

IDENTIFICATION OF AN OPTICAL-LAYER FAILURE IN A PASSIVE OPTICAL NETWORK

TECHNICAL FIELD

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The invention relates generally to identification of an optical-layer failure in a passive optical network.

BACKGROUND

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Recently, fiber to the home (FTTH) deployments have experienced exponential growth from both Asia and Europe to North America. For example, the Infocomm Development Authority of Singapore has launched its Next Generation National Broadband Network (NGNBN) plan and by 2012, 95 per cent of homes and
15 offices in Singapore are expected have broadband access (~1Gb/s) to this new, ultra high-speed, all-fibre network.

Passive optical networks (PONs) are the predominant technology for FTTH deployment. Fig. 1 is a schematic drawing illustrating the general configuration of a
20 passive optical network (PON) 100. Optical Line Terminals (OLTs) 102 are located at a telecomm carrier's central office 104 and Optical Network Terminals (ONTs) 108a/108b (only 2 are shown) are located at customers' premises 106a/106b. The optical distribution network (ODN) 110 is between the OLTs 102 and ONTs 108a/108b, and is generally 10 - 15 km in range. A PON can potentially support high
25 bandwidth transmission due to the use of fibre, and no active (i.e., electrically powered) components are used within the ODN. PONs are currently implemented using two popular technologies: Ethernet (EPON) and Gigabit PON (GPON).

In the practical implementation of PONs, a low-cost optical fault self-
30 diagnostic module for an ONT is important for both telecomm carriers (access network providers) and ONT equipment vendors. With an optical fault self-diagnostic module, users can easily and accurately detect optical layer failures at home with/without the help of technical assistance via a telephone. Telecomm carriers can know whether the failure is in the ONT, fibre patch cord (e.g. cut/dirty/bent) or fiber
35 (e.g. cut) and can then decide if technical assistance is needed at the customer's premises to solve the problem. Operation cost (OPEX) and failure maintenance cost may be reduced as there may be cases where technical assistance need not be sent

to the customer's premises to troubleshoot and rectify failures. This also speeds up the recovery of any service interruption.

Some commercial ONT products may comprise integrated electronic diagnostic functions in ONTs, which can diagnose electronic layer problems. If a failure occurs in the electronic layer that results in customer service interruptions, these ONTs can report the failure to the OLT by sending a failure message or diagnosis via the OLT data communication channel. Telecomm carriers can then identify the fault and decide on the appropriate rectification process.

However, these commercial ONT products cannot diagnose failures in the optical layer, e.g., ONT transmitter/receiver failure, optical path cord bent/cut and dirty fibre connector, etc, as there is a break-down in the communication channel between the OLT and the ONT. Technical staff must visit the customer's premises to check such problems. This increases maintenance cost as in many cases, it may be a simple problem, e.g., bent path cord or dirty path cord connector. Further, telecomm carriers can identify where the optical failures occur and the responsible party for these component failures.

Optical fault diagnostic techniques are important in the practical implementation of PONs. Current optical fault diagnostic methods can be categorized into the following three methods/schemes. Fig. 2 is a schematic diagram illustrating a conventional optical fault diagnostic method using an optical time domain reflectometer (OTDR). In this method, an OTDR 202 is used at the OLT side 203. A single-mode feeder fibre 204 of about 1km, an N-way power splitter 206 and multiple distribution fibres 208a...208n are used to connect the OLT 203 to a number of individual customers. The downlink signal wavelength and uplink signal wavelength are in the 1310 nm and 1550 nm regions, respectively. The failure monitoring light source (i.e., the OTDR 202) wavelength is 1650 nm so that the use of the OTDR 202 does not interfere with the uplink and downlink signals. A Coarse Wavelength Division Multiplexer (CWDM) coupler 210 is used to guide the fault diagnostic signal launched from the OTDR 202 to the ONT 209, and filter the reflected Rayleigh backscattered light to the OTDR 202. When a fibre failure occurs at the feeder fibre 204 or any distribution fibre 208a...208n, the received Rayleigh backscattered power in the OTDR 202 changes (i.e., there is a loss in power). An optical fault (e.g., fiber cut) can be detected according to the received Rayleigh backscattered light power. Other components in the scheme include pulse pattern

generators (PPGs) 212, band pass filters (BPF) 214, optical attenuators (ATT) 216 and error detectors (ED) 218.

