Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (13): 2390-2398, 2009
ISSN 1812-5654

Engineering a Network Management System for FTTH Access Network

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Abstract: This study presented a Fiber-To-The-Home (FTTH) network management system named Smart Access Network_Testing, Analyzing and Database (SANTAD) for optical monitoring and network troubleshooting based on Visual Basic. SANTAD is the new upgraded values of recent FTTH technology toward the implementation of smart network, which involved in the centralized monitoring, failure detection, automatic recovery and increases the survivability and maintainability of FTTH. The working principles of SANTAD are structured into remote access control and advanced data analyzing for pre-configured protection and post-fault restoration in FTTH. The developed program is able to quick identify any occurrence of fault and address the exact failure location in the network system. This study also described how the FTTH can reduce the greenhouse gases (GHG) emissions in order to contribute to wider global struggle to ensure our future environment and discussed the uses of laser as optical source in optical fiber communication system as well as the eye safety issues with laser.

Key words: SANTAD, optical monitoring, network troubleshooting, Visual Basic, fault protection and restoration

INTRODUCTION

FTTH has played the major role in alleviating the last mile bottleneck for next generation broadband optical access network (Yeh and Chi, 2005). Owing the very high capacity of optical fibers, FTTH can deliver greater capacity as compares to copper-based technologies (Keiser, 2000). Since, the optical fiber offers a vast amount of bandwidth that can be utilized for communication, one of utilizing this is signal multiplexing. Due to the large bandwidth and the associated high bit rates, the multiplexing process is beyond the capabilities of pure electronic methods and has to be implemented optically as well. As the reach of optical fiber is being extended to the access network it is economically attractive to share fibers between different end-users without adding active components in the network. The optical Single Mode Fiber (SMF) is a very attractive communication medium since it offers a large scale useful bandwidth (25 THz) and low attenuation (0.2 dB km^{-1}), therefore it can facilitate demanding services such as high quality video transmission (Menif and Fathallah, 2007).

A number of factors are increasing the interest among network service providers in offering the triple play services of voice, video and high-speed data access. Most importantly, subscribers are finding a growing number of applications that drive their desire for higher bandwidth, including Internet Access, Internet Protocol Television (IPTV), High Definition Television (HDTV), Video on Demand (VoD), online games, e-health, advance education and others. Without a doubt, high-speed Internet access is one way to attract foreign investors as video-conferencing with head-offices around the world, or data transfer, has become an essential part of doing business. In the business world, time is money. Speeds of 50 Mbps for downloads and 10 Mbps for uploads will be a norm and this in itself will drive a whole host of online applications and services (Sidhu, 2009).

The first serious interest in FTTH began in the late 1980s as the telephone companies gained experience with Integrated Services Digital Network (ISDN) wideband services to subscribers (Gorshe, 2006). Today, FTTH has been recognized as the ultimate solution for providing various communications and multimedia services,

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including carrier-class telephony, high-speed Internet access, digital cable television (CATV) and interactive two-way video-based services to the end users (Lee *et al*., 2006). FTTH will soon become Fiber-To-Every-Home (FTEH) as standard for new construction in many developed countries by 2010.

Information Communication and Technologies (ICTs) are a significant cause of global warming. It is estimated that ICTs contributed around 6-10% of the world's energy and 2% of global GHS emissions. About 40% of these emissions are from Personal Computers (PCs) and cell phones, while the balance of the output comes from businesses, network operators and application providers. Although, the overall emissions of ICT are relatively small compared to other industry sectors, they are probably fastest growing sector in terms of carbon dioxide (CO_2) emissions. If something is not done soon, the ICT industry within a couple of decades could be one of the larger industry sources of GHG emissions. These percentages are likely to grow as ICTs become more widely available (Arnaud, 2008).

The ICT industry is unique amongst industry sectors in that GHG emissions are not a direct outcome of its deployment and use as opposed to transportation, heating, power generation and other industrial processes. The ICT industry contribution to GHG is indirect through the electrical power produced for the electricity to power the electronic equipment and keep it cool. As almost every watt consumed by electronics results in heat an almost equal or greater amount of electricity is required for cooling ICT equipment (Arnaud, 2008).

