Transmission Surveillance and In-service Troubleshooting in FTTH Access Network

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Summary
This paper proposed an approach for transmission surveillance and in-service troubleshooting for fiber-to-the-home (FTTH) access network with the combination of optical time domain reflectometer (OTDR) and passive in-line monitoring (PIM) devices. PIM device is a fully passive device that used to tap out a small ratio of triple-play signals for monitoring purpose without affecting the transmission in FTTH. The OTDR will be installed with optical line terminal (OLT) at central office (CO) for in-service monitoring and failure identifying against fiber fault in feeder region, while the PIM devices will be permanently installed with drop fibers to allow the technicians to simply connect them to a portable tester unit for transmission surveillance and failure detection in multi-line drop region. The PIM devices enable the statuses of each drop fiber and optical network unit (ONU) to be monitored through a portable tester unit.

Key words:
Transmission surveillance, in-service troubleshooting, FTTH, OTDR, PIM device

1. Introduction

FTTH is a broadband network technology that delivering triple-play (data, voice and video) services with a high speed to the home or business via optical fiber cable. FTTH is the major role in alleviating the last mile bottleneck for next generation broadband optical access network [1]. Today, FTTH has been recognized as the ultimate solution for providing various communications and multimedia services, including carrier-class telephony, high-speed Internet access, digital cable television (CATV), and interactive two-way video-based services to the end users [2]. Owing the very high capacity of optical fibers, FTTH can deliver greater capacity as compares to copper-based technologies [3].

FTTH technology using passive optical network (PON) is the most promising way to provide high quality broadband access [4]. The PON is commonly deployed as it can offer a cost-efficient and scalable solution to provide huge-capacity optical access [5]. PON architecture consists of an OL at CO and multiple 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 (branching device) at remote node (RN) and then connected to a common OLT [6]. The 32 or 64 ways splitting are the most common today, but other splits are possible.

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 [7]. A FTTH failure due to fiber break in current optical communication system could make the network service provider very difficult to restore the system back to normal. According to the cases reported to the Federal Communication Commission (FCC), more than one-third of service disruptions are due to fiber cable problems. These kinds of problems usually take longer time to resolve compared to the transmission equipment failure [8]. Therefore, the survivability of the whole network has to be examined more seriously. Lack of survivability is one of main factors that FTTH is still not been deployed in certain area.

Conventionally, OTDR is used to identify a fiber fault in FTTH. Technician is sent to the ONU side to inject an OTDR pulse into the faulty fiber. By means of OTDR, one can get the distance from the fault site to the measurement site along the optical fiber housed in the optical cable [8]. However, one of the issues with testing using OTDR is this approach would produce inaccurate results if two trouble spots are very close together or if the pulse has a long travel length [9].

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Besides, serious problems may occur when the field engineers or technicians measuring the optical signal strength at each node in the network for monitoring the signal quality and troubleshooting the connection problems. Typically to measure the optical signal, the technicians have to break the connection to shut down the node for measuring the relative optical strength at a node. If there are multiple wavelengths going through the same node, then the technicians need to use an optical spectrum analyzer (OSA) or wavemeter to examining the spectral composition of optical waveform. This creates a risk of contaminating the fiber ends when disconnecting or reconnecting the node to FTTH. It leads to create some serious problems later on and possible costly repairs, therefore these measurements can be quite costly [9].

The OZ Optics had developed *Smart Patchcords* that can be used to monitor FTTH [9]. The *Smart Patchcords* can be built onto the fiber of each node and installed at a convenient location in the network, such as a patch panel. It allows the technicians to simply connect this device to a laptop or personnel digital assistant (PDA) to record and log the measurements effortlessly. The *Smart Patchcords* only tap about 1% of the signal out at a specific wavelength without interrupting transmission. Thus three units could be used to three separate wavelengths (for the triple-play signals) at each node [10]. However, this approach needs relatively additional devices that impose high operation and maintenance cost. The network service providers need to keep capital and operational expenditures (CAPEX and OPEX) low in order to be able to offer economical solutions for the customers. Therefore, improving network reliability performance by adding redundant components and systems have shortcomings in terms of implementation cost and flexibility [5].