This method is relatively simple and low-cost since a commercially available
5 OTDR is used directly at the OLT side and is shared by multiple PONs. No expensive components and complicated signal processing methods are needed for optical-layer fault detection. However, this method can only detect whether there is a failure on distribution fibres. This method can not accurately locate the failure nor differentiate which branch has the failure. In order to overcome this problem, another
10 optical-fault diagnostic method (as described below) can be used.

Fig. 3 is a schematic diagram illustrating a conventional optical fault diagnostic method using a wavelength-sweeping monitoring source. In this scheme, downlink and uplink data are transmitted in the wavelength region of 1540 – 1550
15 nm. The fault monitoring light source is constructed by looping back some of the Erbium Doped Fiber Amplifier (EDFA) 302 emission to its input through a tunable Fabry–Perot etalon band pass filter (FPF) 304, thus generating a gain-clamped saturated laser emission with wavelength-tuning capability. Fiber Bragg gratings (FBGs) 305a...305n of distinct center reflection wavelength are placed at the end of
20 each fiber branch 306a...306n as a branch identifier. In each sweeping cycle, the emission wavelength of the monitoring signal is swept continuously through the unused EDFA 302 gain spectrum. When the FBG 305a...305n centre wavelength matches that of the wavelength sweeping monitoring source, an optical pulse is generated and reflected upstream to a monitoring photodiode 308 via a circulator
25 310. The operational status of a certain fiber branch is signified by the presence of the respective optical pulse in each sweeping period. By demultiplexing the detected optical pulses in each sweeping time period, the status of all fibre branches can be monitored continuously.

30 The above-described scheme can detect feeder fibre failure and differentiate which branch has a failure. However, this scheme is more complicated than the first scheme. In the second scheme, each distribution branch has to be implemented with an extra FBG with a different center wavelength, i.e. it is not colorless. This increases the installation complexity and cost since the extra FBG installed in each
35 branch has to be identical and has to be known by the service centre before usage. Furthermore, the fault diagnostic light source at the OLT has to have a wavelength sweeping capability, which is not cost-effective. The monitoring light source also

occupies a wavelength band. This monitoring waveband is increased with the increase of ONT numbers in the PON. This monitoring waveband is not defined by ITU standards and can potentially affect the downlink and uplink signals transmission, especially when the branch number of the PON significantly increases.

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In order to accurately locate both feeder and distribution fibre failure, while keeping the failure monitoring source simple, there is a third optical fault diagnostic method. Fig. 4 is a schematic diagram illustrating a conventional optical fault diagnostic method using a bi-directional optical time domain reflectometer (OTDR) 402. A test light with a wavelength of λ_1 (1650 nm) from an OTDR 402 in an OLT 404 is introduced into the PON for detection of optical failures in the PON. Optical filters 406a...406n are installed in the termination cables at the front of optical network units (ONUs) 408a...408n at the customer's side to eliminate the test light with a wavelength of λ_1 and to allow the communication light to pass. These optical filters are the same in all branches. When a fibre failure occurs at the feeder fibre, the OTDR 402 in the OLT 404 detects the fibre failure in the PON, which is the same as the first scheme. When a distribution fibre failure occurs, service data is interrupted. Another OTDR 410 with a wavelength of λ_2 (1665 nm) is used at the customer's side to measure and locate the failure of the distribution fibre. The third scheme employs bi-directional conventional OTDR at both OLT 404 and ONT sides to diagnose optical-layer failure and can locate fibers fault accurately. The fault monitoring light source is also simple and low-cost. However, the scheme employs two conventional OTDRs 402/410 and an extra optical filter 406a...406n is needed at each ONU 408a...408n branch. These additional devices increase the system cost.

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It will be appreciated by a person skilled in the art that the above mentioned optical-layer fault diagnostic methods may only detect certain optical-layer faults, i.e., ODN fibre failure (including both feeder fibre and distribution fiber). However, for optical-layer failures caused by Tx, Rx in the ONT and dirty/bent/cut patch cords, the above mentioned optical-layer fault diagnostic methods can not effectively detect and locate these failures. It is desirable for telecomm carriers to be able to detect optical-layer failures caused by Tx, Rx in the ONT and dirty/bent/cut patch cords for efficient operation, maintenance and repair of their networks.

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A need therefore exists to provide a method and apparatus for identifying an optical-layer failure in a passive optical network that seeks to address at least one of the abovementioned problems.