The major contribution of ICTs to climate changes from the proliferation of user services, all of which need power and radiate heat. In addition to the proliferation of users, each individual user may now own many more devices. As the ICTs devices acquire more processing power, their requirements for power and cooling also rise. Part of the concern over the global warming effect of ICTs comes from the seemingly inexorable rise in the power requirements of ICT devices driven by the high transmission capacity. ICTs can be major linchpin in efforts to combat climate change and serve as a potent cross-cutting tool to limit and ultimately reduce GHG emissions across economic and social sectors (Kelly and Adolph, 2008).

To reduce the power requirement for continuing with the broadband access technology, FTTH is one of the examples that provided a reduction in CO_2 emissions (Kelly and Adolph, 2008). A study conducted by FTTH Council Europe and Price Waterhouse Coopers finds that the first 15 years of a given network implementation, with a reduction in GHG emissions equivalent to 330 kg user^{-1} or a car travelling 2000 km. For the other 15 years beyond, the savings are 780 kg user^{-1} or a car travelling 4650 km due to the fact that the network is depreciated and only part of the infrastructure needs to be renewed. If further physical barriers are reduced (ducts access in particular) and a full range of services are developing, the contributions will be far bigger (Ollivry and Osset, 2008).

FIBER FAULT IN FTTH

FTTH technology using Passive Optical Network (PON) is the most promising way to provide high quality broadband access. PON are nowadays extensively studied and some commercial deployments are already reported (Wuilpart *et al*., 2007). PON architecture consists of an Optical Line Terminal (OLT) at Central Office (CO) and multiple Optical Network Units (ONUs) at different residential customer locations that are connected to the OLT through fibers of a tree topology. Given a certain optical split ratio (1:N, where, N = 2, 4, 8, 16, 32, 64 and 128), only a limited number of ONUs can be connected to a passive optical splitter (passive branching device) and then connected to a common OLT (She and Ho, 2008). The 32 or 64 ways splitting are the most common today, but other splits are possible.

The PON is commonly deployed as it can offer a cost-efficient and scalable solution to provide huge-capacity optical access (Prat, 2007). Since the PON can accommodate a large number of subscribers, when any fault occurs in FTTH, the network will without any function behind the break point. Any service outage due to a fiber break can be translated into tremendous financial loss in business for the network service providers (Chan *et al*., 1999).

Meanwhile, the laser (optical source) is highly explored at the transmission end when an optical line broken. Even thought low power laser with just few miliwatts (mW), but it still can cause the retina eye burning and permanent damage in seconds or even less time (This will be happen when the optical fiber cable is broken and exposed to human skin) (Rahman and Ng, 2008). Lack of survivability in the safety issues is one of main factors that FTTH is still not been deployed in certain developing countries. According to the cases reported to the Federal Communication Commission (FCC) in US, more than one-third of service disruptions are due to fiber cable problems. These kinds of problems usually take longer time to resolve compared to the transmission equipment failure (Bakar *et al*., 2007).

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

Optical fiber communication systems often use semiconductor optical sources such as Light-Emitting Diodes (LEDs) and semiconductor lasers because of several inherent advantages offered by them. Some of these advantages are compact size, high efficiency, good reliability, right wavelength range, small emissive area compatible with fiber core dimensions and possibility of direct modulation at relatively high frequencies (Agrawal, 2002). The concept of the semiconductor laser diode was proposed by Basov and Javan. The first laser diode was demonstrated by Robert N. Hall in 1962. Hall's device was made of Gallium Arsenide (GaAs) and emitted at 850 nm in the near infrared region of the spectrum. The first semiconductor laser with visible emission was demonstrated later the same year by Nick Holonyak, Jr. As with the first gas lasers, these early semiconductor lasers could be used only in pulsed operation and indeed only when cooled to liquid nitrogen temperatures (77 K). The semiconductor laser is similar to other lasers, such as conventional solid state and gas laser, but the output radiation is highly monochromatic and the light beam is very directional (Keiser, 2000).

The wavelength range used in modern optical systems is around 1550 nm (near infrared). In this wavelength region, powers greater than 21.3 dBm emanating from a fiber end are considered to be intrinsically hazardous to the eye. High power levels in optical communications systems are typically associated with the output of optical amplifiers such as Erbium Doped Fiber Amplifiers (EDFAs) or Raman fiber amplifiers (Hinton *et al*., 2006). The unprotected human eye is extremely sensitive to laser radiation and can be permanently damaged from direct or reflected beams. The site of ocular damage for any given laser depends upon its output wavelength. According to Bader and Lui (1996), laser light in the visible and near infrared spectrum (400-1400 nm) can cause damage to the retina resulting in scotoma (blind spot in the fovea). This wave band is also known as the retinal hazard region. Meanwhile, laser light in the ultraviolet (290-400 nm) or far infrared (1400-10600 nm) spectrum can cause damage to the cornea and/or to the lens. The extent of ocular damage is determined by the laser irradiance, exposure duration and beam size.

