
|---|---|---|---|---|---|---|
| | Reference value | | | Experimental implementation | | |
| Line | 1310 nm | 1490 nm | 1550 nm | 1310 nm | 1490 nm | 1550 nm |
| Line 1-main line 1 | -8.92 | -8.41 | -6.99 | -4.98 | -5.33 | -4.29 |
| Line 2-protection line 1 | -8.97 | -8.57 | -7.27 | -9.92 | -9.22 | -7.96 |
| Line 3-main line 2 | -7.37 | -7.43 | -6.57 | -4.27 | -4.67 | -3.66 |
| Line 4-protection line 2 | -7.80 | -7.85 | -6.66 | -6.41 | -6.45 | -5.36 |
| Line 5-main line 3 | -8.99 | -8.51 | -7.43 | -7.15 | -6.82 | -5.79 |
| Line 6-protection line 3 | -7.43 | -7.88 | -6.51 | -5.88 | -6.22 | -5.07 |


Fig. 7: Fiber characterization for each optical path in *Optical Testing* form. (a) Line 1-main line 1, (b) Line 2-protection line 1, (c) Line 3-main line 2, (d) Line 4-protection line 2, (e) Line 5-main line 3 and (f) Line 6-protection line 3

condition. We first measured the link loss of each fiber link with optical power meter and fiber characterization with an OTDR as shown in Table 1 and Fig. 7.

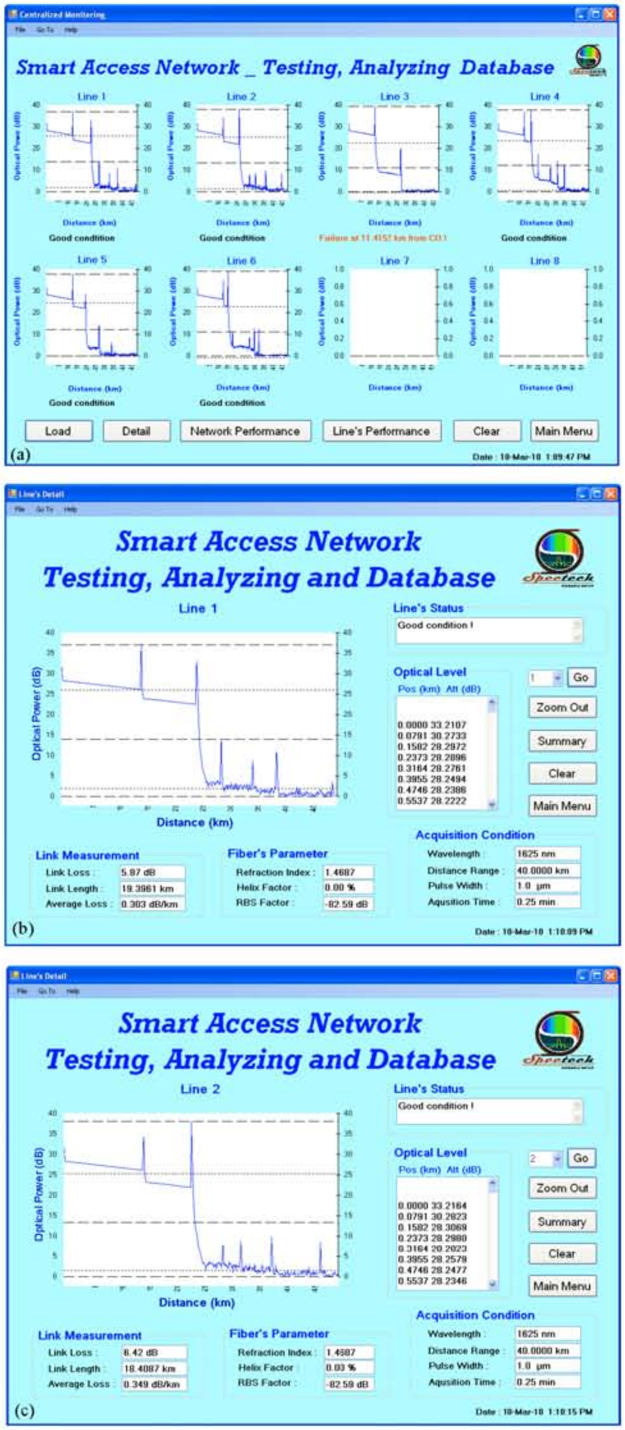
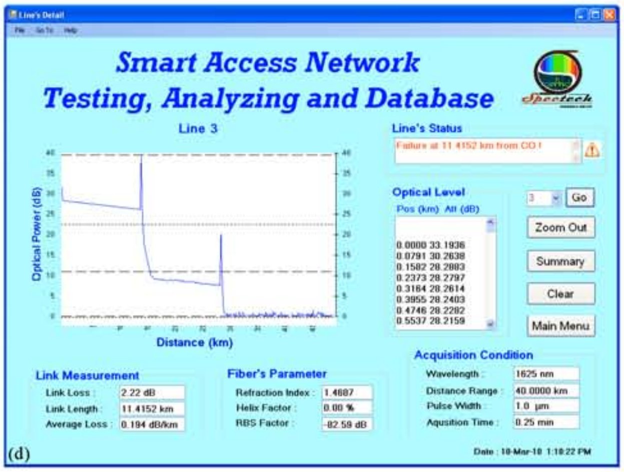
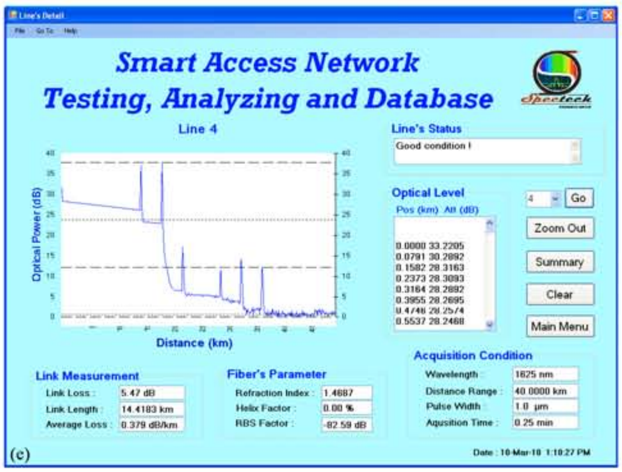