SUMMARY

One aspect of the present invention provides a method of identifying an optical-layer failure in a passive optical network (PON), the method comprising the steps of: performing a loop-back between an optical communication port of an optical network terminal (ONT) and a test port of the ONT; determining if an error persists after the loop-back; connecting the test port of the ONT to an optical distribution network (ODN) of the PON; and determining if the error persists after the connection; wherein the optical-layer failure is identified based on the results obtained from the above steps.

In alternate embodiments, the method may further include a step wherein a patch cord failure is identified when the error persists after the loop-back and after the connection.

In additional embodiments, the method may further include a step wherein a Tx failure is identified when the error persists after the loop-back but not after the connection. Additionally, an ODN fiber failure may be identified when the error does not persist after the loop-back but persists after the connection. An RX failure may be identified when the error does not persist after the loop-back and after the connection. In some embodiments, the error may include an error generated by the ONT.

In other embodiments, the method may further include a step of cleaning fiber connectors and correcting patch cord positioning prior to performing the loop-back. The ONT may be a Gigabit PON (GPON) or Ethernet PON (EPON) ONT.

A further aspect of the present invention provides an optical-layer failure detection method for a passive optical network including an optical network terminal (ONT) with a test port and an optical transmission (Tx) circuit and an optical reception (Rx) circuit both connected to an optical distribution network (ODN) via a communications port connected to an optical patch cord, the method comprising: detecting a communications error state; forming a loop back connection of said patch cord between said communications port and said test port; detecting whether said error state persists; reforming the patch cord connection between said test port and said ODN; detecting whether said error state persists or recurs; determining there to be

an Rx circuit fault if the error state firstly does not persist and secondly does not recur; determining there to be an ODN failure if said error state firstly does not persist but secondly does recur; determining there to be a Tx circuit failure if said error state firstly persists and secondly does not persist; and determining there to be a patch
5 cord failure if said error state firstly persists and secondly persists.

BRIEF DESCRIPTION OF THE DRAWINGS

10 In the drawings:

Fig. 1 is a schematic diagram illustrating the general configuration of passive optical network (PON);

15 Fig. 2 is a schematic diagram illustrating a known (Prior Art) optical fault diagnostic method using an optical time domain reflectometer (OTDR);

Fig. 3 is a schematic diagram illustrating a known (Prior Art) optical fault diagnostic method using a wavelength-sweeping monitoring source;

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Fig. 4 is a schematic diagram illustrating a known (Prior Art) optical fault diagnostic method using a bi-directional optical time domain reflectometer (OTDR);

25 Fig. 5 is a schematic diagram of an optical failure self-diagnostic module for use in a GPON/EPON ONT, according to an embodiment of the present invention;

Fig. 6 is a flow chart illustrating an optical fault diagnostic method according to an embodiment of the present invention;

30 Fig. 7 shows a sequence of photographs illustrating various optical-layer failure diagnostic scenarios under B-C loop-back conditions, according to an embodiment of the present invention; and

35 Fig. 8 is a graph illustrating the estimated total cost reduction between embodiments of the present invention and conventional schemes for providing optical-layer fault diagnostic function.

DETAILED DESCRIPTION

One embodiment of the present invention provides an optical failure self-diagnostic module for use in either a Gigabit PON (GPON) or Ethernet PON (EPON) Optical Network Terminal (ONT). In another embodiment of the present invention, there is provided a self-diagnostic method to diagnose and identify optical-layer failures. In this description, the term "self-diagnostic" refers to end-users performing diagnosing/troubleshooting rather than technical staff from the access network providers. Users can self-diagnose and identify optical-layer failures (e.g., transmitter of ONT, patch cord and ODN fibre failure) easily by using the module and the method according to embodiments of the present invention. In many cases, customers can diagnose problems and repair the failures by themselves. Embodiments of the present invention are not only suitable for current PONs, including GPON and EPON, but also Wavelength Division Multiplexing PON (WDM-PON) and Wavelength Division Multiplexing/Time-Division Multiplexing (WDM/TDM) hybrid PON systems.