Conventional fiber fault localization techniques: Fiber fault within FTTH becomes more significant due to the increasing demand for reliable service delivery (Prat, 2007). Service reliability must be considered because a failure of broadband services may result in large data loss. Optical Time Domain Reflectometer (OTDR) was first reported in 1976 (Barnoki and Jensen, 1976) as a telecommunications application and became an established technique for attenuation monitoring and fault location in optical fiber network within the telecommunications industry (King *et al*., 2004). 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 (Harres, 2006).

Conventionally, OTDR is used to identify a fiber fault in FTTH upwardly from multiple ONUs at different residential customer locations toward OLT at CO (in upstream direction). According to Chomycz (1996), OTDR testing is the best method for determining the exact location of broken optical fiber in an installed optical fiber cable when the cable jacket is not visibly damaged. It determines the loss due to individual splice, connector or other single point anomalies installed in a system. It also provides the best representation of overall fiber integrity. Since, a FTTH has many branches in the drop region. Whenever a fault occurs, OTDR is plugged manually to the faulty fiber by the technician to detect where the failure is located. 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. The OTDR analysis of a PON network is however more difficult, as the Rayleigh Back-Scattering (RBS) signal of each branch is partially masked by the signals of all the others branches and cannot be distinguished in downstream direction (Chan *et al*., 1999).

Recommended fiber fault localization technologies: 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 or OTDR-based testing system using reference reflectors or fiber selectors (Caviglia and Biase, 1998; Prat, 2007). 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, 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 (Prat, 2007). Also, these methods are complex and difficult to implement has prohibited them as a practical solution (Lee *et al*., 2006).

FTTH NETWORK SYSTEM-SANTAD

SANTAD is a centralized access control and surveillance system that enhances the network operators and field engineers with a means of viewing traffic flow and detecting any breakdown as well as other circumstance which may require taking some appropriate action with the Graphical User Interface (GUI) processing capabilities of Visual Basic software.

The functionalities of SANTAD can be generally classified into pre-configured protection and post-fault restoration, which can be broken down into four broad categories: (1) Network system configuration management, (2) Degradation management, (3) Fiber fault management and (4) Performance management. SANTAD can help network operators and field engineers to perform the following activities in FTTH network system:

- Network system configuration management-provides the network operators 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.
- Performance management-monitors and controls the network performance

The working principles of SANTAD are structured into two parts: (1) Remote access control and (2) Advanced OTDR analyzing. A commercially available OTDR with a 1625 nm laser source is used in failure detection control and in-service troubleshooting without affecting the triple-play services transmission. In this design, the OTDR pulses emitted from CO toward multiple ONUs at different customer residential locations (in downstream direction) bypassing the 1×N passive optical splitter and then provides the presentation of surveillance image. The OTDR must be equipped with an Ethernet PC card and connected to an Ethernet Local Area Network (LAN).

A remote access control program is developed to interface the OTDR test module with remote PC/laptop at CO or point of link control (remote site) for distant monitoring. The communication between OTDR and remote PC is achieved via., Standard Commands for Programmable Instruments (SCPI) commands. The Ethernet Transmission Control Protocol/Internet Protocol (TCP/IP) allows the remote PC to transmit SCPI commands over the Ethernet interface of OTDR test module according to Institute of Electrical and Electronics Engineers (IEEE) 488 standard. By using SANTAD together with a remote PC/laptop equipped with modem or LAN connection, the network operators and field engineers can easily communicate with the OTDR test module from anywhere in the world.

After that, all the OTDR measurements are accumulated to be displayed on a PC screen for events/data recording and advanced data analyzing with SANTAD. Every eight network testing results will be displayed in Line's Status form for centralized monitoring. SANTAD is focusing on providing survivability through event identification against losses and failures. A failure message "Line x FAILURE at z km from CO!" will be displayed to inform the network operators and field engineers if SANTAD detect any occurrence of fiber fault in the network system. To obtain further details on the performance of specific line in the network system, every measurement results obtained from the network testing are analyzed in the Line's Detail form. SANTAD is able to identify and present the parameters of each optical fiber line such as the line's status, magnitude of decreasing at each point, failure location and other details as shown in the OTDR's screen (Rahman and Ng, 2008).