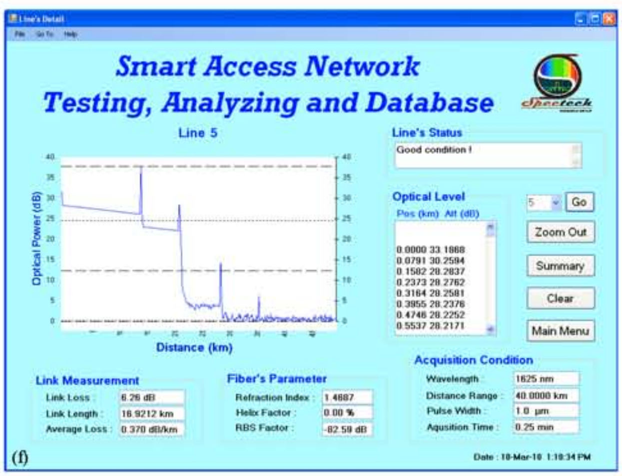

Fig. 8: Continued




(d)




(e)




(f)

Fig. 8: Continued

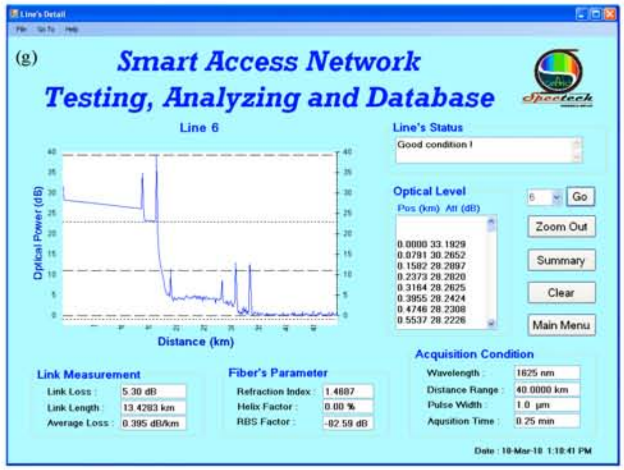



Fig. 8: Screen capture of *Centralized Monitoring* and *Lines Detail* forms. (a) centralized monitoring, (b) details for line 1, (c) details for line 2, (d) details for line 3, (e) details for line 4, (f) details for line 5 and (g) details for line 6

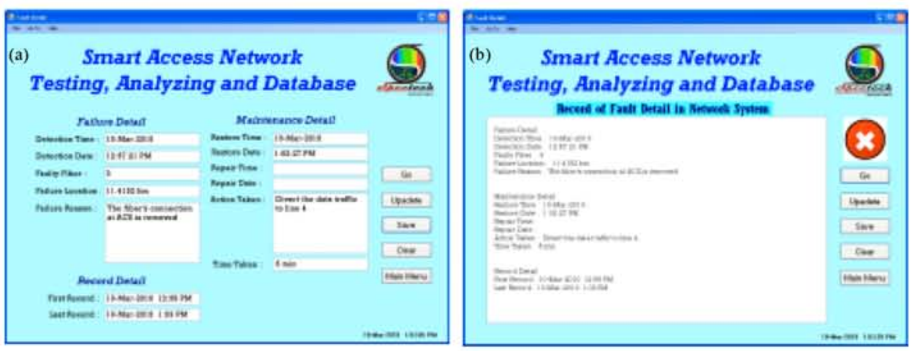



Fig. 9: Recording failure details for line 3 in fault detail form. (a) Recording the failure details, (b) Recalling the failure details

The graphical representations of each fiber link in the network system are presented in Fig. 8, it clearly display the reflective events at every fiber joint location. Figure 8a depicts the capability of SANTAD to configure the optical signal level and attenuation/losses through event identification method and Fig. 8b till 8 h illustrate the further details of the specific testing line in the network system. SANTAD is successfully detecting a fault occurred in the drop section at distance 11.4152 km from CO in line 1 and line 3 within 14 min 12 sec. This method provides a distance deviation of 0 m (minimum) to 63.7 m (maximum) from the exact failure location in real scenario.

The analysis results will then stored in text files acting as database for further processing and queries with certain attributes such as date and time, network failure rate, failure location, etc., as shown in Fig. 9. SANTAD sends 1 bit signal to the daily network performance form, where, 1 for working condition (good and degradation) and 0 for

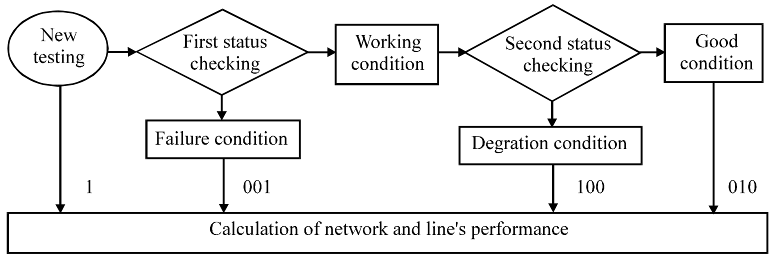



Fig. 10: Systems flow for calculation of network and lines performance in PON-based *i*-FTTH