Fig. 5 is a schematic of an optical failure self-diagnostic module 501 for use in a GPON/EPON ONT 508. Various commercially available ONT devices may be used. By way of example and not limitation, the ONT may be an Aztech, GPON200EL (http://www.aztech.com/prod_GPON.html). The fibers from an OLT 502 to a customer's premise 504 are known as optical distribution network (ODN) fibers 506. A fibre patch cord 506 is used to connect the ONT 508 to a fibre connector socket 510. The fiber connector socket 510 comprises an optical communication port 'A'. The optical failure self-diagnostic module 501 can be easily and independently integrated into the conventional GPON/EPON ONT 508. The ONT 508 comprises an optical communication port 'B' and a test port 'C'. The ONT 508 has a WDM circuit 517 connected to a transmission (Tx) circuit 516 and a reception (Rx) circuit 518. Optical fiber connection ports A, B and C are provided.

The optical failure self-diagnostic module 501 also includes a Photo Detector (PD) 512 with a received wavelength range of 1100 to 1650 nm and an optical-layer fault diagnostic functional module 514. The optical-layer fault diagnostic functional module 514 is configured to process the received optical light from the PD 512 and to display different optical-layer failure scenarios via an indicator 513 (e.g. an LED indicator) according to the received optical power. The received PD power is

advantageously only used for optical-layer fault diagnostic purposes and it is independent of and does not interfere with the original ONT received signal power (i.e., downlink signal received by the Rx circuit 518).

5 Fig. 6 is a flow chart illustrating an optical fault diagnostic method 600. At step 602, a user encounters a service interruption (error state). At step 604, the user checks whether the OLT receives a data and/or error message. If the OLT receives a data and/or error message, the implication is that an electronic layer failure has occurred and the diagnosis is complete (step 606). That is, the OLT does not receive
10 any error message when using an electronic-layer failure diagnostic module found in current commercial ONTs since the optical-layer failure has broken the communication channel between the OLT and the ONT.

 If the OLT does not receive a (communications) data and/or error message, it
15 implies that an optical-layer failure (e.g., ODN fiber, patch cord, Tx circuit, or Rx circuit failure) has occurred. At step 608, the user cleans all fiber connectors and corrects the patch cord position (e.g., no small radius bending, torsion, kink, twist, etc), and forms a B-C port loop back. At step 610, the user checks if an error is indicated (e.g. persists or not; indicated by LEDs or an error message displayed on
20 the ONT panel). If an error is indicated, the implication is that either a Tx circuit 516 or patch cord 506 failure has occurred. Otherwise, the implication is that either an ODN fiber 506 or Rx circuit 518 failure has occurred. In both cases, the user reforms an A-C port connection (step 612 or 614).

25 In the case of either a Tx circuit 516 or patch cord 506 failure, after step 612, the user checks if an error is indicated (e.g. indicated by LED 513 or an error message displayed on the ONT panel). If an error is indicated, the implication is that there is a patch cord 506 failure and the connectors can be either cleaned or replaced (step 616). Otherwise, the implication is that there is a Tx circuit 516 failure
30 and the user can call the telecomm carrier for further assistance (step 618).

 In the case of either an ODN fiber 506 or Rx circuit 518 failure, after step 614, the user checks if an error is indicated (e.g. persists or recurs; indicated by LEDs or an error message displayed on the ONT panel). If an error is indicated, the
35 implication is that there is an ODN fiber 506 failure and the user can call the telecomm carrier for further assistance (step 620). Otherwise, the implication is that

there is an Rx circuit 518 failure and the user can call the telecomm carrier for further assistance (step 622).

In the above described method, the diagnosis allows the telecomm carrier to accurately identify the failure and identify the party that is responsible for the failure. In certain scenarios, customers can repair the fault by themselves or seek assistance from appropriate vendors.

Fig. 7 shows a sequence of photographs illustrating various optical-layer failure diagnostic scenarios under B-C loop-back conditions. The LED 702 is used to indicate optical-layer fault scenarios. In Fig. 7 (a), LED 702 is brightly lit which indicates that adequate light-power has been received in the PD and there is no optical-layer failure. When the LED 702 is not lit, it indicates that an optical-layer failure has occurred as shown in Figs. 7 (b) and (c). In Fig. 7 (b), the optical fiber patch cord is dirty or cut. In Fig. 7 (c), the optical fiber is bent 704.

Table 1 below compares the performance of embodiments of the present invention with the current optical-layer fault diagnostic schemes. It will be appreciated that embodiments of the present invention provide relatively better performance in optical-layer fault diagnostics.