The principle of our technique is presented in Fig. 1 and the whole operation process can be simplified in the flow chart as depicts in Fig. 2. SANTAD is potentially to improve the survivability and increase the monitoring capabilities in FTTH as well as overcoming the upwardly or downwardly monitoring issues with conventional fiber fault localization technique by using OTDR. Overall, it can reduce the time needed to restore the fiber fault to maintain and operate the FTTH more efficiently.

Network system configuration management: Network system configuration management provides the network operators with a control function to intercom all subscribers with CO. The network system configuration knows all the hardware in network system (including the deployment, connection, splice, fibers joint, optical device, component and optical fiber line), the status of each entity and its relation to other entities. This alerts the

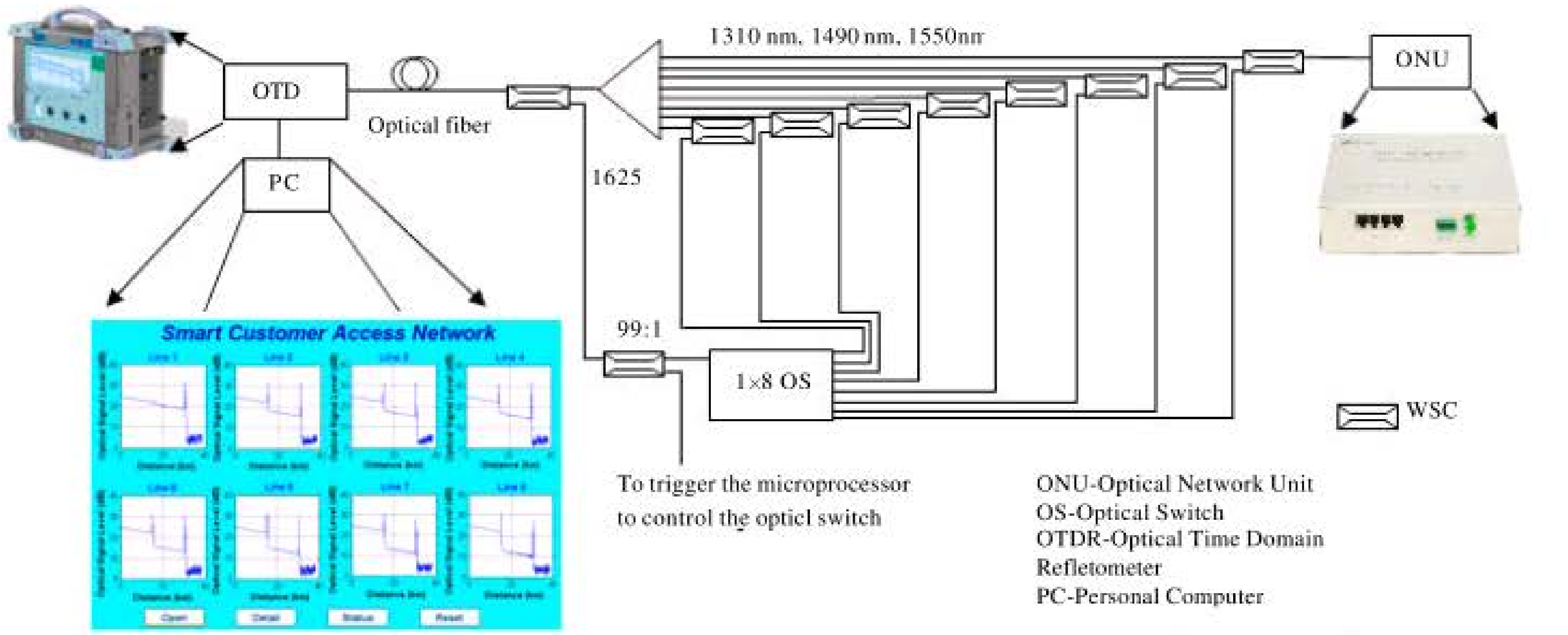

Fig. 1: SANTAD is installed at CO for centralized monitoring and fiber fault identification downwardly from CO (in downstream direction)