2. The PIM Device Prototype

To reduce the cost and enhance the benefits, we are introduced a PIM device in this paper. The PIM device is a fully passive device, where all the optical components in the device do not require electronic control for their operation. It is purposely developed for monitoring the three main operating wavelengths (optical signals; 1310 nm, 1480 nm, and 1550 nm) which associated with PON network. The 1480 nm (or 1490 nm) downstream signal and 1310 nm upstream signal are used to transmit data and voice. The 1550 nm downstream signal is used for analog video overlay. Broadcast video is transmitted at 1550 nm being a low loss window and a wavelength can be amplified by erbium doped fiber amplifier (EDFA). The PIM device prototype is consists of four ports for tapping function, as illustrates in Fig. 1 to 3, which are controlled by optical couplers to perform the optical power combining and splitting in the device.

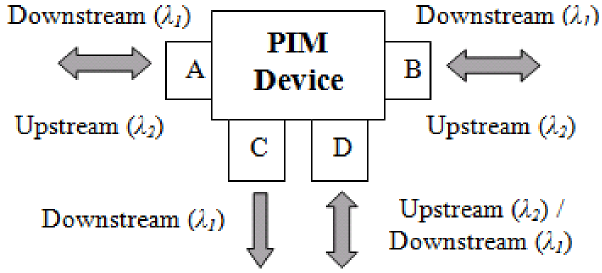

Fig. 1. Block diagram of PIM device prototype.

Fig. 2 Photographic view of PIM device prototype before chasing.

Fig. 3 Photographic view of the developed PIM device prototype.

2.1 Passive Taper Circuit

A passive taper circuit is required to obtain the triple-play signals to provide a visual way of monitoring the receiving signal performance. The entire optical components that had been used in the design of passive taper circuit for the PIM device prototype including connectors for connecting two optical fibers, splices for attaching one bare fiber to another, optical isolators that prevent unwanted light from flowing in a backward direction, and optical couplers used to tap off a certain percentage of light for performance monitoring purposes [3].

Among the optical components, optical coupler is the main components in the PIM device prototype. Since it is one of the passive optical components, it do not require external source of energy to perform an operation or transformation on an optical signal. The concept of a coupler encompasses a variety of functions, including splitting light signal into two streams, combining two light streams, tapping off a small portion of optical power for monitoring purposes, or transferring a selective range of optical power from one fiber to another. Another important component in the prototype is optical isolator that allow light to pass through them in only one direction. This is important in a number of instances to prevent scattered or reflected light from travelling in the reverse direction [3].

2.2 Characteristics of PIM Device Prototype

The PIM device prototype has three important parameters to check: insertion loss, return loss, and directionality. The most important parameter of PIM device prototype is insertion loss. The difference in signal level between the input and output is the insertion loss. The insertion loss of a PIM device prototype should be quite small, typically about 1.5 dB [11].

Two methods are being used to study the specifications of PIM device prototype: device testing and network testing. The parameters of each port in the PIM device prototype such as insertion loss, reflection loss, and crosstalk are measured through a device testing, which used a tunable light source (TLS), circulator, and OSA, as depicts in Fig. 4 and 5. TLS is used for light emitting with different emission wavelengths and OSA is used for examining the spectral composition of optical waveform. Meanwhile the network testing utilizes the OTDR to study the specifications of PIM device.

In specifying the performance of PIM device prototype, we indicate the percentage division of optical power between the output ports of the couplers by means of the splitting ratio or coupling ratio by adjusting the parameters. However, in any practical coupler there is always some light that is lost when a signal goes through it. The two basic losses are excess loss and insertion loss. The excess loss is defined as the ratio of the input power to the total output power, while the insertion loss refers to the loss for a particular port-to-port path. Another

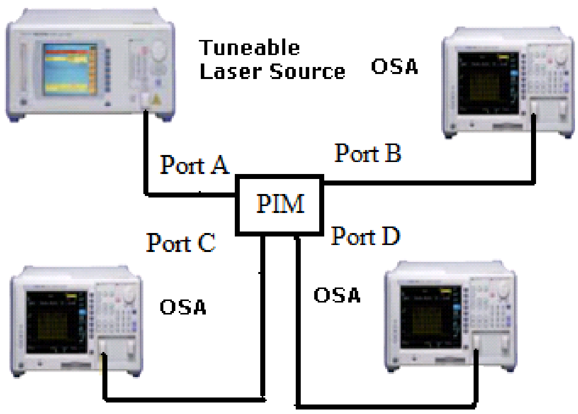

Fig. 4 The experimental setup for measuring the insertion loss of PIM device.