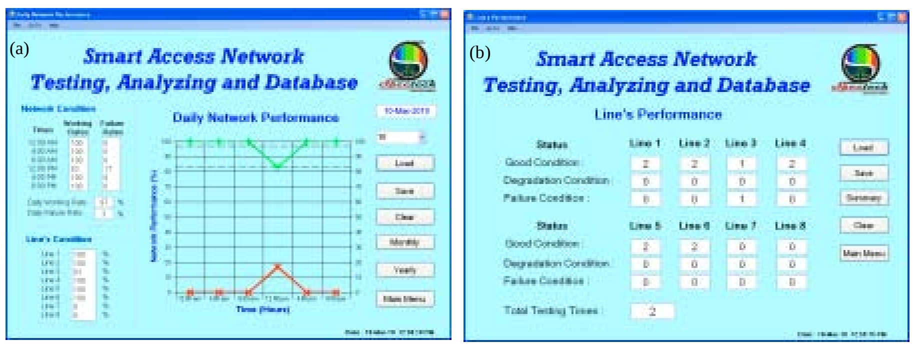



Fig. 11: Monitoring network performance and each lines performance. (a) daily network performance and (b) summary of each lines performance

non-working (failure) condition and 3 bit signal to the lines performance form, where 001 for degradation condition, 010 for good condition and 100 for failure condition. Figure 10 shows the systems flow for calculation of network and lines performance in PON-based *i*-FTTH. The NSPs can first establish the relationship between network failure rate and network performance based on measurements and statistics. The relationship between network failure rate and network performance can be monitored by SANTAD in real time, 24 h a day and 7 days a week. The field engineers can evaluate the network performance by summarizing each network performance plot as shown in Fig. 11, which may require some prompt action.

Table 2 analyzes the cumulative time that required during optical testing and measurement, degradation and failure detection in PON-based *i*-FTTH, as well as failure notification to field engineers from the preparation at first stage until the documentation process at final stage.

## CONCLUSIONS

In this study, we have presented our novel optical monitoring and management technique for current PON-based FTTH with excellent combination of CFDS and SANTAD. CFDS and SANTAD monitor the network performance as well as alert the NSPs when degradation of the fiber cable starts to affect performance beyond user limits or when faults occur in the network system. The flexibility of our program has been highlighted through a series of experiments that exhibit its performance and an example scenario for evolution. It

Table 2: Cumulative time that required in optical testing and network analyzing

| Actions | Average time | Total time |
|---|---|---|
| **Preparations** | | |
| 1. Preparation on OTDR | 2 min 31 sce | 2 min 31 sce |
| 2. Preparation on sceANTAD | 1 min 30 sce | 1 min 30 sce |
| 3. Preparation on ACS | 39 sce | 39 sce |
| 4. sceynchronization between OTDR module and remote PC | 58 sce | 58 sce |
| **Optical testing and measurement** | | |
| 1. Initializing the current used OTDR module | 2 sce | 2 sce |
| 2. sceelecting the acquisition configurations (testing parameters) | 3 sce | 3 sce |
| 3. sceelecting and routing OTDR sceignal to the testing line through ACS and CAPU controlling webpage (for 6 lines) | 8 sce | 48 sce |
| 4. scetart new OTDR acquisition (set the acquisition time as 15 sce for 6 lines) | 34 sce | 3 min 24 sce |
| 5. Recoding data (for 6 lines) | 25 sce | 2 min 30 sce |
| **Centralized monitoring and advanced data analyzing** | | |
| 1. Data Analyzing | | |
| -Transferring data into database | 20 sce | 20 sce |
| -Uploading data into centralized monitoring form | 2 sce | 2 sce |
| - Checking each line's scetatus (for 6 lines) | 1 sce | 6 sce |
| - Scehowing each line's details (for 6 lines) | 2 sce | 12 sce |
| 2. Failure notification via e-mail | 7 sce | 7 sce |
| 3. Documentations | 1 min | 1 min |
| Total required time for a complete testing = 14 min 12 sce | | |

concluded that CFDS and SANTAD provide a flexible, convenient, fast and cost-effective method of turning up and restoring service when any failure occurs within PON-based FTTH. It is potentially to improve the service reliability and reduce the restoration time and maintenance cost.

## ACKNOWLEDGMENT

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