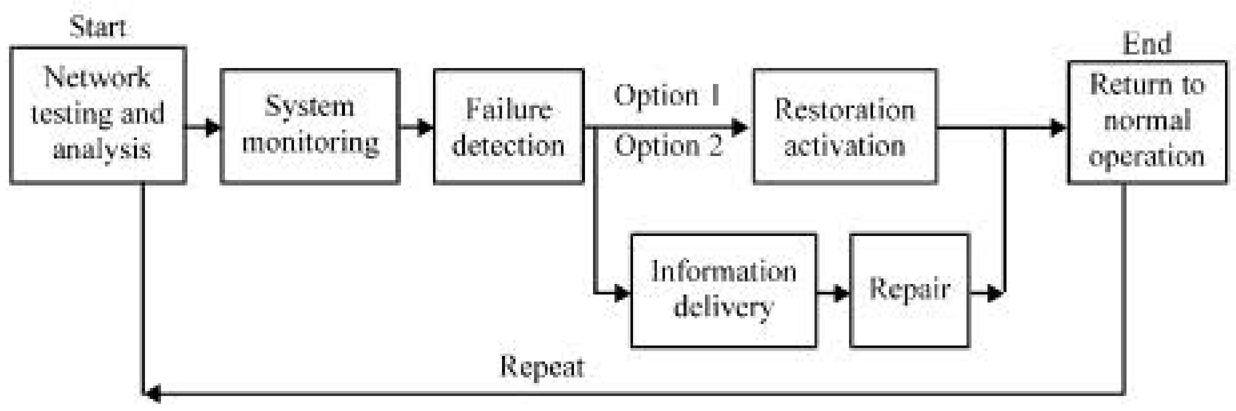

Fig. 2: The process flow for failure detection and self restoration in SANTAD

network services providers to determine the path used by the services through the network in working (ideal/good) condition and non-working (failure/breakdown) condition. Figure 3 shows the ability of SANTAD to accumulate every eight network testing results to be displayed in a single PC screen (in Line's Status form) for centralized monitoring and then analyzed the status of each line connected between the CO and Customer Premises Equipment (CPE).

Degradation management: Degradation management aims to prevent fiber fault occurring/happening from monitoring the network system status and triggering necessary actions if is needed. Degradation management plays an important role in ensuring network connectivity and resilience to fault. Although, this is not always possible, however some types of failure can be predicted and prevented. The Quality of Services (QoS) of triple-play in optical communication system/optical access networks are affected by many factors such as environment, network topology/configuration, equipments/components and losses/attenuation.

SANTAD can tracks small changes based on the optical signal level (input/output power) and losses (connection losses, splice losses, optical device/component losses, fiber losses or attenuation) at each point for the preventive maintenance purposes as indicated in Fig. 4. By in-service monitoring with SANTAD, the field engineers can view the service delivery and detecting any circumstances which may require some promptly action before it turns into big trouble and causes a tremendous financial loss.

Fiber fault management: Fiber fault management involves the fiber fault detection, notification, verification, restoration functions and documentation (recording fiber fault). The first step taken by the fiber fault management system is to detect any fiber fault occurs in a faulty line and the exact failure location. Once any fiber fault in the primary entity is detected as shown in Fig. 5, 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