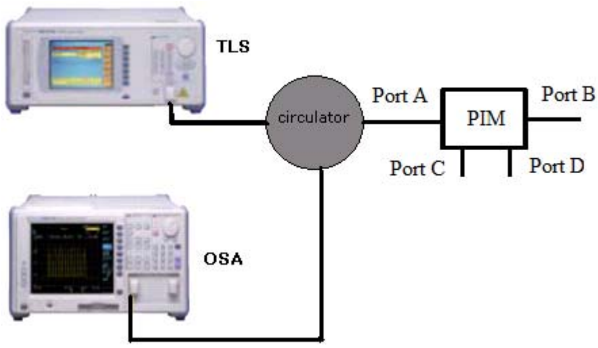

Fig. 5 The experimental setup for measuring the crosstalk of PIM device.

Table 1: The specifications and performances of PIM device.

Specifications	***Parameters***
Operating Wavelength	1310 / 1480 / 1550 nm
Operating Bandwidth	±15 nm
Insertion Loss	≤ 1.5 dB
Return Loss	≥ 35 dB
Directionality	≥ 55 dB
Storage Temperature Range	- 40 to 85^{o} C

performance parameter is crosstalk, which measures the degree of isolation between the input at one port and the optical power scattered or reflected back in to the other input port [11]. The specifications and performances of PIM device are listed in Table 1.

2.3 Power Budget

PON is the most common form of FTTH in several parts of the world where it using a shared optical fiber cables from CO to deep in the network and usually terminates at a splitter cabinet. The connectivity in PON is based on point-to-multipoint (P2MP) structure, where the OLT located in the CO providing connectivity to multiple ONUs at different residential customer locations via 1xN passive optical splitter. Since the attenuation (reduction) of the signal strength arises from various loss mechanisms in a transmission medium is important when considering the factors such as the effects of tapping off a small part of an optical signal for monitoring purposes, for examining the power loss through some optical element, or when calculating the signal attenuation in a specific length of optical fiber. We are doing a power budget to calculate the maximum number of PIM device that can be installed in the network.

The power budget for network configuration is based on the power drop for each type of optical splitter, which has different value of insertion loss. All the losses for basic components including OLT and ONUs in FTTH are estimated in the power budget. This is purposely to calculate the maximum number of PIM devices can be installed in the FTTH without affecting the upstream and downstream transmission. The more number of devices installed with the main line, the more easily to specify the failure part before verifying the exact location with an OTDR.

Fig. 6 shows the unit number of PIM devices allow to be installed in the network without any disruptions. With the sensitivity level -30 dBm and safe margin 5 dB, the maximum losses in the network are allow are less than -25 dB. As shown in the Fig. 6, only maximum up to 4 unit of PIM devices are achieve the acceptability signal level, to consider it as safe (no interruption). With the maximum distance between the OLT and ONU can up to 20 km, this indicates that each PIM device can be installed at every 1 to 2.5 km within drop region of FTTH. However, if the maximum number of PIM devices is more than 4 units, the subscribers still can receive the triple-play signal with several noise and disruption.

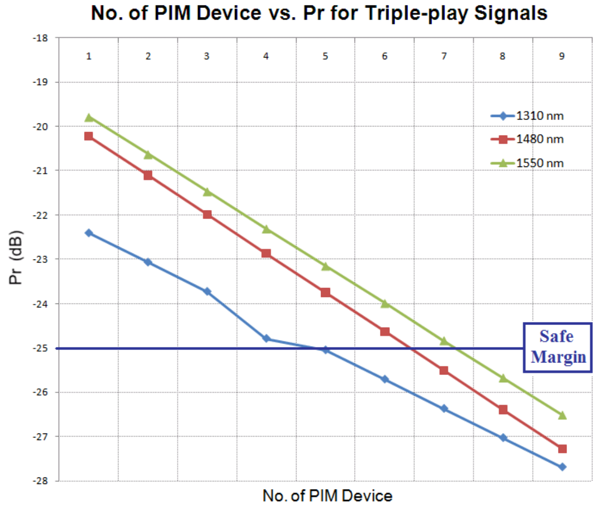

Fig. 6 Unit number of PIM devices vs. receiving power, *Pr*, plot for the triple-play signals in FTTH access network.