	Scheme 1	Scheme 2	Scheme 3	Example embodiments of the present invention
Failure monitoring light source	OTDR/ Single wavelength	Broadband light source	Two OTDR/Two wavelengths	No failure monitoring light source
Potential effect on downlink/uplink data	Low	Strong	medium	No effect
Extra wavelength reflector at each branch	No	Yes/FBG with different centre wavelength	Yes/optical filter with identical centre wavelength	No
Patch cord/Rx/ Tx diagnostic capability	No	No	No	Yes
Scheme complexity	Simple	Complex	complex	simple

Table 1

Fig. 8 is a graph illustrating the estimated total cost reduction between embodiments of the present invention and conventional schemes (described above) for providing optical-layer fault diagnostic function. Here, total cost reduction: $C_{TCR} = (C_{\text{scheme } i} - C_{\text{inv}}) / C_{\text{scheme } i}$, where $i = 1, 2, 3$; $C_{\text{scheme } i}$ represents the total increased cost per ONU for providing optical-layer fault diagnostic function in scheme i ; and C_{inv} represents the total increased cost per ONU for providing optical-layer fault diagnostic function according to embodiments of the present invention. Fig. 8 shows that in providing an optical-layer fault diagnostic function, embodiments of the present invention can potentially provide a reduction of 91%, 96% and 99% total cost per ONU, respectively compared with the current three schemes.

Embodiments of the present invention provide a low-cost optical failure self-diagnostic module design for GPON/EPON ONT and a method to diagnose optical-layer failures (e.g., ONT transmitter/receiver failure, cut/bent/dirty patch cords and ODN fiber failure) accurately and easily so that a telecomm carrier's operation cost (OPEX) can be reduced and failure recovery time can be shortened. Currently, these failures optical-layer failures cannot be effectively detected by conventional commercial ONT products. With embodiments of the present invention, telecomm carriers can easily determine the optical-layer failure and identify the party responsible for the optical-layer failures (since networks components are provided by multiple vendors). It is envisioned that value-added services (e.g., an alarm when a fiber patch cord is bent or a connector is dirty) can also be provided to customers.

The embodiments described above are applicable to broadband optical access networks; particularly passive optical networks. Furthermore, the embodiments described above advantageously utilize off-the-shelf optical active and passive components that are readily available and relatively low-cost.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the embodiments without departing from a spirit or scope of the invention as broadly described. The embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method of identifying an optical-layer failure in a passive optical network
5 (PON), the method comprising the steps of:
performing a loop-back between an optical communication port of an optical
network terminal (ONT) and a test port of the ONT;
determining if an error persists after the loop-back;
connecting the test port of the ONT to an optical distribution network (ODN) of
10 the PON; and
determining if the error persists after the connection;
wherein the optical-layer failure is identified based on the results obtained
from the above steps.
- 15 2. The method as claimed in claim 1, wherein a patch cord failure is identified
when the error persists after the loop-back and after the connection.
3. The method as claimed in claim 1, wherein a Tx failure is identified when the
error persists after the loop-back but not after the connection.
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4. The method as claimed in claim 1, wherein an ODN fiber failure is identified
when the error does not persist after the loop-back but persists after the connection.
5. The method as claimed in claim 1, wherein a RX failure is identified when the
25 error does not persist after the loop-back and after the connection.
6. The method as claimed in any of the preceding claims, wherein the error
comprises an error generated by the ONT.
- 30 7. The method as claimed in any of the preceding claims, further comprising the
step of cleaning fiber connectors and correcting patch cord positioning prior to
performing the loop-back.
8. The method as claimed in any of the preceding claims, wherein the ONT is a
35 Gigabit PON (GPON) or Ethernet PON (EPON) ONT.

9. An optical-layer failure detection method for a passive optical network including an optical network terminal (ONT) with a test port and an optical transmission (Tx) circuit and an optical reception (Rx) circuit both connected to an optical distribution network (ODN) via a communications port connected to an optical

5 patch cord, the method comprising:

detecting a communications error state;

forming a loop back connection of said patch cord between said communications port and said test port;

detecting whether said error state persists;

10 reforming the patch cord connection between said test port and said ODN;

detecting whether said error state persists or recurs;

determining there to be an Rx circuit fault if the error state firstly does not persist and secondly does not recur;

15 determining there to be an ODN failure if said error state firstly does not persist but secondly does recur;

determining there to be a Tx circuit failure if said error state firstly persists and secondly does not persist; and

determining there to be a patch cord failure if said error state firstly persists and secondly persists.

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