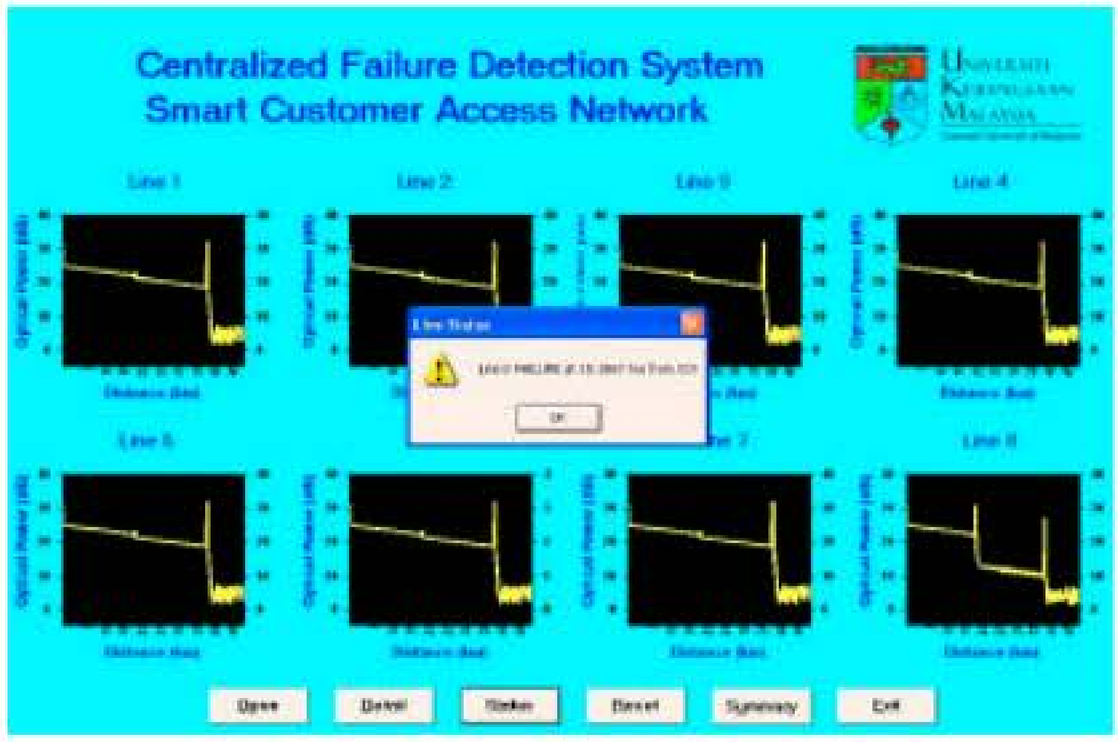

Fig. 3: Every eight measurement results are displayed on the Line's Status form. A failure message displays to show the faulty line and failure location in the optical network