3. Transmission Surveillance and In-service Troubleshooting Scheme

The proposed surveillance scheme in this paper can be broken down into two main parts: (i) Transmission surveillance in feeder region using OTDR and (ii) Transmission surveillance in multi-line drop region using PIM device and portable tester unit.

4.1 Transmission Surveillance in Feeder Region using OTDR

A commercially available OTDR will be installed with OLT at CO for in-service monitoring and failure identifying against fiber fault in feeder region. To locate a fiber fault without affecting the triple-play services, it is essential to use a wavelength different from the triple-play signals for failure detection [12]. As illustrates in Fig. 7, the triple-play signals are multiplexed with a testing signal (1625 nm) from OTDR. When four kinds of signals are distributed, the triple-play signals will be split up by the wavelength selective couplers (WSCs) or wavelength division multiplexing (WDM) couplers, which are installed after the OLT and before the optical splitter. The WSCs only allow the triple-play signals to pass through the optical splitter and reject the testing signal at 1625 nm that contaminates the triple-play services.

The status of the network system in feeder region can be monitored by using OTDR easily because there is just only one single sharing fiber (feeder fiber) with a point-to-point (P2P) connection from OLT to the optical splitter.

However, we blocked the OTDR testing signal in this architecture because the Rayleigh back-scattering (RBS) signal of each branch is partially masked by the signals from all branches and cannot be distinguished [7]. This was making the troubleshooting work become difficult to detect any failure occurs in the drop region (in a P2MP connectivity equipped with optical splitter) by using OTDR downwardly from CO towards the customer premises (in downstream direction).

4.2 Transmission Surveillance in Multi-line Drop Region using PIM Device and Portable Tester Unit

The PIM devices will be installed on every node with the main lines permanently in the multi-line drop region. The upstream or downstream signals from the FTTH trunk line will be entering the taper circuit. The PIM device provides a visual way of monitoring the receiving signal performance, when connected to a small television (TV) screen which the user can view the broadcast channel of CATV video or PDA for data communication. It taps out a small ratio of these signals in order to monitor the status along the main line without affecting both upstream and downstream transmission.

The technicians only need to bring a portable tester unit to test the transmission signal from. The PIM device enables the status of each drop fiber and ONU to be monitored through a portable tester unit by connecting the port C and D to a mini CATV and PDA. As indicates in Fig. 7, the output signals from port C and D are connected to a portable tester located at CO. The portable tester can be shared by different PIM device by the use of space-division devices or other suitable devices (e.g. optical selector. The optical selectors can he mechanical integrated optic switches) [13]. It allows the field engineers to identify the faulty fiber and failure location without making a site visit to the drop region or residential location. One there is any fiber fault or system downs reported by the subscribers, it enables the field engineers to firstly determine the problem occurs in which respective region and then the exact failure location (break point) will be identified through an OTDR.

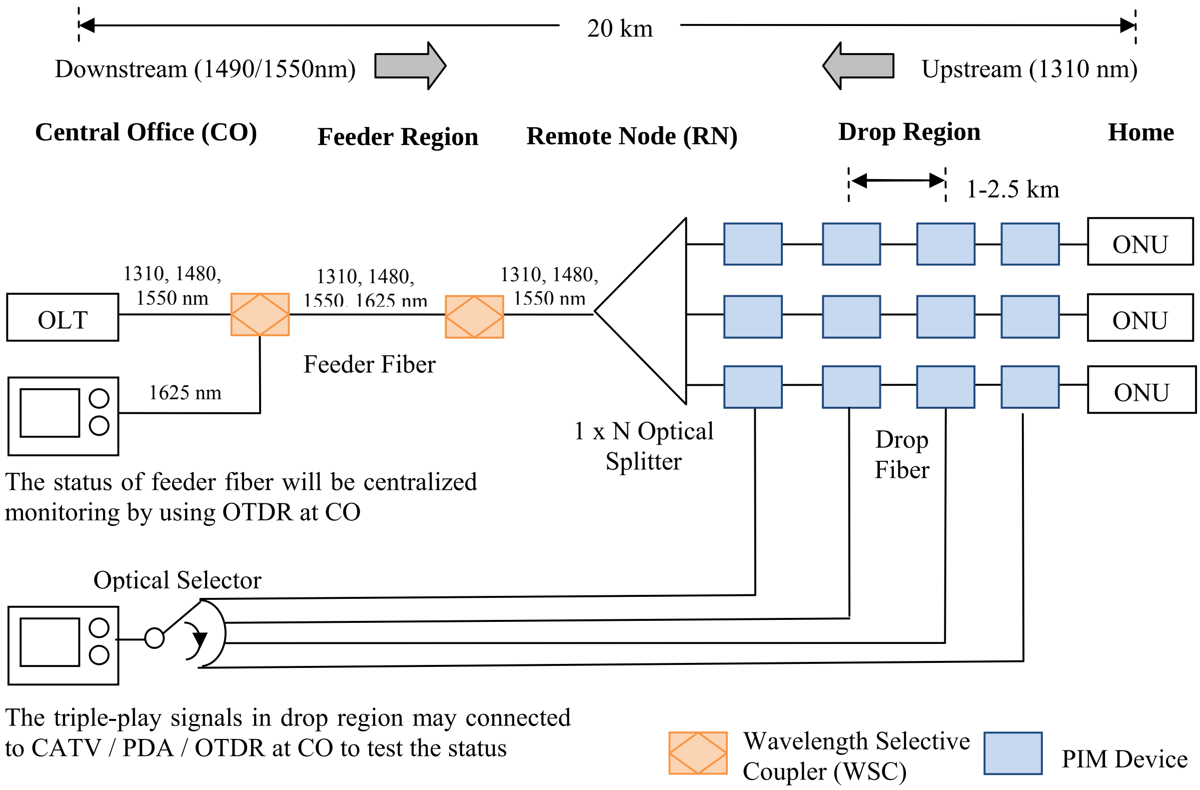

Fig. 7 The proposed surveillance scheme for tree-structured FTTH access network with combination of OTDR and PIM devices.

A CATV tester unit (CTU) prototype, as depicts in Fig. 8, was developed in this research work for testing the video signal in the proposed surveillance scheme. The CTU is connected to the port C to tap out 10% of video signal. Fig. 9 shows one example of the capture video signals at CTU. The quality (clearness and brightness) of the receiving video signal is very poor. However, this is unimportant because we only interested on whether the video signal is successfully being delivered to the customer premises. A CATV is connected to port B to represent the receiving video signal (90% of video signal) at the residential customer location. Fig. 10 shows one example of the capture video signals at CATV. The quality (clearness and brightness) of the receiving video signal is same as the transmitting signal at OLT. Thus, we can conclude that the PIM device that used to tap out 10% video signal for monitoring purpose does not affect the video service in FTTH.

Fig. 8 Photographic view of the developed CTU prototype.

Fig. 9 One example of the capture video signals at CTU.

Fig. 10 One example of the capture video signals at CATV.

5. Future Enhancement and Conclusions

In this paper, we bring up a transmission surveillance and in-service troubleshooting against fiber fault to improve the service reliability and reduce the repairing cost and time in FTTH network system through the combination of OTDR and PIM device. The PIM device is focused on determining the faulty fiber and failure location in the multi-line drop region of FTTH before taking some appropriate action. In future research activity, we aim to simplify the passive taper circuit to reduce the insertion losses of PIM device. By using less optical components but still enhance the functionalities, more unit number of PIM devices can be installed with the FTTH trunk lines and the failure part can be specified more easily. Besides, the circuit will be packaged into two layers, so that it will require a small spacing.

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