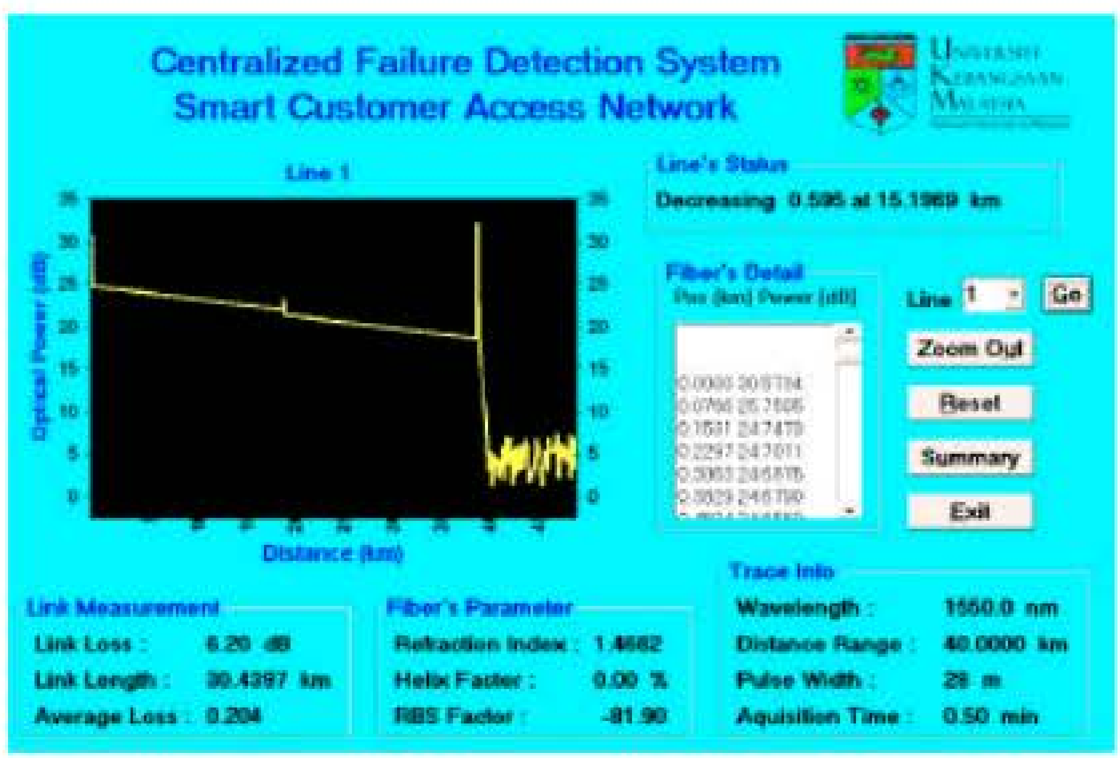

Fig. 4: An example of working line in the Line's detail form

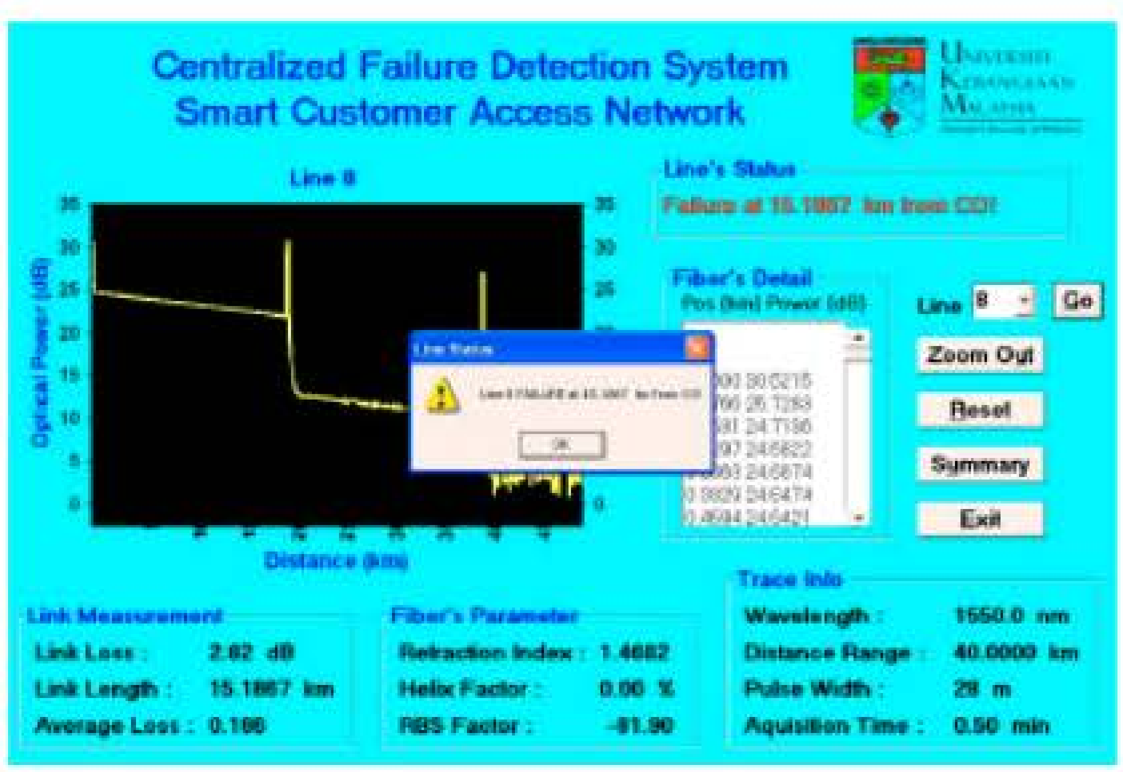

Fig. 5: An example of non-working line in the Line's detail form

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 (backup) line to ensure the traffic flow continuously. This functionality alerts the network operators 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 should show 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 network operator or field engineers 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 (Forouzan, 2007).

Performance management: Performance management is closely related to degradation management and fiber fault management, tries to monitor and control the network to ensure that it is running as efficiently as possible (Forouzan, 2007). SANTAD stores the real time, daily, weekly, monthly, quarterly and yearly analysis results in database for further processing and queries. All kinds of additional information can be easily accessed and queried later. The database system enables the history of network scanning process to be analyzed and studied by the field engineers. The network operators and field engineers 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 24 h a day and 7 days a week. Figure 6 shows one of relationship between network failure rate and network performance. The field engineers can evaluate the network performance via., summarized the each network performance plot, which may require some promptly action.

Future enhancement: All of these four management operations are the first report up to this point of time. In the future, we aim to add another three management operations: (1) Users accounting management, (2) Identification management and (3) Security management into SANTAD.

- Users accounting management-verifies a given subscriber is permitted to access a given service controls the users for accessing to the network resources through charges
- Identification management-determines whether an identified entity or element of the content and prevents tracking by an unauthorized person
- Security management-controls the users for accessing to the network resources through predefined policy

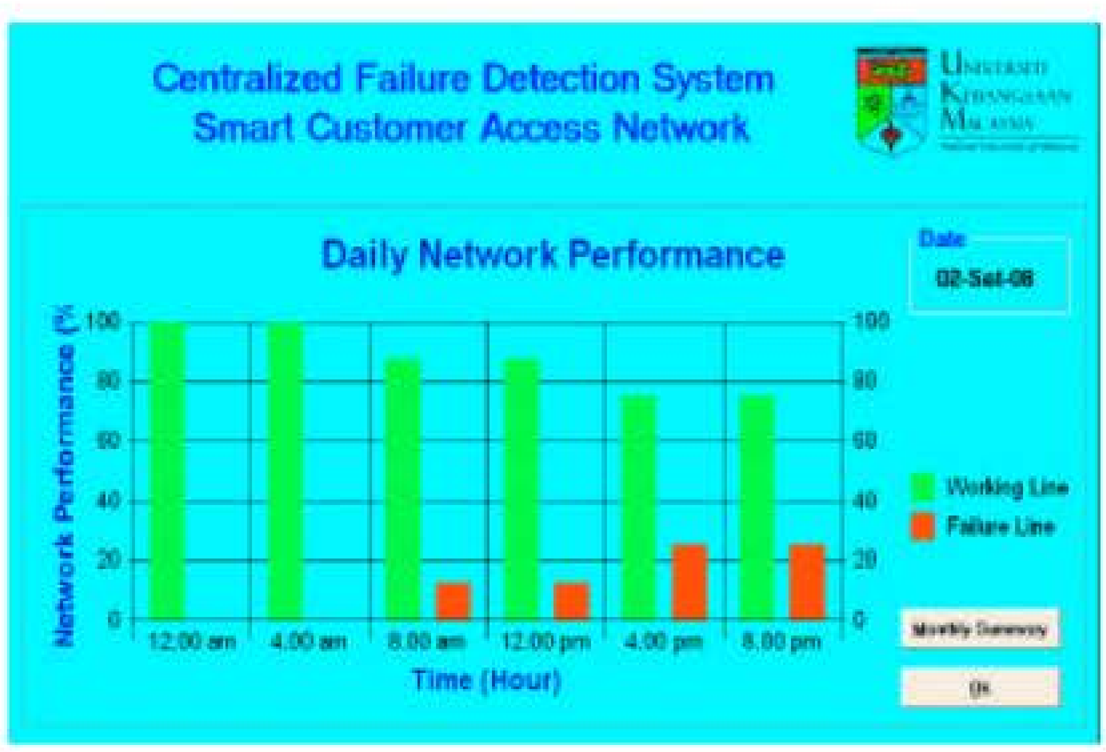

Fig. 6: Analysis of the relationship between network failure rate and network performance

In combination of the distinctive management operations, the network operators and field engineers can centralized monitoring, testing, analyzing, configuring and troubleshooting the FTTH network system more efficiency to provide the predefined QoS for customer premises/subscribers.

CONCLUSION

This study discussed the effect of fiber break in optical communication system and reviewed current techniques for localizing (detecting) fault in FTTH access network. The proposed FTTH network management system (SANTAD) is interfacing with OTDR test module to enable the network operators and field engineers to operate the measurement system running on a remote PC/laptop at CO via Ethernet TCP/IP connection for distant monitoring. All the OTDR measurements are accumulated to be displayed on a PC screen for advanced data analyzing. SANTAD accurately determined the faulty fiber as well as addressed the failure location in the network system through event identification method. It is a cost-effective way to prevent and detect the occurrence of fiber fault within FTTH to improve the service reliability and reduce the restoration time and maintenance cost.

ACKNOWLEDGMENTS

This research was supported by the Ministry of Science, Technology and Innovation (MOSTI), Government of Malaysia, through the National Science Fund (e-Science) 01-01-02-SF0493. SANTAD had firstly been exhibited in 8th Malaysia Technology Expo (MTE 2009), Putra Word Trade Centre (PWTC), Kuala Lumpur, Malaysia, 19-21 Feb, 2009 and was awarded with Bronze medal in Electronic-Electricity-Computer Science-Radio-Television-Video-Telecommunication Invention and Innovation Award Category.

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